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應用個體經濟之三篇研究

Three Essays on Applied Microeconomics

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Three Essays on Applied Microeconomics

本論文係施琇涵君（學號 D99323006）在國立臺灣大學經濟學系完成之博士學位論文，於民國 105 年 6 月 14 日承下列考試委員審查通過及口試及格，特此證明

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摘要

本論文包含了三篇應用個體經濟之研究。第一篇文章爲政治經濟學之研究, 第二與第三篇文章則爲健康經濟學之研究。

第一篇文章使用台灣2004-2008年之各區每周收視率資料, 檢視新聞節目之政治傾向和正確度對消費者選擇新聞節目的重要性。我們發現, 泛藍之新聞節目在泛藍比例較高地區的收視率較高。此外, 我們發現在特殊政治事件發生時, 收視觀眾的政治偏好組成更爲極端化。這個結果除了並非來自於反向的因果關係, 更顯示出消費者傾向收看與自己政治意識形態相近之新聞節目。最後, 本文使用兩個假新聞事件, 探討消費者對新聞正確度的敏感度。我們發現假新聞事件對收視率的影響極小, 甚或不顯著。

第二篇文章利用台灣1950年代瘧疾根除計畫, 探討早期 (胚胎與嬰兒時期) 暴露於瘧疾風險之長期影響。我們合併1992-2012年台灣社會變遷調查所提供之個人資料, 與其出生時間和地點之瘧疾嚴重度資料。透過差異中之差異法 (difference-in-differences), 本文發現瘧疾根除計畫對男性的教育程度與家庭所得具有正向的影響。我們亦使用台灣1980年戶口普查資料進行分析, 同樣發現瘧疾根除計畫之後, 教育程度有了顯著的增加。此外, 我們發現瘧疾根除計畫對男性其配偶的教育程度亦產生正向的影響。最後, 分量迴歸分析結果顯示, 瘧疾根除計畫之影響主要集中於低所得者。本文結果顯示早期暴露於瘧疾風險將對個人產生負面的影響。

最後一篇文章探討胚胎時期暴露於空氣汙染風險對台灣新生兒健康之影響。我們使用2001-2011年之出生通報資料與2000-2011年之空氣品質資料, 並透過工具變數法以減輕內生性所造成的估計偏誤, 來檢視胚胎時期健康狀況之影響。利用大氣溫度, 濕度, 以及雨量作爲空氣汙染之工具變數, 我們發現胚胎時期暴露於懸浮微粒 (PM10) 使得新生兒早產, 體重過輕, 以及出生健康狀況不佳之機率皆提高。此外, 二氧化硫 (SO2) 與二氧化氮 (NO2) 亦使得新生兒早產與體重過輕 (懷孕週數限於37至44週) 之機率增加。本文結果顯示胚胎時期暴露於空氣汙染風險將對新生兒健康造成不利的影響。

關鍵詞: 消費者偏好, 新聞政治傾向, 瘧疾根除計畫, 胚胎起源假說, 空氣汙染, 新生兒健康

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Abstract

This dissertation consists of three essays on Applied Microeconomics. The first essay contributes to political economics, and the second and third essays contribute to health economics.

The first chapter (with Chun-Fang Chiang) investigates the role of news slant and news accuracy in consumers' choices of TV news programs in Taiwan. Using weekly audience ratings data from different regions in Taiwan between 2004 and 2008, we find that news programs leaning toward the Pan-Blue parties had more viewers from areas with more Pan-Blue supporters. Moreover, we find that consumers were more politically segregated in choosing news programs during political events than on ordinary days. The finding cannot be explained by reverse causality and suggests that consumers are inclined to watch news programs with a political ideology that approximates their own. Regarding consumer preferences for news accuracy, we examine changes in viewership caused by two well-known false news scandals involving reports that provided erroneous information. We find that the effects of these two incidents were either small or insignificant.

The second chapter (with Ming-Jen Lin) utilizes the eradication campaign in Taiwan in the 1950s to estimate the long-term impacts of early-life (in utero and postnatal) exposure to malaria. Matching adults in the 1992 – 2012 Taiwan Social Change Survey to the malaria intensity in their individual place and year of birth, difference-in-difference estimation shows strong evidence that the eradication increased men's own educational attainment as well as their family income in adulthood. We also use the 1980 census data to show there was a sharp education increase after the eradication. Furthermore, the eradication increased the educational attainment of married men's spouses. Finally, quantile regressions show that the effect concentrated on the lower percentile of the income distribution. Overall, our results suggest negative effects of early-life exposure to malaria.

The last chapter (with Ming-Jen Lin) examines the health effects of air pollution during pregnancy on newborn babies in Taiwan. Using the birth data from 2001 to

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2011 and data on atmospheric condition from 2000 to 2011, we examine the effects of in utero health conditions through the instrumental-variable (IV) method to address potential endogeneity problems. We use variation in temperature, humidity, and rainfall to instrument for in utero exposure to air pollution. We find that the increase in exposure to PM10 during pregnancy resulted in prematurity, low birth weight, and being born in bad health. Moreover, exposure to SO2 and NO2 during pregnancy led to prematurity and low birth weight for those born between 37 and 44 weeks of gestation. Our results suggest that air pollution had negative health effects on newborn babies.

Keywords: consumer preferences; news slant; malaria eradication; fetal origins hypothesis; air pollution; infant health

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Chapter 1

Consumer Preferences Regarding News Slant and Accuracy in News Program

1.1 Introduction

The TV news market in Taiwan is competitive. There are seven news exclusive channels and many other channels also air news programs. However, the credibility of the TV news in Taiwan ranked lowest among 48 countries in the world value surveys (Chiu, 2011). This low credibility could result from consumer judgments based on the following two elements: (1) objective inaccuracy, which involves the distortion of news content or the provision of erroneous information and (2) news slant, which involves focusing on either the favorable or the unfavorable portions of an incident or selecting information that is favorable to particular groups. In the Taiwanese TV news market, it is believed that news channels present news reports in ways that apparently favor different political parties, and numerous false news incidents have occurred. In this paper, we investigate how consumers respond to news slant and news accuracy in their choice of TV news programs in Taiwan.

First, we use the survey data from Taiwan's Election and Democratization Study (TEDS) to examine whether consumers are more likely to watch news programs with news that is slanted toward the political parties that they support. Previous studies have presented evidence that Formosa Television (FTV) and Sanlih E-Television News (SET) significantly favor the Democratic Progressive Party (DPP) and that Television

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Broadcasts Satellite (TVBS) tends to downplay negative news regarding the Kuomintang Party (KMT) (Lo et al. 2004; Liu 2009; Tsai 2008; Li 2008; and Huang 2009). Using survey data, we find that the consumers who support the KMT are more likely to select TVBS than FTV, supporting the idea that consumers prefer to watch news that approximates their own beliefs.

The link between the media's political ideology and consumer preferences may vary between media markets. Gentzkow and Shapiro(2011) develope a ideological segregation index for consumers in a media market, and find that ideological segregation on the Internet is low in magnitude but higher than offline media outlets. Based on the survey data from TEDS, we calculate the segregation index for consumer political-ideology segregation derived by Gentzkow and Shapiro (2011) and find that, consumers in the TV news market in Taiwan are more politically segregated than consumers in the US media markets.

The TEDS survey data confirm a significant correlation between the political ideology of consumers and their choice of TV channels in Taiwan. However, this phenomenon could be caused by the effect of news stories on the political preferences of viewers. We then compare viewers' selection of TV news programs during political events with their selection on ordinary days using the weekly audience ratings of news channels. If consumers prefer news programs that favor the political parties that they support, then more political news will result in greater extremes in the segregation of consumers by political ideology through their choice of various news sources. We combine data from the weekly audience ratings of news channels with the political preferences of regional consumers between 2004 and 2008, and we find that during the 2008 presidential election and the Chen Yunlin incident (i.e., a unique political incident), the increase in ratings for TVBS was greater than that for FTV in regions with greater proportions of Pan-Blue supporters. This finding indicates that during political incidents, consumers are more inclined to watch news programs with a political ideology that approximates their own. In contrast to the findings using TEDS data,

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the phenomenon observed from the weekly viewership data cannot be explained by reverse causality. Our findings suggest that consumers are aware of the slant in news programs and prefer programs that favor the political parties that they support.

Our findings are consistent with the results of previous empirical studies that address reader responses to political slant in news reports. For instance, Gentzkow and Shapiro (2010) used data from contemporary U.S. newspapers in their analyses and find that the primary source of media bias in the U.S. is the tendency to cater to consumers. In contrast, the political ideology of a newspaper company's owner has nearly no influence on the newspaper's bias. Durante and Knight (2010) analyzed Italy's TV media and found that news reports on public TV became more rightist after a center-right party was elected to succeed a center-left ruling party in 2001. Furthermore, the authors employed election questionnaire data to show that the number of rightist viewers of public TV channels increased and that the leftist viewers who originally watched public TV shifted to other TV channels that were more leftist.

Finally, we examine whether consumers are sensitive to news accuracy in news program. Theories of media bias provide various explanations regarding the origin of media under different assumptions regarding consumer preferences with respect to news slant and accuracy (Simeon Djankov et al., 2003; Besley and Prat, 2006; and Baron, 2006). It is natural to assume that consumers prefer to watch news stories that slant towards their own ideologies and to infer that greater competitiveness in the media market results in greater media bias (Mullainathan and Shleifer, 2005; Stone, 2011; and Sobbrio, 2012). It is also natural to assume that people appreciate news accuracy because the primary demand for news is related to the acquisition of information. The model proposed in Gentzkow and Shapiro (2006) assumes that consumers prefer to receive accurate information while maintaining biased beliefs, predicting that media bias decreases when the probability of consumers learning the actual facts increases. The existing empirical studies on media bias, however, are primarily focused on news slant rather than news accuracy. In this paper, aside from news slant, we also examine the

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role of news accuracy in the choice of news programs. We use two false news events, TVBS's Chou Cheng-Pao videotape incident and SET's 228 false footage incident, to estimate the effect of news accuracy on viewership. We analyze ratings fluctuations for TVBS and SET after the disclosure that these reports were false. We find that compared with other news channels, SET and TVBS did not experience significant decreases in ratings as a result of false news incidents. These findings indicate that consumers are not very sensitive to accuracy in news programs.

The remainder of this paper is organized as follows. Section 1.2 describes the background of the news channels and examines the correlation between consumer ideology and the selection of TV channels. Section 1.3 introduces the audience rating data. Section 1.4 presents a demand model for news. Section 1.5 presents the empirical specifications and estimation results. Section 1.6 concludes the paper.

1.2 Background

This section contains the following content: (1) an overview of various news channels and their possible political ideologies and (2) an examination of the correlation between consumer ideology and choices of TV channels based on survey data from the TEDS.

1.2.1 News Channel Overview

Prior to 1990, the market structure of Taiwan's wireless TV industry was characterized by a long-term oligopoly of three channels, primarily because of government control. The operation of cable TV systems was not legalized until 1993. Since then, Taiwan's TV market structure has undergone extensive changes. On average, clients of Taiwan's cable TV system can watch between 74 and 108 basic channels, of which TVBS, FTV, SET, Eastern Television News (ETT), Eastern Television Today (ETTO), Chung T'ien Television News (CTI), and Era Television News (ERA) are exclusively news channels. Table 1.1 contains an overview of Taiwan's major news channels.

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Regarding the political ideology of news channel reports in Taiwan, previous studies that have adopted the quantitative content analysis method to examine news content have indicated that different news channels process political news using various methods. Lo et al. (2004) asserted that during the 2004 presidential election, FTV significantly favored DPP candidates compared with other TV channels (e.g., TTV, CTV, TVBS, and CTI). In addition, 43.9% of FTV's information sources were DPP supporters, known as Pan-Green supporters (the average for all news channels was 33.5%). The duration of news reports on the DPP and coverage of DPP candidate speeches exceeded that of candidates from other parties (i.e., 71.1% for former DPP presidential candidate Chen Shui-bian's speeches compared with an average of 55% for all news channels). This fact suggests an overall impression that was more beneficial for DPP candidates. Tsai (2008) examined 100 episodes of news programs from ETT, FTV, SET, and CTI between April 15 and May 9, 2007. The results show that in terms of the number of reports and the language used, ETT and CTI both showed preferences for the KMT, whereas FTV and SET favored the DPP. In another study, Liu (2009) examined various news channel reports on the 312 Wei-xin incident during the 2008 presidential election. The results showed that TVBS reported only 8 relevant news stories during the 7 p.m. hourly news, whereas SET provided 34 reports. Furthermore, the news titles used by TVBS tended to be more supportive of the KMT, and negative reports on the KMT were understated. Conversely, SET had a more critical attitude toward the KMT. In other works, Li (2008) and Huang (2009) analyzed the news content of various channels during the 2008 presidential election. Li (2008) asserted that FTV, compared with other news channels, referenced the most information from the DPP and that their reporting content was more beneficial to the DPP. However, TVBS's reports were found to be more supportive of the KMT. Huang (2009) found that the proportion of election news involving KMT candidates was significantly greater for TVBS and CTI. Conversely, FTV's reporting durations were significantly longer for DPP candidates than for KMT candidates, and its information sources were primarily

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Pan-Green.

In summary, during the analysis period for this study (2004 to 2008), empirical evidence indicates that TVBS, CTI, and ETT news reports were beneficial to Pan-Blue politicians, whereas FTV and SET news reports were favorable to Pan-Green politicians.

1.2.2 Consumer Choices of News Programs

Prior to conducting our primary analysis, we use TEDS survey data for 2004, 2005, 2006, and 2008 to examine consumer choices of news programs.[1] The survey provides information regarding the choices of news channels, political party preferences, and demographic characteristics of the respondents. We use a multinomial logistic model to estimate the consumer selection of news programs. One key variable is the Pan-Blue dummy variable, with 1 indicating that the viewer supports the Pan-Blue Coalition. Descriptive statistics of the variables in the sample are reported in Table 1.2; Table 1.3 presents the estimation results, and Table 1.4 presents the average marginal effects of some key variables. The results suggest that Pan-Blue Coalition supporters are more likely to watch news on TVBS, CTI, and ETT and less likely to watch news programs on FTV and SET. In addition, viewers who are more educated are more likely to watch TVBS and less likely to choose FTV. Viewers with a higher income showed a greater probability of choosing TVBS, CTI, and ETT compared with lower-income individuals. Viewers above the age of 50 had a greater probability of choosing FTV than those between 20 and 29 years old.

We also use the survey data to calculate the ideological segregation index as defined

[1] Data analyzed in this section were from TEDS, 2004-2008: The Survey of Legislative Election in 2004 (TEDS 2004L) (NSC 94-2420-H004-008-SSS), the Survey of County Magistrate/City Mayoral Elections in 2005 (TEDS 2005M) (NSC 94-2420-H004-008-SSS), the Survey of Taipei City/Kaohsiung City Mayoral Elections in 2006 (TEDS 2006C) (NSC 94-2420-H004-008-SSS), and the Survey of Legislative Election in 2008 (TEDS 2008L) (NSC 94-2420-H004-008-SSS). The coordinator and principal investigators of above projects include Chi Huang, I-Chou Liu, Shiow-duan Hawang, and Yun-han Chu. More information is on TEDS website (http://www.tedsnet.org). The authors appreciate the assistance in providing data by the institute and individuals aforementioned. The authors are alone responsible for views expressed herein.

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by Gentzkow and Shapiro (2011) and find that the ideological segregation of the TV news market in Taiwan was much higher than that of the media markets in the U.S. The segregation index ranges from 0 to 1; an index with a higher value denotes a more segregated readership, meaning that some news outlets have more conservative readers while others have more liberal readers. In the work of Gentzkow and Shapiro (2011), the segregation index was found to be 0.033 in the cable TV market and between 0.018 and 0.104 for broadcast news, magazines, local newspapers, the Internet, and national newspapers in the U.S. The segregation index of Taiwan's TV media market was 0.31, which is greater than that for the U.S. media markets. This result could mean that the TV news programs are more politically polarized in Taiwan than in the U.S. or that consumers in Taiwan care more about the ideology of news stories.

The above results from the TEDS survey data indicate a strong correlation between the political ideologies of consumers in Taiwan and their choices of TV channels. This correlation may result from the tendency of consumers to watch news that has a political ideology similar to their own. Alternatively, the political preferences of consumers could be influenced by their viewing of TV channels with a specific ideology. In Section 1.4, we rely on fluctuations in program ratings by region during periods in which there are more political news to examine consumer preferences in relation to news slant and news accuracy. In the next section, we begin introducing our data.

1.3 Data: Viewership and Consumer Ideology

1.3.1 Viewership

In this study, we use audience ratings data from AGB Nielsen to examine consumer sensitivity to the political ideology and accuracy of news programs. The ratings were measured and collected through people meters that were installed in households for gathering individual ratings records. The sample examined in this study consists of the weekly average ratings data for the 8 p.m. news programs on TVBS, SET, ETT, ETTO, FTV, CTI, and ERA in the four regions of Taiwan from the beginning of 2004 to the

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end of 2008. The four regions are the greater Taipei region, the northern region, the central region, and the southern region.[2] All of the news channels analyzed broadcast news reports (either hourly news or news features) at 8 p.m. during the sampling period. After combining the ratings data with consumer political ideology by region, we obtained a total of 6,073 observations.[3]

1.3.2 Consumer Political Ideology

The public opinion surveys conducted by TVBS from April 2004 to 2006 and by Global Views between May 2006 and 2008 provide us with information regarding the political preferences of people in each region by month.[4] We classify people who support the KMT and the People First Party as Pan-Blue supporters. Supporters of the DPP and the Taiwan Solidarity Union are classified as Pan-Green supporters.

The descriptive statistics for consumers' political ideology by region are shown in Table 1.5, demonstrating that although the proportion of Pan-Blue supporters was greater than that of Pan-Green supporters in the four major regions, the greater Taipei region and the northern region possessed a significantly greater proportion of Pan-Blue supporters, whereas the disparity between these proportions was less in the southern region.

Table 1.6 presents the descriptive statistics for the weekly average ratings of the news channels. The greater Taipei region had the highest ratings for all news channels. In addition, the ratings for TVBS in the northern region were significantly higher than

[2] The greater Taipei region includes Taipei City and the following 10 towns in Taipei County: Xindian, Sinjhuang, Yonghe, Zhonghe, Banciao, Sanchong, Tucheng, Lujhou, Sijhih, and Shulin. The northern region includes Taipei County (excluding the above 10 towns in the greater Taipei region), Taoyuan County, Hsinchu County, Yilan County, and Keelung City. The central region includes Taichung County, Miaoli County, Changhua County, Nantou County, Yunlin County, and Hualien County. The southern region includes Chiayi County, Tainan County, Kaohsiung County, Pingtung County, and Taitung County.

[3] ETTO was off-air between August 7, 2005, and June 25, 2006; thus, no ratings data were available during this period.

[4] The surveys were collected by TVBS in May, June, July, August, September, and December 2004 and from January 2005 (excluding August and October) to April 2006 (excluding February).

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in the southern region, whereas the ratings for FTV and SET exhibited a smaller gap in the northern and southern regions.

1.4 Market Demand for News

In this section, we provide a simple model with settings similar to the model presented in Gentzkow and Shapiro (2010) to infer market demand for TV news programs.

1.4.1 Consumer Preferences

First, we assume that when consumers watch political news, they are aware of news slant and prefer news reports with ideologies that are closer to their own. Second, consumers always prefer more accurate news. The utility of individual i in region r at time t from watching news channel j can be expressed as follows:

$$u_{irjt} = \delta_{jt} - \gamma_1 P_t (x_{rt} - n_{jt})^2 + \gamma_2 Q_{jt} + \varepsilon_{irjt}, \tag{1.1}$$

where x_{rt} represents the preferred slant in region r at time t, and n_{jt} is the slant of news channel j, with higher values indicating more pro-Pan-Blue parties. P_t is the proportion of political news coverage in the news program at time t. The term $-\gamma_1 P_t (x_{rt} - n_{jt})^2$ represents the disutility for watching a news program whose slant n_{jt} deviates from the preferred slant x_{rt}. Q_{jt} is the news accuracy of news channel j. ε_{irjt} represents taste shocks. Finally, the term δ_{jt} is the average utility for consumers from watching news channel j at time t, derived from other unobservable characteristics of program j at time t.

In each region, the preferred slant in news reporting, x_{rt}, is assumed to be related to the the ideological position of region r at time t, B_{rt}.

$$x_{rt} = \alpha + \beta B_{rt}, \tag{1.2}$$

B_{rt} represents the ideological position of region r at time t. In our estimation, we use the proportion of people who support Pan-Blue coalition to proximate the ideological

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position of region r. Under the hypothesis that the preferred news slant is positively correlated with the ideological position of region r, β is greater than 0.

1.4.2 Market Demand

All consumers are utility maximizers. A consumer can choose to watch a news program or to not watch any news program if the utility from the news channels is lower than the utility of the outside options. We assume that the utility of the outside options is zero for all consumers. Let y_{rjt} be the market share of news channel j in region r at time t, and y_{rot} be the share of consumers who are not watching any news channel in region r at time t:

$$y_{rot} = 1 - \sum_{j=1}^{J} y_{rjt}. \tag{1.3}$$

According to Berry (1994), under the assumption that the error term ε_{irjt} has an extreme value type I distribution, the market share of news channel j can be derived as follows:

$$\ln(y_{rjt}) - \ln(y_{rot}) = \delta_{jt} - \gamma_1 P_t (x_{rt} - n_{jt})^2 + \gamma_2 Q_{jt} + \upsilon_{rjt}, \tag{1.4}$$

The derivation from the individual utility to market share enables us to infer consumer preferences using aggregate data at market level. Substituting equation (1.2) into equation (1.4), we obtain the following:

$$\begin{aligned}\ln(y_{rjt}) - \ln(y_{rot}) = \delta_{jt} - \alpha^2\gamma_1 P_t + 2\alpha\gamma_1 P_t n_{jt} - \gamma_1 P_t {n_{jt}}^2 - 2\alpha\beta\gamma_1 P_t B_{rt} - \beta^2\gamma_1 P_t {B_{rt}}^2 \\ + 2\beta\gamma_1 n_{jt} P_t B_{rt} + \gamma_2 Q_{jt} + \upsilon_{rjt}\end{aligned} \tag{1.5}$$

Under the hypothesis that consumers care for news slants and that preferred news slant is related to consumer ideology, the parameters γ_1 and β should be greater than 0. In the next section, we will test this hypothesis using weekly viewership data.

1.5 Empirical Strategy and Estimation Results

We are interested in estimating the parameters in the news demand model. The estimation, however, suffers from several difficulties. First, we do not observe the ideo-

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logical position for each news channel or other program characteristics. Second, the estimation could suffer from the endogenous problem due to omitted variables, the simultaneous problem (reverse causality), and measurement errors. Here, we present our empirical strategies to address these difficulties and derive our empirical specifications.

The first difficulty we have is that many program characteristics that would influence overall program viewership are not observable. We therefore include channel-week fixed effects in our estimation to control for unobserved program characteristics over time. Let k_{jt} be the channel-week fixed effects that absorb all observed and unobserved variation at the channel-week level:

$$k_{jt} = \delta_{jt} - \alpha^2 \gamma_1 P_t + 2\alpha\gamma_1 P_t n_{jt} - \gamma_1 P_t {n_{jt}}^2 + \gamma_2 Q_{jt}. \tag{1.6}$$

Equation (1.5) derived from section 1.4 can be rewritten as follows:

$$\ln(y_{rjt}) - \ln(y_{rot}) = k_{jt} - 2\alpha\beta\gamma_1 P_t B_{rt} - \beta^2\gamma_1 P_t {B_{rt}}^2 + 2\beta\gamma_1 n_{jt} P_t B_{rt} + \upsilon_{rjt} \tag{1.7}$$

The week-channel fixed effects k_{jt} (terms of interaction between the week dummies and the news channel dummies) capture the influence from unobservable characteristics of news channel j and of week t. The variation of viewership that we rely on, therefore, comes from the regional variation of viewership for the same channel at the same time.

The second difficulty we have is that we do not observe the ideological position for each news channel. Without news program ideologies, n_{jt}, we cannot estimate $\beta\gamma_1$ directly. However, assuming that the news slant of a news channel does not vary significantly during our sample period, we can use FTV news as a reference group and rewrite the term $2\beta\gamma_1 n_{jt} P_t B_{rt}$ as $2\beta\gamma_1(n_j - n_{FTV})P_t B_{rt} + 2\beta\gamma_1 n_{FTV} P_t B_{rt}$. For any news channel j with an ideology that significantly differs from the ideology of FTV, the coefficient of $P_t B_{rt}$ will significantly differ from zero if $\beta\gamma_1$ differs from zero. Therefore, instead of estimating of the value of $\beta\gamma_1$, we are going to estimate $\beta\gamma_1(n_j - n_{FTV})$, the coefficient of $P_t B_{rt}$.

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Considering that the demand for news may vary by regions, we include regional fixed effects, ϕ_r, in our estimation. We thus change the notation of taste shocks from υ_{rjt} to ζ_{rjt} ($\zeta_{rjt} = \upsilon_{rjt} - \phi_r$).

We can express the estimation equation as follows:

$$\begin{aligned}\ln(y_{rjt}) - \ln(y_{rot}) &= k_{jt} - 2\alpha\beta\gamma_1 P_t B_{rt} - \beta^2\gamma_1 P_t {B_{rt}}^2 + \sum_{j\neq FTV}^{J} 2\beta\gamma_1(n_j - n_{FTV})P_t B_{rt} I_j \\ &\quad + 2\beta\gamma_1 n_{FTV} P_t B_{rt} + \phi_r + \zeta_{rjt}, \qquad (1.8)\end{aligned}$$

where I_j represents a dummy variable for news channel j, k_{jt} represents week-channel fixed effects, and ϕ_r represents regional fixed effects. [5] We use the proportion of people who support the Pan-Blue party coalition from the monthly survey as a measure of the ideological preferences of consumers, B_{rt}. In our baseline specification, we assume that the amount of political news does not vary over time, $P_t = \bar{P}$. The baseline specification can be expressed as follows:

$$\ln(y_{rjt}) - \ln(y_{rot}) = k_{jt} + \lambda_1 B_{rt} + \lambda_2 {B_{rt}}^2 + \sum_{j\neq FTV}^{J} \lambda_{3j} B_{rt} I_j + \phi_r + \zeta_{rjt}, \qquad (1.9)$$

where $\lambda_1 = -2\alpha\beta\gamma_1\bar{P} + 2\beta\gamma_1 n_{FTV}\bar{P}$, $\lambda_2 = -\beta^2\gamma_1\bar{P}$, and $\lambda_{3j} = 2\beta\gamma_1(n_j - n_{FTV})\bar{P}$. Our coefficient of interest in the baseline specification, $\lambda_{3j} = 2\beta\gamma_1(n_j - n_{FTV})\bar{P}$, is the coefficient of $B_{rt}I_j$, the interaction term between the region's ideology and the dummy variable of news channel j. Under the hypothesis that consumers prefer a news channel that is slanted toward their own ideology, the coefficient λ_{3j}, should be larger if the ideology for news channel j is much more pro-Pan-Blue than FTV; thus, a pro-Pan-Blue news channel should gain more viewership in regions with more Pan-Blue supporters.

Column 1 of Table 1.7 presents the results using audience ratings data for FTV and TVBS. As noted in Section 1.2, previous studies suggest that FTV news leans toward

[5] We express the term $2\beta\gamma_1(n_j - n_{FTV})P_t B_{rt}$ as $\sum_{j\neq FTV}^{J} 2\beta\gamma_1(n_j - n_{FTV})P_t B_{rt} I_j$ in equation (1.8). These two terms are equivalent. For example, for news channel TVBS, the term $\sum_{j\neq FTV}^{J} 2\beta\gamma_1(n_j - n_{FTV})P_t B_{rt} I_j$ in equation (1.8) is equal to $2\beta\gamma_1(n_{TBVS} - n_{FTV})P_t B_{rt}$, which is the same as the expression of $2\beta\gamma_1(n_j - n_{FTV})P_t B_{rt}$ when j is equal to TVBS.

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the Pan-Green parties and that TVBS leans toward the Pan-Blue parties. Therefore, we expected the coefficient of the interaction term between the region's ideology and TVBS to be positive. As expected, our coefficient of interest is positive and statistically significant, implying that consumers may prefer a news channel whose slant is closer to their own ideology.

Third, the estimation of our baseline specification could suffer from reverse causality. If the viewers' political preferences can be influenced by political slant in the news stories, then when more people watch news programs with a Pan-Blue ideological position, there will be also more people who support the Pan-Blue coalition parties. In this case, even when we observe that the viewership of channel j of region r is larger when the correlation between the ideology of news channel j and consumer ideology of region r is stronger, we cannot infer that the viewership segregation pattern is driven by the influence of the news programs or the choices of consumers.

Our empirical strategy to address the reverse causality issue is to use the variation in political news caused by political events. If the correlation that we observe is completely driven by the influence of news programs, rather than consumers' choices, then the viewership segregation should not vary significantly over a short period of time. In other words, the viewership segregation pattern will be more significant during political events only when the viewership pattern is driven by consumers' choices rather than the influence of news stories. Next, we present specifications and empirical results using the variation caused by political events.

1.5.1 Viewership Patterns During Political Events

Theoretically, if consumers prefer news channels that lean toward their favored parties, then news channels with Pan-Blue leanings will gain relatively greater viewership in areas with more Pan-blue supporters when more political coverage is presented. In other words, viewers of news programs should be more politically segregated when there is more political news. From an empirical perspective, because the political

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preferences of consumers were unlikely to be influenced in a short period of time, any change in viewership pattern that we observe in the data is unlikely to be driven by reverse causality.

Given the variation in the amount of political news over time, $P_t = P + d_t E_t$, our estimating equation becomes the following:

$$\ln(y_{rjt}) - \ln(y_{rot}) = k_{jt} + \phi_r + \lambda_1 B_{rt} + \lambda_2 {B_{rt}}^2 + \sum_{j \neq FTV}^{J} \lambda_{3j} B_{rt} I_j + \lambda_4 E_t B_{rt} + \lambda_5 E_t {B_{rt}}^2 + \sum_{j \neq FTV}^{J} \lambda_{6j} E_t B_{rt} I_j + \zeta_{rjt}, \quad (1.10)$$

where E_t is a dummy variable indicating political events that raised the proportion of political news coverage. The coefficient of interest in this specification is $\lambda_{6j} = 2\beta\gamma_1 d_t (n_{jt} - n_{FTV,t})$, the coefficient of $E_t B_{rt} I_j$. We expect the coefficient to be positive for channels with ideologies that are more pro-Pan-Blue than FTV because during political events, consumers are more likely to choose news programs that cater to their political ideologies. We also expect λ_{3j} to be positive for channels with ideologies that are more pro-Pan-Blue than FTV, as in our baseline specifications.

The political events in our study include the 2008 presidential election and the Chen Yunlin incident during the Second Chen-Chiang summit in 2008. The summit occurred from November 3 to 7 and was part of a series of cross-strait meetings. On the night before the first day of the summit, the representative from China, Chen Yun-lin, was trapped by protesters at the Grand Formosa Regent Taipei Hotel. Hundreds of protesters surrounded the hotel, chanting, throwing eggs, and burning Chinese flags. The riot police clashed with the protesters, and dozens of people were injured. Another protest occurred when President Ma met with Chen Yun-lin at the Taipei Guest House on November 6. The protest quickly snowballed until thousands of people had joined the demonstration rally. During the event, the DPP criticized the government for mobilizing all its resources to suppress public opinion, whereas the KMT blamed the DPP for unruly protests. In this paper, we use the week between November 2 and November 8 in 2008 as the period of the Chen Yunlin incident and the week of the

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election as the 2008 presidential election period.

The second and fourth columns of Table 1.7 report the results from examining the change in viewing patterns during political events. During political events, the ratings of TVBS are expected to increase more than those of FTV in regions with more Pan-Blue supporters if the consumers prefer slanted news programs when watching political news. As a result, we expect the coefficient of $E_t B_{rt} I_{TVBS}$ to be positive. Column 2 presents the results using data from FTV and TVBS. These results show that in addition to the coefficient of $B_{rt} I_{TVBS}$ remaining positive and statistically significant, the coefficient of $E_t B_{rt} I_{TVBS}$ is also positive and statistically significant. The magnitude of these coefficients is large. For example, the coefficient of $E_{Chen} B_{rt} I_{TVBS}$ is 3.04, which implies that in the region with full of Pan-Blue supporters, the ratings of TVBS during the event would be three times larger than its ratings on ordinary days provided that the ratings of FTV and the outside options had not changed during the event. This finding implies that consumers do prefer news channels whose slant is close to their own ideology, especially when exceptional political events are occurring.

The third and fourth columns of Table 1.7 show the results with the inclusion of all news channels. The results of using data from all news channels are similar to the results of using data from FTV and TVBS only. Furthermore, the results for other news channels are consistent with the findings of previous studies regarding the slant of news channels. For example, our coefficients of interest that are related to CTI and ETT, $\lambda_{6,CTI}$ and $\lambda_{6,ETT}$ are positive, which is consistent with the assertion that the news content of both CTI and ETT is more Pan-Blue than the content of FTV, as documented by Tsai (2008) and Huang (2009). In addition, our results show that the coefficients related to SET are insignificant. This finding is fairly consistent with the previous finding that both FTV and SET favored the Pan-Green coalition.

Finally, our estimation could suffer from measurement errors. In our estimation, the measurement of consumers' ideologies, and thus the inferred ideologies of preferred slants, could be measured with errors due to the limited sample size of the sur-

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veys. In this case, the measurement errors will cause the estimation to be biased toward zero. The measurement errors could also come from consumer misreporting because it is believed that people who support the Pan-Green parties are less likely to reveal their political preferences. In this case, the variation in political preferences that we observed will be smaller than the true variation, which will also cause the estimation to be biased toward zero. Therefore, while our estimates may be biased downward, the interpretation of the results is still valid.

1.5.2 Robustness Checks

In this section, we present three sets of robustness checks. First, we use month-channel fixed effects instead of week-channel fixed effects to reduce the number of variables to be estimated in the model. Because the characteristics of news channels may vary across months but are unlikely to vary substantially within a month, using the interactions between month dummies and news channel dummies should allow us to control for unobservable program characteristics varying over time. The results are reported in Table 1.8. Second, we include channel specific time trend variables instead of week-channel or month channel fixed effects. The channel specific time trend variables include t, t^2, and t^3 as well as the interactions between these time-related variables and the news channel dummy I_j. Table 1.9 presents the estimation results. As shown in Table 1.8 and Table 1.9, while some of the coefficients are more significant than in the previous results, the results are generally consistent with the previous findings.

The derivation of market demand from individual utility in section 1.4 requires the assumption that the individual unobservable taste shock, ε_{irjt}, is distributed as an extreme value type I distribution; thus, our dependent variable is $\ln(y_{rjt}) - \ln(y_{rot})$ in all of the specifications above. In our third set of robustness checks, we present results with the ratings of news channels, y_{rjt} , as the dependent variable in a linear regression model. As shown in Table 1.10, the results are qualitatively consistent with the previous findings.

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1.5.3 Accuracy of News

In this section, we investigate consumer sensitivity to the accuracy of news programs. We use two false news events, TVBS's Chou Cheng-pao videotape incident and SET's 228 false footage incident, to estimate the effect of news accuracy on viewership. We introduce these two events below.

1.5.3.1 TVBS's Chou Cheng-Pao Videotape Incident

On March 25, 2007, TVBS aired a shocking video in which a wanted gangster sat next to a number of pistols and rifles, claimed that he was behind three shooting incidents in the Taichung area, and threatened to shoot his former gangster boss. When airing the video in the news program, TVBS claimed that the video had been received by mail. On March 27, however, it was revealed that Chou's video was shot by a TVBS reporter. TVBS subsequently fired the reporter and his superior. On March 30, the National Communications Commission (NCC) fined TVBS NT$2 million and required TVBS to replace the general manager. Lee Tao subsequently announced his resignation as general manager of TVBS News on April 2.

1.5.3.2 SET's 228 False Footage Incident

SET broadcasted a series of special reports on the 228 Incident between March 3 and March 7 in 2007. On May 8, it was revealed that SET had misrepresented an image of KMT soldiers publicly executing a person in Shanghai in 1948 as occurred during the 228 Incident. SET apologized for its misuse of the footage on May 9, and the NCC fined SET NT$1 million for misleading the public.

1.5.3.3 Empirical Results

These two false news events attracted a substantial amount of public criticism and should thus be expected to hurt the viewership of these channels if consumers are concerned about accuracy. We use the week from March 25 to March 31, 2007, as the period of the Chou Cheng-Pao videotape incident to examine the effect of this incident.

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Furthermore, to explore how long the effect of this incident persisted, we also analyze the effect one, two, and more weeks after the incident. We use the week from May 6 to May 12, 2007, as the period in which the SET's 228-related false footage was exposed.

Under the assumption that consumers care about accuracy, these two false news events should have harmed the viewership of TVBS or SET. Therefore, we expected that ratings fluctuations for TVBS and SET after the disclosure of false news would be negative relative to that of other news channels. Rather than use channel-week fixed effects, we use two different methods to estimate the effects of false news. In the first method, we include week fixed effects and channel fixed effects. In the second method, we include the channel-specific time trend (t, t^2, t^3, and their interactions with channel dummies) in our baseline specifications to estimate the effects of Q_{jt}.

Table 1.11 shows the estimation results for consumer sensitivity to the accuracy of news: Columns 1 and 2 are the results of using only data from 2007, and Columns 3 and 4 are the results of using the full set of data from 2004 to 2008. In Columns 1 and 3, we include week fixed effects and channel fixed effects, and in Columns 2 and 4, we include the channel-specific time trend. Columns 1 and 2 show that when using data that are exclusively from 2007, the effect of TVBS's Chou Cheng-Oao videotape incident for TVBS is negative one or two weeks after the disclosure of false news. However, the effect of SET's 228 false footage incident for SET is positive during the week in which the false footage was exposed, but the effect becomes negative between one week and three weeks after the disclosure.

Using the full set of data in Columns 3 and 4, we find that the results are various in different specifications. Column 3 shows that when we include week fixed effects, only the effect of SET's false footage incident for SET is significant and positive during the week in which the false footage was exposed, and furthermore, there is no significant effect for TVBS. However, when we include the channel-specific time trend in Column 4, the effect of TVBS's incident is negative for TVBS two weeks after the disclosure of false news, and the effect of SET's incident for SET is also negative between one week

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and three weeks after the disclosure. Together, these results show that the changes in the ratings for TVBS and SET during incidents of false reports are either small or insignificant.

1.6 Conclusions

This study investigates consumer political ideology preferences regarding TV news programs in Taiwan's environment of open and competitive contemporary media. We use audience ratings data for Taiwan's news channels between 2004 and 2008 to examine the sensitivity of consumers to the political ideology and accuracy of news programs. The survey data and regional viewership data considered in this study suggest that consumers may prefer news channels whose slant is close to their own ideology.

However, the estimation results above may suffer from endogeneity problems resulting from reverse causality. Thus, we also explore changes in viewership patterns during periods with more political news to further examine consumer preferences regarding the slant of news channels. We find that during the 2008 presidential election and the Chen Yunlin incident, the increase in ratings for TVBS was greater than that for FTV in regions with greater proportions of Pan-Blue supporters. This finding indicates that during political events, consumers are more inclined to watch news programs with a political ideology approximating their own.

Moreover, the results for other news channels are consistent with previous studies regarding the slant of each news channel. Our results show that the increase in ratings for CTI and ETT was greater than that for FTV in regions with a greater proportion of Pan-Blue supporters; in contrast, there was no significant difference between changes in ratings for FTV and SET. These findings are in accordance with the results of previous studies indicating that the news content of CTI and ETT are more Pan-Blue than FTV and that both FTV and SET are Pan-Green.

After examining consumer sensitivity to political ideology, we explore the sensitivity of consumers to the accuracy of news programs. We employ TVBS's Chou

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Cheng-Pao videotape incident and SET's 228 false footage incident as examples of sudden changes in news accuracy for these two news channels. We find that changes in ratings for TVBS and SET during incidents in which false reports were exposed are small or insignificant.

This paper shows that consumers tend to watch news that reflects a political ideology that is similar to their own in Taiwan's current environment of open and competitive contemporary media. Furthermore, compared to the tendency to watch news that approximates self-beliefs, consumers are not very sensitive to accuracy in news programs.

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Tables

Table 1.1

24-hour Television News Channels in Taiwan

Name	Abbreviation in the paper	Company	Year of establishment
TVBS NEWS	TVBS	TVBI Company Limited (a subsidiary of Television Broadcasts Limite in Hong Kong) ERA Group of Taiwan (2004-2005) TVBI Company Limited (2005--)	1995
FTV News	FTV	Formosa Television Inc.	1997
CTi News	CTI	China Times Group (2004- Nov. 2008) Want Want China Times Group (Nov. 2008--)	1997
SET News	SET	Sanlih E-Television Inc.	1998
Era News	ERA	ERA Communications Inc.	1996
ETTV News	ETT	Eastern Broadcasting Co.	1997
ETtoday	ETTO	Eastern Broadcasting Co.	1999

Note: ETtoday was off-air between August 7, 2005, and June 25, 2006. It changed its name to EBC Financial News on mid-December, 2008.

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Table 1.2

Summary Statistics of the TEDS Survey Sample

	Observations	Mean	S.D
Choice of TV channels:			
FTV	3,584	0.182	0.386
TVBS	3,584	0.252	0.434
SET	3,584	0.112	0.315
ETT	3,584	0.099	0.299
CTI	3,584	0.096	0.295
Political ideology:			
Pan-blue	3,584	0.571	0.495
Gender:			
Male	3,584	0.516	0.500
Level of education:			
Junior high school	3,584	0.116	0.320
High school	3,584	0.292	0.455
Junior college	3,584	0.157	0.364
Above university	3,584	0.293	0.455
Ethnic Group:			
Minnanese	3,584	0.733	0.442
Mainlander	3,584	0.166	0.372
Aborigine	3,584	0.009	0.097

Notes: (1) The data samples comprise TEDS survey data from the 2004 and 2008 legislative elections, the 2005 county governor and city mayor elections, and the 2006 Taipei and Kaohsiung City mayor elections. (2) S.D. represents the standard deviation of the variable.

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Table 1.3

Choices of TV News Channels

Choice of TV channels	TVBS	SET	ETT	CTI	Others
Pan-Blue	2.842***	0.400**	2.366***	2.410***	2.065***
	[0.149]	[0.175]	[0.171]	[0.177]	[0.137]
Male	0.127	0.265*	-0.014	0.091	-0.088
	[0.128]	[0.140]	[0.151]	[0.154]	[0.122]
Level of education:					
Junior high school	0.363	0.175	0.399	-0.037	0.047
	[0.262]	[0.234]	[0.349]	[0.308]	[0.204]
High school	1.381***	0.269	0.977***	0.640**	0.463**
	[0.235]	[0.232]	[0.322]	[0.284]	[0.192]
Junior college	1.543***	0.321	0.748**	0.587*	0.660***
	[0.267]	[0.284]	[0.363]	[0.324]	[0.231]
Above university	1.648***	0.420	0.549	0.805**	0.675***
	[0.264]	[0.270]	[0.369]	[0.314]	[0.225]
Ethnic Group:					
Minnanese	-0.321	0.161	0.076	-0.025	-0.330
	[0.307]	[0.356]	[0.363]	[0.380]	[0.290]
Mainlander	0.639	0.320	0.871*	0.832*	0.615
	[0.419]	[0.515]	[0.479]	[0.486]	[0.406]
Aborigine	1.006	-13.077***	1.583	0.926	0.772
	[1.076]	[1.209]	[1.132]	[1.282]	[0.977]
Year of interview:					
2005	-0.248	-0.278	-0.441**	-0.409*	-0.322*
	[0.186]	[0.213]	[0.207]	[0.227]	[0.168]
2006	-0.124	0.479**	-0.530**	0.016	-0.124
	[0.195]	[0.218]	[0.225]	[0.233]	[0.182]
2008	0.099	0.908***	-0.691**	0.219	-0.537**
	[0.218]	[0.237]	[0.277]	[0.261]	[0.209]
Constants	-2.256***	-0.970*	-1.023*	-2.487***	-0.209
	[0.488]	[0.523]	[0.607]	[0.581]	[0.431]
Observations	3,584	3,584	3,584	3,584	3,584

Notes: (1) Coefficients from the multinomial logit model are presented in this table. The reference group is FTV. (2) Standard errors are in brackets. (3) The control group of "level of education" is "below elementary school." The control group of "Ethnic Group" is "Hakka." The control group of "year of interview" is "2004." (4) Other control variables not presented in this table include: age, income categories, occupation, regions, and mother's ethnicity. (5) ***Significant at 1 percent level. **Significant at 5 percent level. *Significant at 10 percent level.

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Table 1.4

Choices of TV News Channels (Average Partial effects)

Choice of TV channels	FTV	TVBS	SET	ETT	CTI
Pan-Blue	-0.216***	0.188***	-0.108***	0.041***	0.040***
	[0.013]	[0.014]	[0.011]	[0.009]	[0.010]
Male	-0.008	0.020	0.023**	-0.006	0.004
	[0.012]	[0.014]	[0.011]	[0.010]	[0.010]
Level of education:					
Junior high school	-0.020	0.044	0.005	0.022	-0.021
	[0.020]	[0.038]	[0.020]	[0.028]	[0.024]
High school	-0.077***	0.146***	-0.027	0.024	-0.010
	[0.019]	[0.032]	[0.019]	[0.025]	[0.021]
Junior college	-0.087***	0.167***	-0.027	-0.005	-0.023
	[0.024]	[0.035]	[0.022]	[0.027]	[0.023]
Above university	-0.093***	0.181***	-0.021	-0.029	-0.006
	[0.023]	[0.034]	[0.021]	[0.028]	[0.023]
Ethnic Group:					
Minnanese	0.015	-0.035	0.028	0.023	0.014
	[0.031]	[0.031]	[0.026]	[0.023]	[0.025]
Mainlander	-0.069	0.010	-0.013	0.029	0.024
	[0.045]	[0.035]	[0.036]	[0.026]	[0.027]
Aborigine	0.308***	0.290***	-1.232***	0.190***	0.125
	[0.109]	[0.108]	[0.105]	[0.063]	[0.079]
Year of interview:					
2005	0.037**	0.010	-0.005	-0.016	-0.012
	[0.017]	[0.022]	[0.017]	[0.014]	[0.016]
2006	-0.000	-0.007	0.053***	-0.043***	0.010
	[0.018]	[0.022]	[0.017]	[0.015]	[0.016]
2008	-0.001	0.048**	0.097***	-0.058***	0.029*
	[0.021]	[0.024]	[0.018]	[0.019]	[0.017]
Observations	3,584	3,584	3,584	3,584	3,584

Notes: (1) Average partial effects are presented in this table. The reference group is FTV. (2) Standard errors are in brackets. (3) The control group of “level of education” is “below elementary school.” The control group of “Ethnic Group” is “Hakka.” The control group of “year of interview” is “2004.” (4) Other control variables not presented in this table include: age, income categories, occupation, regions, and mother’s ethnicity. (5) ***Significant at 1 percent level. **Significant at 5 percent level. *Significant at 10 percent level.

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Table 1.5

Consumer Political Preference in Taiwan

		Proportion of Pan-Blue		Proportion of Pan-Green	
	Observations	Mean	Standard errors	Mean	Standard errors
Greater Taipei region	51	0.419	0.088	0.223	0.064
Northern region	51	0.444	0.094	0.203	0.073
Central region	51	0.379	0.072	0.219	0.056
Southern region	51	0.348	0.058	0.272	0.050

Notes: (1) The data is from monthly public opinion surveys conducted by TVBS in May, June, July, August, September, and December 2004 and from 2005 (excluding August and October) to April 2006 (excluding February), and from the public opinion survey data collected by Global Views Monthly between May 2006 and 2008. (2) We classify people who support for KMT and PFP as Pan-Blue Coalition supporters. People who support for the DPP and TSU are classified as Pan-Green Coalition supporters.

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Table 1.6

Weekly Average Ratings For the News Channels

Region	All		Greater Taipei	Northern	Central	Southern
Channel	Mean	Std. Dev.	Mean	Mean	Mean	Mean
TVBS	0.57	0.20	0.72	0.67	0.39	0.49
FTV	0.30	0.10	0.36	0.30	0.25	0.30
CTI	0.42	0.14	0.53	0.44	0.32	0.38
SET	0.44	0.14	0.57	0.41	0.36	0.42
ERA	0.21	0.06	0.26	0.22	0.17	0.19
ETT	0.34	0.12	0.44	0.38	0.26	0.29
ETTO	0.21	0.10	0.30	0.20	0.15	0.19

Notes: (1) Sample period: December 28, 2003, to December 28, 2008. (2) ETTO was off-air between August 7, 2005, and June 25, 2006. After discarding monthly ratings data that were not included in the public opinion survey data, 6,073 samples are obtained.

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Table 1.7

Viewership Patterns During Political Events

Samples	FTV and TVBS		All news channels	
Pan-blue ×TVBS	2.324***	2.303***	2.324***	2.303***
	[0.181]	[0.182]	[0.184]	[0.185]
Pan-blue × CTI			1.008***	0.984***
			[0.201]	[0.202]
Pan-blue × ERA			0.961***	0.938***
			[0.210]	[0.211]
Pan-blue × ETT			1.990***	1.956***
			[0.194]	[0.194]
Pan-blue × SET			0.330*	0.338*
			[0.183]	[0.185]
Pan-blue × ETTO			1.373***	1.344***
			[0.324]	[0.327]
Chen × Pan-blue × TVBS		3.043*		3.043*
		[1.691]		[1.779]
Chen × Pan-blue × CTI				2.130
				[2.160]
Chen × Pan-blue × ERA				3.531*
				[1.833]
Chen × Pan-blue × ETT				2.910
				[1.843]
Chen × Pan-blue × SET				-1.953
				[1.659]
Chen × Pan-blue × ETTO				1.966
				[1.992]
08 election ×Pan-blue × TVBS		1.701***		1.701*
		[0.428]		[0.879]
08 election ×Pan-blue × CTI				3.585***
				[0.910]
08 election ×Pan-blue × ERA				1.515
				[0.981]
08 election ×Pan-blue × ETT				5.050***
				[0.950]
08 election ×Pan-blue × SET				0.224
				[1.614]
08 election ×Pan-blue × ETTO				3.743***
				[1.138]
Observations	1,774	1,774	6,073	6,073
R-squared	0.857	0.859	0.861	0.863

Notes: (1) Standard errors are in brackets. (2) The dependent variable is $\ln(y_{rjt}) - \ln(y_{rot})$. (3) Column 1 and 2 present results using data of FTV and TVBS. Column 3 and 4 present results using data of all news channels. (4) All other controls not presented in this table include: the proportion of pan-blue supporters in a region (B_{rt}), the square term of the proportion of pan-blue supporters in a region (B_{rt}^2), the interaction term between the exceptional event and the proportion of pan-blue supporters in a region ($E_t \cdot B_{rt}$), the interaction term between the exceptional event and the square term of the proportion of pan-blue supporters ($E_t \cdot B_{rt}^2$), regional fixed effects ϕ_r, and week-channel fixed effects k_{jt}. (5) The control group of news channels is FTV. “Chen” represents the Chen Yun-lin incident, and “08 election” represents the 2008 presidential election. (6) ***Significant at 1 percent level. **Significant at 5 percent level. *Significant at 10 percent level.

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Table 1.8

Robustness Checks I

Samples	FTV and TVBS		All news channels	
Pan-blue ×TVBS	2.317***	2.295***	2.317***	2.295***
	[0.177]	[0.178]	[0.179]	[0.180]
Pan-blue × CTI			0.997***	0.973***
			[0.198]	[0.199]
Pan-blue × ERA			0.958***	0.935***
			[0.207]	[0.208]
Pan-blue × ETT			1.967***	1.933***
			[0.197]	[0.198]
Pan-blue × SET			0.328*	0.337*
			[0.181]	[0.182]
Pan-blue × ETTO			1.356***	1.327***
			[0.322]	[0.324]
Chen × Pan-blue × TVBS		3.051*		3.051*
		[1.593]		[1.613]
Chen × Pan-blue × CTI				2.141
				[1.958]
Chen × Pan-blue × ERA				3.533**
				[1.663]
Chen × Pan-blue × ETT				2.933*
				[1.672]
Chen × Pan-blue × SET				-1.952
				[1.505]
Chen × Pan-blue × ETTO				1.983
				[1.810]
08 election ×Pan-blue × TVBS		1.708***		1.708**
		[0.405]		[0.799]
08 election ×Pan-blue × CTI				3.595***
				[0.828]
08 election ×Pan-blue × ERA				1.517*
				[0.893]
08 election ×Pan-blue × ETT				5.073***
				[0.865]
08 election ×Pan-blue × SET				0.225
				[1.464]
08 election ×Pan-blue × ETTO				3.760***
				[1.040]
Observations	1,774	1,774	6,073	6,073
R-squared	0.856	0.857	0.830	0.832

Notes: (1) In these specifications, month-channel fixed effects (the interactions between month dummies and news channel dummies) are used to control for unobservable program characteristics varying over time. (2) The dependent variable is $\ln(y_{rjt}) - \ln(y_{rot})$. (3) Column 1 and 2 present the result using data of FTV and TVBS. Column 3 and 4 present the result using data of all news channels. (4) Standard errors are in brackets. (5) The control group of news channels is FTV. "Chen" represents the Chen Yun-lin incident, and "08 election" represents the 2008 presidential election. (6) ***Significant at 1 percent level. **Significant at 5 percent level. *Significant at 10 percent level.

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Table 1.9

Robustness Checks II

Samples	FTV and TVBS		All news channels	
Pan-blue ×TVBS	1.220***	1.207***	1.220***	1.207***
	[0.169]	[0.169]	[0.171]	[0.170]
Pan-blue × CTI			0.517***	0.508***
			[0.168]	[0.167]
Pan-blue × ERA			0.130	0.111
			[0.184]	[0.184]
Pan-blue × ETT			1.141***	1.124***
			[0.183]	[0.182]
Pan-blue × SET			0.023	0.027
			[0.169]	[0.168]
Pan-blue × ETTO			0.283	0.257
			[0.318]	[0.320]
Chen × Pan-blue × TVBS		4.139***		4.139***
		[1.465]		[1.543]
Chen × Pan-blue × CTI				2.605
				[1.872]
Chen × Pan-blue × ERA				4.358***
				[1.587]
Chen × Pan-blue × ETT				3.742**
				[1.598]
Chen × Pan-blue × SET				-1.641
				[1.437]
Chen × Pan-blue × ETTO				3.053*
				[1.733]
08 election ×Pan-blue × TVBS		2.796***		2.796***
		[0.403]		[0.797]
08 election ×Pan-blue × CTI				4.060***
				[0.818]
08 election ×Pan-blue × ERA				2.342***
				[0.868]
08 election ×Pan-blue × ETT				5.882***
				[0.857]
08 election ×Pan-blue × SET				0.536
				[1.384]
08 election ×Pan-blue × ETTO				4.830***
				[0.989]
Observations	1,774	1,774	6,073	6,073
R-squared	0.733	0.743	0.715	0.721

Notes: (1) In these specifications, channel-specific time trends (t、t^2、t^3 and the interactions between these time-related variables and news channel dummies) are used to control for channel specific time trends. (2) The dependent variable is $\ln(y_{rjt}) - \ln(y_{rot})$. (3) Column 1 and 2 present the result using data of FTV and TVBS. Column 3 and 4 present the result using data of all news channels. (4) Standard errors are in brackets. (5) The control group of news channels is FTV. "Chen" represents the Chen Yun-lin incident, and "08 election" represents the 2008 presidential election. (6) ***Significant at 1 percent level. **Significant at 5 percent level. *Significant at 10 percent level.

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Table 1.10

Robustness Checks III (Reduced Form Estimation)

Samples	FTV and TVBS		All news channels	
Pan-blue ×TVBS	1.537***	1.515***	1.537***	1.515***
	[0.087]	[0.087]	[0.089]	[0.089]
Pan-blue × CTI			0.538***	0.520***
			[0.074]	[0.074]
Pan-blue × ERA			0.158***	0.156**
			[0.061]	[0.061]
Pan-blue × ETT			0.660***	0.642***
			[0.064]	[0.063]
Pan-blue × SET			0.242***	0.247***
			[0.068]	[0.068]
Pan-blue × ETTO			0.166**	0.160**
			[0.070]	[0.070]
Chen × Pan-blue × TVBS		2.588**		2.588**
		[1.010]		[1.067]
Chen × Pan-blue × CTI				1.221
				[1.196]
Chen × Pan-blue × ERA				-0.070
				[0.829]
Chen × Pan-blue × ETT				1.430*
				[0.866]
Chen × Pan-blue × SET				-1.408
				[0.879]
Chen × Pan-blue × ETTO				0.026
				[0.808]
08 election ×Pan-blue × TVBS		2.491***		2.491***
		[0.434]		[0.577]
08 election ×Pan-blue × CTI				3.194***
				[0.322]
08 election ×Pan-blue × ERA				0.682**
				[0.268]
08 election ×Pan-blue × ETT				2.965***
				[0.267]
08 election ×Pan-blue × SET				0.434
				[1.643]
08 election ×Pan-blue × ETTO				1.195***
				[0.389]
Observations	1,774	1,774	6,073	6,073
R-squared	0.857	0.859	0.861	0.863

Notes: (1) Standard errors are in brackets. (2) The dependent variable is y_{rjt}. (3) Column 1 and 2 present the result using data of FTV and TVBS. Column 3 and 4 present the result using data of all news channels. (4) All other controls not presented in this table include: the proportion of pan-blue supporters in a region (B_{rt}), the square term of the proportion of pan-blue supporters in a region (B_{rt}^2), the interaction term between the exceptional event and the proportion of pan-blue supporters in a region ($E_t \cdot B_{rt}$), the interaction term between the exceptional event and the square term of the proportion of pan-blue supporters ($E_t \cdot B_{rt}^2$), regional fixed effects ϕ_r, and week-channel fixed effects k_{jt}(interaction terms of week dummies and news channel dummies). (5) The control group of news channels is FTV. "Chen" represents the Chen Yun-lin incident, and "08 election" represents the 2008 presidential election. (6) ***Significant at 1 percent level. **Significant at 5 percent level. *Significant at 10 percent level.

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Table 1.11

Consumers' Sensitivity to News Accuracy

Samples	2007		2004 to 2008	
TVBS × the week of the Chou videotape incident was exposed	-0.129	-0.076	-0.079	-0.079
	[0.095]	[0.086]	[0.103]	[0.064]
TVBS × one week after the Chou videotape incident was exposed	-0.150**	-0.014	-0.096	-0.043
	[0.066]	[0.047]	[0.075]	[0.049]
TVBS × two weeks after the Chou videotape incident was exposed	-0.151	-0.153*	-0.097	-0.185**
	[0.108]	[0.085]	[0.106]	[0.085]
TVBS × three weeks after the Chou videotape incident was exposed	0.044	0.012	0.099	-0.022
	[0.111]	[0.090]	[0.104]	[0.090]
TVBS × four weeks after the Chou videotape incident was exposed	-0.057	-0.023	-0.003	-0.059
	[0.050]	[0.047]	[0.067]	[0.046]
SET × the week of the false footage was exposed	0.213*	0.235**	0.341**	0.160
	[0.120]	[0.111]	[0.140]	[0.114]
SET × one week after the false footage was exposed	-0.130*	-0.149**	-0.002	-0.233***
	[0.072]	[0.066]	[0.067]	[0.060]
SET × two weeks after the false footage was exposed	-0.014	0.062	0.115	-0.031
	[0.094]	[0.073]	[0.123]	[0.078]
SET × three weeks after the false footage was exposed	-0.171**	-0.123*	-0.043	-0.225***
	[0.076]	[0.070]	[0.098]	[0.078]
SET ×four weeks after the false footage was exposed	-0.074	0.010	0.046	-0.101*
	[0.064]	[0.059]	[0.075]	[0.052]
Week and channel fixed effects	✓		✓	
Channel Specific Time Trend		✓		✓
Observations	1,456	1,456	6,073	6,073
R-squared	0.773	0.773	0.722	0.722

Notes: (1) Standard errors are in brackets. (2) The dependent variable is $\ln(y_{rjt}) - \ln(y_{rot})$. (3) Column 1 and 2 present the result using data of year 2007. Column 3 and 4 present the result using data of all years. (4) All other controls not presented in this table include: news channel dummies, the proportion of pan-blue supporters in a region (B_{rt}), the square term of the proportion of pan-blue supporters in a region (B_{rt}^2), the interaction term between the exceptional event and the proportion of pan-blue supporters in a region ($E_t \cdot B_{rt}$), the interaction term between the exceptional event and the square term of the proportion of pan-blue supporters ($E_t \cdot B_{rt}^2$), the interaction term between the exceptional event and news channel dummy($E_t \cdot I_j$), regional fixed effects ϕ_r, week dummies in column 1and 3, t、t^2、t^3 and the interactions between these time-related variables and news channel dummies to control for channel specific time trends in column 2 and 4. (5) The control group of news channels is FTV. The coefficient on "TVBS/SET× the week of the Chou videotape/special reports broadcast" captures relative to FTV, ratings fluctuations for TVBS/ SET during these two false reports incidents. (6) ***Significant at 1 percent level. **Significant at 5 percent level. *Significant at 10 percent level.

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Chapter 2

Long-Term Impacts of Early-life Exposure to Malaria: Evidence from Taiwan's 1950 Eradication Campaign

2.1 Introduction

Research has indicated that health conditions in early life could have long-lasting impacts on various developmental outcomes into adulthood (Case et al., 2005; Almond and Currie, 2011a). Early-life health conditions predetermine one's health capital later in life, and health capital is a crucial element of economic competence throughout one's life. Researchers used to believe that the placenta was an impeccable filter; hence, it was acceptable for pregnant women to smoke or drink in the 1950s (Almond and Currie, 2011b).

Barker (1992) first formalized this conjecture by proposing the fetal origins hypothesis. The fetal origins hypothesis posits that "certain chronic conditions later in life can be traced to the course of fetal development." Consequently, certain chronic health conditions such as diabetes and cardiovascular diseases in middle or old age can be traced back to the fetal environment. Extensive evidence in the medical literature supports this hypothesis. For example, Langley-Evans (2001) and Brown et al. (2004) find that poor early fetal conditions increase the risks of vascular resistance, hypertension, and schizophrenia. In addition, a series of epidemiological studies indicate that cohorts in utero during the Dutch famine suffered from coronary heart disease morbid-

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ity and several other health problems in middle age (Roseboom et al., 2000; Roseboom et al., 2001; Ravelli et al., 2005). This evidence shows a strong relationship between the in utero environment and long-term outcomes.

However, it is not easy to demonstrate the causality between health conditions in early life and long-term outcomes. The main problem with estimating the effect of early-life health is mainly due to omitted confounders, such as socioeconomic conditions. To address this identification concern, researchers have established ingenious methods to mitigate potential bias from omitted confounders. For example, Almond (2006) uses the abrupt and unexpected attribute of the 1918 influenza pandemic as a natural experiment to test the fetal origins hypothesis. He compares long-term outcomes for cohorts born during the 1918 influenza epidemic to the outcomes of cohorts born one year before or after the epidemic and finds large negative long-term consequences from exposure to the 1918 influenza virus, such as lower educational attainment and socioeconomic status and higher disability rates. Chen and Zhou (2007) indicate that cohorts exposed to the China's Great Famine in early life were significantly shorter, worked fewer hours and earned less income in adulthood. Lee (2014) also shows that prenatal exposure to the Korean War led to lower educational attainment and labor market performance and higher disability rates later in life.

In recent years, a series of studies has employed malaria exposure to estimate the effects of early-life health shocks. Some studies use the instrumental variables identification strategy and employ climatic factors such as rainfall and temperature as instruments for malaria deaths. These studies indicate that cohorts exposed to malaria in their year of birth have significantly lower levels of educational attainment, shorter height as adults, and a higher possibility of cardiovascular and lung diseases in old ages (Hong, 2007; Barreca, 2010; Chang et al., 2014). Moreover, a series of studies exploits the implementation of malaria eradication campaigns in historically endemic countries as quasi-experiments and finds that malaria exposure in early life has negative effects on one's socioeconomic outcomes but has an ambiguous effect on education attain-

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ment in adulthood (Lucas, 2010; Bleakley, 2010; Cutler et al., 2010; Barofsky et al., 2011; Venkataramani, 2012; Hong, 2013) (further discussion in Section 2.2).

Based on the aforementioned literature, this paper estimates the long-term impacts of in utero and postnatal exposure to malaria in Taiwan. In Taiwan, malaria accounted for most of the overall disease burden during the early 20th century. The death rate was approximately 0.3%. Malaria still affected people severely (especially children) in the late 1940s. In the 1950s, Taiwan implemented a nationwide malaria eradication campaign. The campaign led to a significant decline in malaria. Taiwan was certified by the WHO as an area where malaria had been eradicated in 1965, and the country has successfully maintained its malaria-free status through today.

Utilizing the malaria eradication campaign in Taiwan as a quasi-experiment, this paper estimates the long-term impacts of early-life (in utero and postnatal) exposure to malaria through the combination of geographic variation in the reduction of malaria intensity that resulted from eradication and cohort exposure based on the timing of the national malaria eradication campaign. Specifically, we match adults in the 1992 – 2012 Taiwan Social Change Survey to the malaria intensity in their individual place and year of birth in the 1950s and use the difference-in-differences identification strategy to alleviate potential biases caused by omitted factors and measurement errors

The contribution of this paper is twofold. First, in addition to examining the impacts of malaria exposure on own education attainment and income as discussed in existing studies, this paper investigates the effect on spousal educational attainment, which is a marriage-related outcome. To the best of our knowledge, this paper is the first that attempts to investigate the impacts of early-life malaria exposure on marriage. Second, rather than using the pre-eradication geographic variation in malaria risk used in most previous studies on malaria eradication campaigns, this paper utilizes the geographic variation in the reduction in malaria intensity between the pre-eradication period and the post-eradication period because the reduction in malaria intensity that resulted from the eradication campaign could capture the geographic variation more

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precisely and allow us to directly examine the impacts of the eradication.

In addition to contributing to the research on early-life health conditions, the crucial fact that malaria continues to be a severe public health issue in developing countries today underscores the importance of this paper. Malaria occurs in nearly 100 countries today, most of which are in Africa, and more than 3 billion people are at risk of suffering from the disease. Children under five years of age and pregnant women are the most severely affected (WHO, 2013). This paper helps to verify the long-term impacts of malaria and evaluate malaria control policies using Taiwan's experience during the mid-twentieth century.

Our estimates show that men born after the malaria eradication in regions with larger decreases in malaria intensity had larger increases in their own educational attainment, in family income, and in their spouses' educational attainment in adulthood. We also use the 1980 census data to show there is a sharp education increase after the eradication, and the identification strategy is very similar to the regression discontinuity design. Although malaria eradication increased women's educational attainment based on data from the 1980 census, other significant benefits for women from the eradication were not observed in most specifications, and explanations for this result are discussed. Our results suggest that there were negative and significant effects of early-life malaria exposure on long-term outcomes in Taiwan.

The remainder of this paper is organized as follows. Section 2.2 describes the literature review. Section 2.3 introduces background information on malaria and the data used in this paper. Section 2.4 presents the empirical specification. Section 2.5 discusses the estimation results, and section 2.6 concludes the paper.

2.2 Literature Review

The fetal origins hypothesis proposed by Barker (1992) posits that "certain chronic conditions later in life can be traced to the course of fetal development." Inadequate in utero nutrition could "program" a fetus to prioritize brain growth at the expense of

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other organs and tissues. Correspondingly, certain chronic health conditions such as diabetes, stroke, and heart problems in middle or old age can be traced back to the fetal environment.

A considerable amount of evidence in the medical literature supports this hypothesis. Ozanne and Hales (2004) find that the lifespan of experimental mice is significantly shortened if the postnatal period of growth is accelerated to compensate for reduced growth in utero. Langley-Evans (2001) indicates that poor early fetal conditions result in increased vascular resistance and hypertension. Brown et al. (2004) also suggest that poor early fetal conditions increase the risk of schizophrenia. In addition, epidemiological evidence from studies of famine episodes is notable. This series of studies shows that cohorts in utero during the Dutch famine suffered from coronary heart disease morbidity and various other health deteriorations in their middle age (Roseboom et al., 2000; Roseboom et al., 2001; Ravelli et al., 2005).

The fetal origins hypothesis has also attracted the interest of economists. In addition to health conditions in adulthood, economists are curious whether early-life health conditions are related to a person's social and economic outcomes. Case, Fertig, and Paxson (2005) find that a low birth weight and mother's smoking during pregnancy are related to poor academic achievement and poor health in adulthood. Moreover, health in childhood is associated with adult socioeconomic status.

The aforementioned evidence confirms a strong correlation between early-life health and long-term outcomes. However, it is not easy to determine the causality between them. The main challenge in estimating the effect of early-life health conditions is mainly due to omitted confounders, such as socioeconomic conditions. To cope with this identification problem, Almond (2006) investigates the long-term impact of the 1918 influenza pandemic in the United States. The author uses the abrupt and unexpected attribute of the 1918 influenza pandemic as a natural experiment to test the fetal origins hypothesis. He shows that compared with those born just before or after the epidemic, cohorts in utero during the peak of the influenza pandemic presented

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lower educational attainment, lower income, lower socioeconomic status, higher disability rates, and higher transfer payments. Similarly, Schwandt (2014) also finds that in utero exposure to seasonal influenza in Denmark is associated with worse health at birth, a lower labor market participation rate and earnings, and higher rates of welfare dependence.

Chen and Zhou (2007) use a difference-in-differences strategy to test the long-term effects of early-life malnutrition and find that cohorts exposed to the China's Great Famine in early childhood were significantly shorter, worked fewer hours and had lower income in adulthood. Lee (2014) indicates that prenatal exposure to the Korean War led to lower educational attainment and labor market performance and a higher rate of disability later in life. Moreover, using the difference-in-differences method, Lee finds that the adverse effect of the Korean War was larger for people whose places of birth were more seriously ravaged by the war.

Recently, a series of studies has utilized exposure to malaria as a health shock in early life to clarify the importance of early-life health conditions through different identification strategies. In some of these studies, researchers estimate the malaria risk using epidemiological theories that indicate that malaria risk is principally determined by environmental factors. For example, Hong (2007) utilizes environmental factors such as rainfall, temperature, and elevation to estimate the malaria risk of counties in the United States that do not have reliable data from the 1850s. The author indicates that malaria exposure in childhood resulted in shorter height because of malnutrition and higher susceptibility to infections due to immune disorders.

Barreca (2010) utilizes the instrumental variables strategy to estimate the long-term impact of in utero and postnatal exposure to malaria in the early twentieth-century United States. The author uses variation in "malaria-ideal" temperatures that are favorable to malaria transmission as an instrument for malaria exposure and suggests that in utero and postnatal exposure to malaria resulted in noticeably lower educa-

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tional attainment and higher rates of poverty later in life.[1] For example, schooling decreases by close to half a year with ten additional malaria deaths per 100,000, and early-life malaria exposure can explain approximately 25 percent of the difference in long-term educational attainment between cohorts born in malaria-infested states and non-infested states. Chang et al. (2014) employ other climatic factors such as rainfall, rainy days, relative humidity and wind speed to instrument for malaria deaths. Combining historical data for Taiwan during Japanese colonization and current data, the authors find that people exposed to a higher malaria risk around their birth period exhibited worse cognitive functions and a higher risk for cardiovascular disease in old age.

Furthermore, a series of studies examines countries that historically suffered from malaria but eliminated the disease early in the twentieth century, and employs pre-eradication geographic variation in malarial intensity within the country and cohort exposure based on the timing of the national anti-malaria campaign. For instance, utilizing malaria eradication campaigns in Sri Lanka in the 1940s and in Paraguay in the 1960s as quasi experiments, Lucas (2010) estimates malaria's effect using a standard difference-in-differences method and demonstrates that malaria eradication increased levels of educational attainment and literacy. Barofsky et al. (2011) also show that malaria eradication in Uganda in the 1950s led to improvements in schooling and literacy. However, Cutler et al. (2010) find that malaria eradication in India in the 1950s had no effect on educational attainment but had a positive influence on economic status for prime-age men. Similarly, Venkataramani (2012) indicates that malaria eradication around the birth year in Mexico in the 1950s resulted in better performance on adult cognition tests and higher consumption expenditures for men, but it had no influence on schooling.[2] Bleakley (2010) uses the malaria eradication campaigns in the United

[1] One concern of this study is whether "malaria-ideal temperatures" is a sufficiently strong instrument. The F-statistic in the first stage is nearly 9.6 in Barreca's main specification, which to a certain extent mitigates the weak instrument issue.

[2] The magnitude of the effect for men found by Venkataramani (2012) is larger than that for women, and the estimates for women are not statistically significant.

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States, Brazil, Colombia, and Mexico to measure the impact of childhood exposure to malaria on labor productivity. The author shows that, compared with non-malarious areas, cohorts born after eradication had higher income as adults than the former cohorts in malarious areas. Hong (2013) also finds that the anti-malaria campaign in the U.S. in the 1920s was effectual in decreasing work disability later in life.

Table 2.1 summarizes the effects of malaria on education and economic outcomes in the aforementioned research. As Table 2.1 shows, malaria exposure in early life has negative effects on one's socioeconomic outcomes but has an ambiguous effect on educational attainment. Moreover, existing studies mainly consider the effect on educational attainment and economic outcomes such as income and poverty later in life, but not on marriage outcomes. To provide more abundant evidence of the importance of early-life health conditions, this paper uses the eradication campaign in Taiwan in the 1950s to estimate the long-term impacts of early-life (in utero and postnatal) exposure to malaria on own educational attainment, income, and spousal educational attainment, which is a marriage-related outcome that has never been discussed in previous studies. In the next section, we introduce some background information on malaria and the eradication campaign in Taiwan.

2.3 Background and Data

2.3.1 Background

Malaria is caused by a parasite called Plasmodium, which is transmitted via the bites of infected female Anopheles mosquitoes. Since the late 1940s, the World Health Organization (WHO) has undertaken malaria eradication campaigns in various countries, generally by spraying DDT (Dichloro-Diphenyl-Trichloroethane). Eradication campaigns diminish the likelihood that the disease will be transmitted from mosquito to human and vice versa by decreasing contact between humans and mosquitoes. If the cycle of transmission between mosquitoes and people can be fractured for long enough, malaria can be annihilated. Eradication campaigns succeeded in eliminating

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malaria from Europe, North America, the Caribbean and parts of Asia and South-Central America.

In Taiwan, malaria accounted for most of the overall disease burden during the early 20th century. Taiwan was a Japanese colony from 1895 to 1945. From 1906 to 1911, malaria killed more than 10,000 people each year. The total population was approximately 3 million, which implies that the death rate was approximately 0.3%. Thus, malaria was the leading cause of death at that time. To control malaria, the Japanese colonial government adopted the Koch's method in 1911, which included blood tests in highly malarious areas and forcing people who were found to carry malaria parasites to take antimalarial drugs. This method maintained the malaria infection rate at 2% – 3% for the next 30 years, but it did not eliminate malaria in the country.

At the end of World War II in 1945, Taiwan was transferred from Japan to China. The Nationalist government established a research institute with the support of the Rockefeller Foundation to examine the malaria problem. However, the Rockefeller Foundation ended its support in 1949. Therefore, malaria still severely affected the population in the late 1940s. Based on a malaria survey in 1946, the infection rates of elementary school children were approximately 20% – 40%. After the Nationalist government retreated from China to Taiwan in 1949, it continued antimalarial efforts with the support of the WHO and other international agencies.

In the 1950s, Taiwan implemented a malaria eradication campaign with technical support from the WHO. Based on the epidemiological information available as of 1951, a four-year malaria control program was drafted for the period 1952 – 1955, which is shown in Figure 2.1. The malarious areas were identified and labeled hyper-, meso- and hypo-endemic areas.[3] DDT spraying began experimentally in the pilot project area in 1952. It was extended to the hyper-endemic area in 1953 and to the

[3] The figure comes from the book *Malaria Eradication in Taiwan (2005).* However, the book does not provide specific information about epidemiological data and the baseline to classify each place into the hyper-, meso- and hypo-endemic areas.

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meso- and hypo-endemic areas in 1954. In 1955, these areas were sprayed again. Except for those areas confirmed to be non-malarious, another two rounds of nationwide DDT spraying were implemented in 1956 and 1957.

The eradication campaign resulted in a significant decline in malaria. Figure 2.2 illustrates the number of malaria cases for preschool children from 1951 – 1960 nationwide. The deep gray bar in the figure represents the number of cases of all types of malaria, and the light gray bar represents the number of cases of falciparum and mixed malaria. As Figure 2.2 shows, malaria was a serious health problem, particularly in 1951 – 1952 when the eradication campaign was just getting started, and then, cases decreased after 1953. In 1965, Taiwan was certified by the WHO as an area where malaria had been eradicated, and it has successfully maintained its malaria-free status through today. [4]

2.3.2 Data

2.3.2.1 Malaria Intensity

To construct an appropriate measurement of the prevalence of malaria, we use two different data sources at different geographic levels. The first dataset is the malaria spleen rates of school children at the county level in 1953 and 1955, which is derived from the Health Statistics Yearbook compiled by the government.[5] We define the reduction in malaria intensity as the difference in the spleen rate between 1953 and 1955 for each county. Note that the difference in the spleen rate is the spleen rate *in 1953* minus the spleen rate *in 1955*. Therefore, the difference in the malaria spleen rate can be regarded as the reduction in malaria intensity that resulted from the malaria eradication campaign, although the value of the difference is not necessarily positive. However, all of the differences in the malaria spleen rate are positive in our sample.

The second dataset is the level of malaria spleen rates at the township level in

[4] The information in this section comes from the book *Malaria Eradication in Taiwan (2005).*

[5] The spleen rate is the percentage of people who have enlarged spleens, which is commonly used to measure malaria prevalence.

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1953 and 1955, which is derived from two maps from the book, *Malaria Eradication in Taiwan*. In the two maps, every township in Taiwan is classified into five levels according to malaria spleen rates: 0%–10%, 10%–25%, 25%–50%, 50%–75%, and more than 75%. In this study, we use 1 to represent spleen rates of 0%–10%, 2 to represent 10%–25%, etc. Thus, the lowest level of malaria spleen rates is represented by 1, and the highest is represented by 5. Then, we define the reduction in malaria intensity as the difference in the level of malaria spleen rates between 1953 and 1955 for each township.[6] Figures 2.3 and 2.4 illustrate the spleen rate of each county and the level of spleen rate of each township in 1953 and 1955, both of which indicate a considerable decrease in the spleen rate after the implementation of the eradication campaign.

2.3.2.2 Adult Outcomes

The data on adult outcomes are derived from the Taiwan Social Change Survey. The Taiwan Social Change Survey (TSCS) traces changes in long-term trends and provides insight into them through national representative survey data on diverse topics. In the mid-1980s, the National Science Council began archiving baseline information about Taiwanese society by surveying the general adult population through scrupulous sampling designs. Using prudently designed questionnaire interviews, the TSCS is an interdisciplinary research project that measures Taiwan's political, economic, social, and cultural changes. Since the first nationwide survey was completed in 1985, this long-term and cross-sectional survey project has followed 5-year cycles that rotate selected modules to capture the dynamics of social changes. Many of these surveys utilize repetitious modules that have run through up to five cycles of survey operations, which enables researchers to investigate social changes from longitudinal viewpoints. The TSCS has become the largest survey series among all of the common social surveys in the world.

[6] Similarly, the difference in the level of malaria spleen rates is the level of malaria spleen rates *in 1953* minus the level of malaria spleen rates *in 1955*.

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In this paper, we use data from the TSCS for the period from 1992 – 2012. During this period, the TSCS conducted five rounds of the surveys. Among these surveys, we use the surveys that provide individual information regarding educational level, birth year, birth place at the county and township level, parents' educational level and ethnicity, marital status, spouse's educational level, and personal and family income. We use dummy variables to categorize respondents by survey round.

The adulthood outcomes of interest are personal and spousal educational attainment and personal and family income. First, we use junior high school and high school completion to measure personal/spousal educational attainment. We define the indicator variable, *Above high school* $= 1$ (or *Above junior high school*) if the respondent has at least graduated from high (or junior high) school; otherwise, the indicator variable is equal to zero.

Second, the respondents are classified into groups based on personal and family income obtained from the TSCS. The classification of personal/family income includes 42 levels. Rather than directly using these levels to measure income, we use the midpoint of each income level as our measure for income. In addition, to make income comparable over time, we use the CPI to deflate nominal income into real income, and then, we take the natural logarithm of the real income.[7] The family backgrounds of the respondents, such as educational level and ethnicity of parents, are included as control variables in the analysis. All of these variables are dummy variables. The categories of parents' educational level are no education, elementary school, junior high school, senior high school, and university or above. The categories of parents' ethnicity are Minnanese, Hakka, Mainlander, and Aborigine.

It is worth noting that we limit the sample to those born from 1950 – 1955 because of the following two concerns: On the one hand, at the end of the World War II in 1945, Taiwan was transferred from Japan to China and was placed under the control of the Nationalist government. Due to the intervention of the government, hyperinflation oc-

[7] In this paper, we chose 2011 as the base year.

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curred from 1945 – 1949. Furthermore, tension across the Taiwan Strait was extremely high. Therefore, Taiwan experienced extreme political and economic instability at that time. The situation in Taiwan was permanently changed when the Korean War broke out in 1950. The U.S. government immediately decided to provide economic and military aid to Taiwan, which stabilized the country politically and economically (Wu, 1997).

The other concern is reforms in educational policy that extended compulsory education from 6 to 9 years in 1968. The 1968 reforms ended junior high school entrance examinations and enabled every primary school graduate to continue their education at a junior high school. Thus, individuals born after 1956 (i.e., younger than 12 in 1968) were affected by these reforms. Based on the above historical background, we limit the sample to those born from 1950 – 1955 to prevent these factors from confounding our analysis. Finally, considering the small sample size of those born in Yangmingshan, Taitung, and Penghu, we drop respondents born in these regions from our analysis. There are 19 counties in terms of county level and 344 townships in terms of township level in our sample.

In addition, we use data from the 1980 Taiwan Census, which is conducted every ten years by the Directorate of General Budgeting, Accounting, and Statistics (DGBAS). The census provides information about individuals' birth year, native place (or original domicile) at the county level, educational level, and other basic demographic characteristics.[8] The advantage of using the census is that it contains the full sample of Taiwan's residents. However, it provides less information on individual characteristics than the Taiwan Social Change Survey, such as its lack of information about parental and spousal educational levels. Therefore, we only utilize the data in a robustness check analysis on the impact of malaria on own educational attainment, not in our main analysis. Below, we introduce our empirical strategy, which addresses endogeneity problems, and we present the primary independent variable in our analysis.

[8] A person's native place is not necessarily his or her birthplace, but it generally is. In this paper, we use native place as a proxy for birthplace.

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2.4 Empirical Strategy

The main challenges in identifying the impacts of malaria on long-term outcomes are from omitted variables, simultaneity (reverse causality), and measurement error. For example, highly malarious regions are usually poor regions, and changes in income levels in a region may result in changes in malaria intensity. In addition, regions with low educational attainment could develop high levels of malaria transmission. To address these endogeneity problems, we use the malaria eradication campaign in Taiwan as an exogenous change in malaria intensity to identify the effect of malaria on later life outcomes.

We use the following standard difference-in-differences specification to estimate the effect of malaria:

$$y_{irc} = \alpha + \beta(Malaria_r \times Era_c) + \gamma X_{irc} + \phi_r + \lambda_c + \varepsilon_{irc}, \tag{2.1}$$

where y_{irc} is the adult outcome of individual i in region r (county or township level) of cohort c. The region r represents county r or township r according to which data source we use. The outcomes of interest include one's own educational level, spousal educational level, personal income, and family income. X_{irt} are controls of individual characteristics, ϕ_r is the regional (county or township level) fixed effect, and λ_c is the cohort (birth year) fixed effect. $Malaria_r$ is the reduction in malaria intensity between 1953 and 1955. When we use data from the *Health Statistics Yearbook*, $Malaria_r$ is the difference in the malaria spleen rate between 1953 and 1955 for each county.[9] When we use data from the book *Malaria Eradication in Taiwan*, $Malaria_r$ is the difference in the level of malaria spleen rates between 1953 and 1955 for each township.[10] Because of the possibility of serial correlation within a region, we present the standard errors using county- or township-level clustering. In this paper, we also use sampling weights in the analysis.

[9] The difference in the spleen rate is the spleen rate *in 1953* minus the spleen rate *in 1955*.

[10] The difference in the level of malaria spleen rates is the level of malaria spleen rates *in 1953* minus the level of malaria spleen rates *in 1955*.

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Era_c is a dummy for a post-eradication cohort. DDT spraying was extended to highly malarious areas in 1953 and to moderate and low malarious areas in 1954. Most of those born in 1953 were not influenced by the DDT spraying when they were still fetuses, while most of those born after 1954 were affected by the spraying when they were fetuses. In this paper, we define an individual in the post-eradication cohort as being born after 1954 (including 1954) in our basic specification.

Using a difference-in-differences approach to estimate the impact of malaria implies that variations are derived from the following two sources. First, cohorts born after eradication might have better long-term outcomes than those born before eradication in the same region. Second, reductions in malaria intensity that resulted from eradication varied across regions. Regions with higher reductions in malaria intensity might gain relatively more from eradication than regions with lower reductions.

The coefficient of our interest in this specification is β, which is the coefficient of $Malaria_r \times Era_c$, the interaction term between the reduction in malaria intensity in a region and the dummy variable for a post-eradication cohort. $Malaria_r \times Era_c$ is represented by $SpleenRateDif_{county} \times Era$ when we use the difference in the malaria spleen rate at the county level to measure the reduction in malaria intensity, and $Malaria_r \times Era_c$ is represented by $SpleenLevelDif_{township} \times Era$ when we use the difference in the level of malaria spleen rates at the township level.[11] Under the hypothesis that malaria has negative effects on long-term outcomes, the post-eradication cohorts born in regions with larger decreases in malaria intensity should have better long-term outcomes than those born before eradication in the same region. Thus, we expect that the coefficient β will be positive.

[11] The unit of $SpleenRateDif_{county}$ is a percentage. The level of malaria spleen rates at the township level in 1953 and 1955 is a categorical variable that ranges from 1 to 5, hence the integer values of $SpleenLevelDif_{township}$ (i.e., the difference in the level of malaria spleen rates between 1953 and 1955) range from -4 to 4.

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2.5 Estimation Results

2.5.1 Descriptive Statistics

Before performing our analysis, we present descriptive statistics on own educational attainment, spousal educational attainment, and personal and family income after grouping the respondents according to malaria intensity and birth cohort in Table 2.2. We use the average of the difference in the malaria spleen rate between 1953 and 1955 at the county level as the baseline to classify each region into ”Highly malarious” or ”Less malarious”. Cohorts born from 1954 – 1955 are placed in the ”Post-Eradication” group, whereas those born from 1950 – 1953 are placed in the ”Pre-Eradication” group.

Table 2.2 indicates that men had higher educational attainment than women in all groups, while their spouse’s educational attainment was lower than that of women. Overall, cohorts born after eradication had higher educational attainment than those born before eradication, both in the highly malarious and the less malarious regions. Furthermore, when we compare men born after eradication with those born before eradication, highly malarious regions had larger increases in educational attainment than less malarious regions, as shown in the seventh column. The patterns for spousal educational attainment and income for men are quite similar to those of own educational attainment; in contrast, women have different patterns from men’s. These results provide preliminary evidence regarding the negative effects of malaria for men. In the next section, we present the results of the difference-in-differences specification analysis.

2.5.2 Results

2.5.2.1 Education

Table 2.3 reports the effects of the malaria eradication on own educational attainment. In the estimations, other controls of individual characteristics include educational level and ethnicity of one’s parents, regional and birth year fixed effects, and dummy vari-

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ables to categorize respondents by survey round. Panel A of Table 2.3 presents the results of using the difference in malaria spleen rate between 1953 and 1955 for each county to measure the reduction in malaria intensity, which shows that the coefficients of interest are positive and statistically significant for the overall and male samples.

Panel B of Table 2.3 shows the results of using the difference in the level of malaria spleen rates between 1953 and 1955 for each township, which indicates that the coefficients of interest are positive and statistically significant only for males. In contrast, all of the coefficients for females are insignificant. These results show that men born after eradication in regions with larger decreases in malaria intensity had larger increases in the probability of completing junior high and high school, while there are no significant differences between women born in regions with different changes in malaria intensity.[12]

The magnitude of the coefficients for men is also considerably large. Based on the estimates in Panel A of Table 2.3, a 1 percentage point decrease in the spleen rate results in a 0.27 percentage point increase in the probability of high school completion and a 0.21 percentage point increase in the probability of junior high school completion.[13] In Taiwan, the nationwide average spleen rate in 1953 was 23.20%, and it decreased to 10.59% in 1955. This reduction of the spleen rate from 23.20% to 10.59% would result in a 2.65 percentage point increase in the probability of junior high school completion and a 3.4 percentage point increase in the probability of high school completion. Comparing the male cohorts born from 1950-1953 to those born

[12] A possible concern was that selective migration would bias the results. To address this concern, we constructed a variable, *mover*, to indicate that an individual's birthplace was different from his or her longest place of residence before age 15. However, not all of the cycles of the survey asked respondents to provide their longest place of residence before age 15. Only 200 to 300 male and female respondents were movers, and 1200 to 1800 respondents were non-movers, both of which represent quite small samples. Nevertheless, we find that malaria eradication had a positive and significant effect on the probability of junior high school completion for male non-movers. We also observe that the interaction term between the independent variable of interest (i.e., $Malaria_r \times Era_c$) and *mover* is insignificant (results not reported).

[13] In all of the estimations, the unit of the difference in malaria spleen rate between 1953 and 1955 is a percentage.

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from 1954-1955, there was a 9 percentage point increase in the probability of junior high school completion and a 9 percentage point increase in the probability of high school completion. Therefore, eradication accounts for approximately 30% – 38% of the increases in the probability of junior high and high school completion for men over the period, which implies that malaria exposure in early life did have a significant influence on one's educational attainment.

2.5.2.2 Marriage and Income

In addition to education, malaria eradication may affect a person's long-term well-being in areas such as marriage and income. Table 2.4 shows the influence of malaria eradication on spouses' educational attainment. Panel A of Table 2.4 indicates that, when we use the difference in the malaria spleen rate for each county to measure the reduction in malaria intensity, a 1 percentage point decrease in the spleen rate leads to a 0.3 percentage point increase in the probability of high school completion for a man's wife after controlling for men's own education level. Compared with the coefficient without controlling for men's own education level, the magnitude of the coefficient does not change much after controlling for own education level. This significant effect of malaria eradication implies that eradication enabled a man to marry a more educated woman not only through the channel of the increase in his own educational attainment but also through other channels. Another potential channel is the improvement in one's health. A man who is taller or healthier than others with the same educational level might be more attractive in the marriage market. However, the effect of using the difference in the level of malaria spleen rates between 1953 and 1955 for each township is insignificant, as shown in Panel B of Table 2.4.

Table 2.5 presents the effects of malaria eradication on personal and family income. Panel A of Table 2.5 shows the results of using the difference in the malaria spleen rate between 1953 and 1955 for each county to measure the reduction in malaria intensity. We find that malaria eradication significantly increased family income for men. Fur-

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thermore, the effect becomes smaller after controlling for men's educational level and their spouses' educational level, but it is still significant, although the level of statistical significance is smaller. This result implies that malaria eradication might have partially affected a man's income through the mechanism of his own and his spouse's education, although it also might have affected income through other mechanisms such as increasing one's health capital. Thus, health improvement would be beneficial for men both in marriage and in the labor market. Moreover, the magnitude of the coefficient is still significant. According to the estimate when controlling for both one's own and a spouse's educational level, a 1 percentage point reduction in the spleen rate results in a 0.47 percentage point increase in men's family income. Panel B of Table 2.5 shows the result of using the difference in the level of malaria spleen rates for each township; it shows an insignificant effect for all respondents.

In addition to using the ordinary least squares (OLS) regression, which is based on the mean of the conditional distribution of the regression's dependent variable, we utilize the quantile regression model that allows for a full characterisation (percentiles) of the conditional distribution of the dependent variable. Table 2.6 reports the quantile regression estimates of the effects of malaria eradication on personal and family income for male, with OLS estimates shown at the top for comparison. The quantile regression estimates indicate that the effects of malaria eradication on family income is much larger and more significant at the lower quantiles. Specifically, the coefficient for the 0.25 quantile of family income suggests that a 1 percentage point reduction in the spleen rate results in a 0.75 percentage point increase in men's family income after controlling for both one's own and a spouse's educational level, while the 0.5 quantile coefficient suggests that a 1 percentage point reduction in the spleen rate only leads to a 0.39 percentage point increase in men's family income. Moreover, the coefficients become smaller and insignificant at the 0.6 and 0.75 quantiles. The results show that returns to malaria eradication decrease over the income distribution; in other words, the benefits from malaria eradication are higher for men with less income, conditional on

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their observable characteristics. The results imply that malaria eradication may reduce within-group income inequality.

Overall, our estimates indicate that malaria eradication increased men's educational attainment and family income in adulthood. Furthermore, it increased the educational attainment of married men's spouses. However, there was no significant benefit from the eradication for women. The results suggest that there were negative effects of early-life exposure to malaria in Taiwan.[14]

2.5.3 Robustness Checks

In this section, we present several sets of robustness checks. First, in our main specification, we use the sample of respondents born from 1950 – 1955 because of the political and economic instability before 1950 and the extension of compulsory education from 6 to 9 years in 1968, which affected people born after 1955.[15] To create a more narrow and balanced sample before and after malaria eradication, we redo our analysis with respondents born from 1951 – 1955.[16] Table 2.7 and Table 2.8 report the results of own and spousal educational attainment and personal and family income, respec-

[14] We also performed the analysis using the pre-eradication geographic variation in malaria intensity (i.e., $Malaria_r$ is the malaria spleen rate in 1953), which is often used in previous studies on the malaria-eradication campaigns. We find that malaria eradication had positive and significant effects on the probability of high school completion for men and the probability of high school completion for married men's spouses, but the coefficients became smaller. The effects of malaria eradication on personal and family income became insignificant after controlling for men's educational level and their spouses' educational level, but the directions of the effects from eradication were consistent with the previous findings (results not reported). It is possible that although the four-year malaria control program for the period 1952 – 1955 resulted in a significant decline in malaria spleen rates, the spleen rates in 1955 were still positive. The pre-eradication geographic variation in malaria intensity may not be a appropriate measure to examine the impacts from the malaria control program. Since the reduction in malaria intensity that resulted from the malaria control program could capture the geographic variation more precisely and directly, we use the reduction in malaria intensity between 1953 and 1955 to examine the impacts from the malaria eradication campaign in our main analysis.

[15] A possible concern was that individuals born after September 1, 1955 would be affected by the 1968 reforms. To address this concern, we redid the analysis with respondents born from 1950 to August 1955. The results were similar to those in the main study (results not reported).

[16] We also performed the analysis a second time with respondents born from 1952 – 1955. The results were insignificant, which is likely because the sample size was too small. However, the directions of the effects from eradication were consistent with the previous findings (results not reported).

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tively. While the coefficients for personal and spousal educational attainment are more significant and the coefficients for family income are less significant than those in the previous results, all of the results are generally consistent with the previous findings.

Second, we use the respondents born from 1950 – 1955 from the 1980 Taiwan Census to further check the effect of malaria. The data from the 1980 census lack parents' and spouse's educational level and income. Therefore, we can only utilize the data estimating the impact of malaria on educational attainment with regional and birth year fixed effects, which are shown in the first three columns of Table 2.9. The coefficients for the probability of junior high school completion are positive and statistically significant for the whole sample, while the coefficient for women is less significant. However, these results are still consistent with our main findings.

Third, we construct "fake" interventions as additional robustness checks. Our data are sufficient to allow us to create fake interventions occurring both before and after the true intervention (i.e., 1954). The results are reported in columns 4 to 9 of Table 2.9, where Panel A shows the results using the TSCS data, and Panel B shows the results using the census data. Table 2.9 indicates that, with an intervention in 1944 or 1964, all of the coefficients for one's own educational attainment become statistically insignificant. As expected, our main findings are not replicated for the fake interventions.

Finally, we use an alternative specification to estimate the effect of malaria eradication, which is presented below:

$$y_{irc} = \alpha + \tau Era_c + k(C) + \gamma X_{irc} + \phi_r + \varepsilon_{irc}, \qquad (2.2)$$

where C is the birth month of an individual relative to the timing of malaria eradication. We define an individual in the post-eradication cohort as being born after October 1953 in this specification. Therefore, we define $C = 0$ for those born in October 1953, $C = 1$ for those born in November 1953, $C = -1$ for those born in September 1953, etc. Era_c is a dummy for a post-eradication cohort. $k(C)$ is the linear or quadratic form of C and their interaction terms with Era_c. In fact, this specification is nearly a

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reduced form of a fuzzy RD (regression discontinuity) design. C is the forcing variable, the cutoff point of C is zero, and the effect of interest is captured by τ. Ideally, we should show the discontinuity at the cutoff point for both the treatment and the outcome variables, where the treatment variable would be the spleen rate or other measures for malaria intensity. However, we can only show the discontinuity for the outcome variables because our data can only provide annual spleen rates in 1953 and 1955. Nevertheless, we can still use this specification as an alternative way to examine the effect of eradication.

Figure 2.5 shows the jump or discontinuity for the junior high school completion rate of males at the cutoff point, and the estimation results of equation (2.2) are presented in Table 2.10. The coefficients of interest are positive and statistically significant in both the highly and the less malarious regions whether we use the linear or quadratic form of the birth month, implying that malaria eradication has a positive and significant effect on own educational attainment. Furthermore, the coefficients for the highly malarious regions are larger than those for the less malarious regions, which is consistent with the results of the difference-in-differences specification.

2.5.4 Discussion

Other than the effects of one's own educational attainment, our estimations are statistically insignificant when we use the variation in malaria intensity at the township level. The reason for this result might be that the sample becomes smaller when we need more individual information such as income and spousal characteristics. Moreover, we include regional fixed effects in the estimation model, which contains much more dummy variables when we use the variation in malaria intensity at the township level. Nevertheless, the coefficients using township variation display the same sign as those using county variation.

One possible concern is that the effects of eradication might be due to regional convergence. If the regions had distinct trends in educational attainment or income

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before the eradication campaign, the improvement in education or income could have appeared even without the eradication campaign. Because we restrict the sample to only those born from 1950 – 1955, which is a very short period, it is less possible that regional convergence accounts for the effects. Moreover, when we further limit our sample to a more narrow range and construct fake interventions as robustness checks, which are shown in the previous section, we find that the results are consistent with our main findings.

In addition, we find there are gender differences in the impact of the eradication. Other than our finding that malaria eradication increased educational attainment for women when we use data from the 1980 census, we find that there was no significant benefit from the eradication for women in most of the specifications. One possible explanation is that the sample drawn from the TSCS is too small or too noisy to find significant effects for women. Cutler et al. (2010) also find that malaria eradication in India only had a positive influence on economic status for males. The authors argue that women's lower participation rate in the labor market might be the explanation if the effects for men were driven by improvements in labor market productivity stemming from the eradication campaign. However, our results indicate that the gender difference not only exists for the impact on income but also for the impact on education, implying that women's lower participation rate in the labor market cannot explain the gender differences in this paper.

There are two other possible explanations for the gender differences in our results. First, biomedical researchers propose that boys are biologically more vulnerable than girls both in utero and in early childhood (Kraemer, 2000; Mizuno, 2000; Low, 2001). Therefore, boys were more likely to be afflicted by malaria and thus suffered more negative impacts on their cognitive or physical development. Second, the son preference in Taiwan prior to 1990 is a well-documented phenomenon (Coombs and Sun, 1981; Williamson, 1976). Taiwan's society has a strong Confucian influence. Family norms in such societies dictate that a married couple is expected to live with and finan-

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cially support the husband's parents. Thus, parents in Taiwan in the 1950s had more incentives to invest a large amount of resources in their sons than in their daughters. Nevertheless, we need a larger dataset with more detailed data on in utero health conditions and parental investments to determine the possible validity of either of these explanations for the gender differences.[17]

2.6 Conclusions

This paper investigates the long-term impacts of in utero and postnatal exposure to malaria in Taiwan during the 1950s. Utilizing the malaria eradication campaign in Taiwan as a quasi-experiment, we use the difference-in-differences identification strategy to mitigate potential biases. We find that malaria eradication had positive and significant effects on the probability of junior high and high school completion for men and on the probability of high school completion for a man's wife. A 1 percentage point decrease in the spleen rate resulted in a 0.27 percentage point increase in the probability of high school completion for men and a 0.31 percentage point increase in the probability of high school completion for a man's wife. Moreover, we find that a man who is taller or healthier than others with the same education level might be more attractive in the marriage market.

In addition, the results show that malaria eradication significantly increased family income for men. A 1 percentage point reduction in the spleen rate resulted in a 0.47 percentage point increase in men's family income. Furthermore, the effect becomes smaller but is still significant after controlling for men's education level or the education level of their spouses, implying that malaria eradication might have partially affected men's income through the channel of education as well as other channels such as increasing one's health capital. In summary, the results suggest that there were negative and significant effects of early-life malaria exposure on long-term outcomes in

[17] Venkataramani (2012) estimates whether malaria eradication effects are increasing in measures of opportunities available to women to test differential investments by gender, but the author finds no evidence to support the contention because of sparse and less detailed data.

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Taiwan.

Today, malaria is endemic in nearly 100 countries, and more than 3 billion people around the world are at risk from the disease. Most cases (80%) and deaths (90%) occur in Africa, and children under five years of age and pregnant women are the most affected (WHO, 2013). Identifying the mechanism through which malaria affects long-term economic outcomes is urgent and important. Our results regarding malaria eradication in Taiwan suggest that health condition at the time of birth is the crucial determinant for long-run developmental outcomes. Therefore, health policies that target pregnant women and infants may have considerably positive returns for society.

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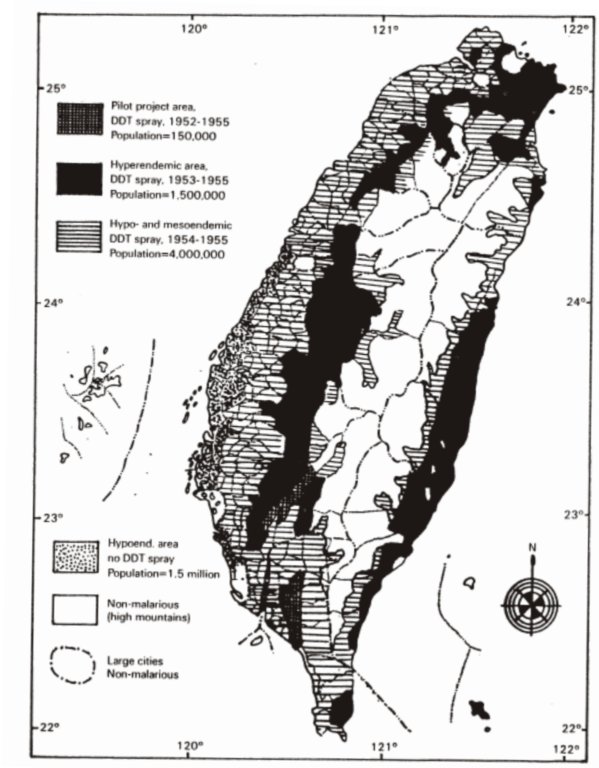
Figures and Tables

Figure 2.1

Four-year Malaria Control Program, 1952-1955



Source: Malaria Eradication in Taiwan (2005).

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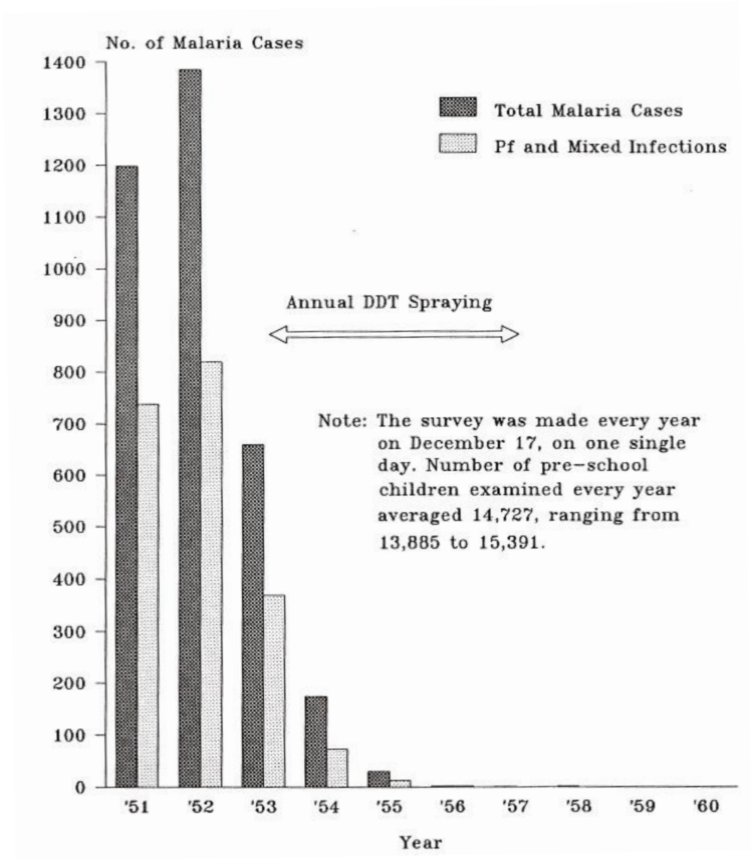
Figure 2.2

The Number of Malaria Cases of Preschool Children Nationwide, 1951-1960



Source: Malaria Eradication in Taiwan (2005).

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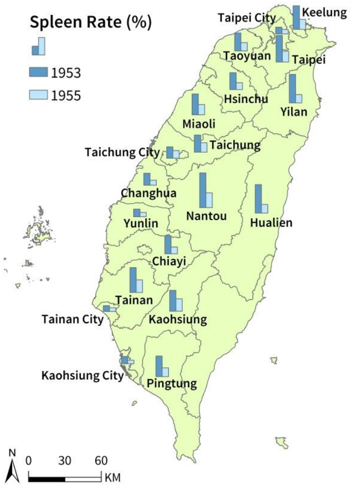
Figure 2.3

Spleen Rate in 1953 and 1955 (County-Level)



Note: The figure shows the malaria spleen rates of school children at the county level in 1953 and 1955.
Source: Health Statistics Yearbook.

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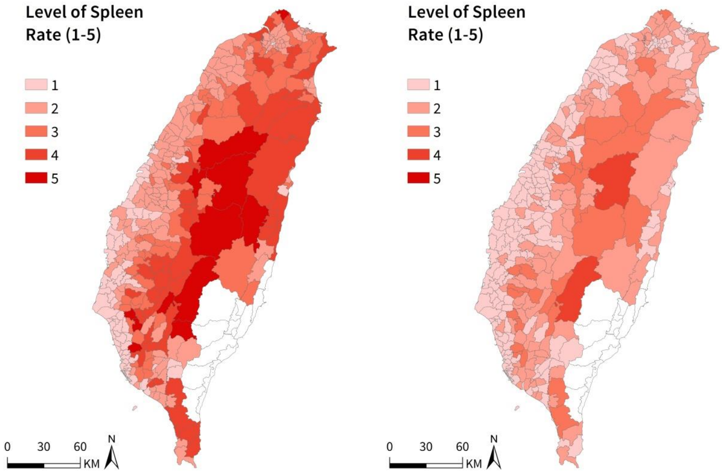
Figure 2.4

Level of Spleen Rate in 1953 and 1955 (Township-Level)

(a) 1953 (b) 1955



Note: The figure shows the level of malaria spleen rates at the township level in 1953 and 1955.

Source: Malaria Eradication in Taiwan (2005).

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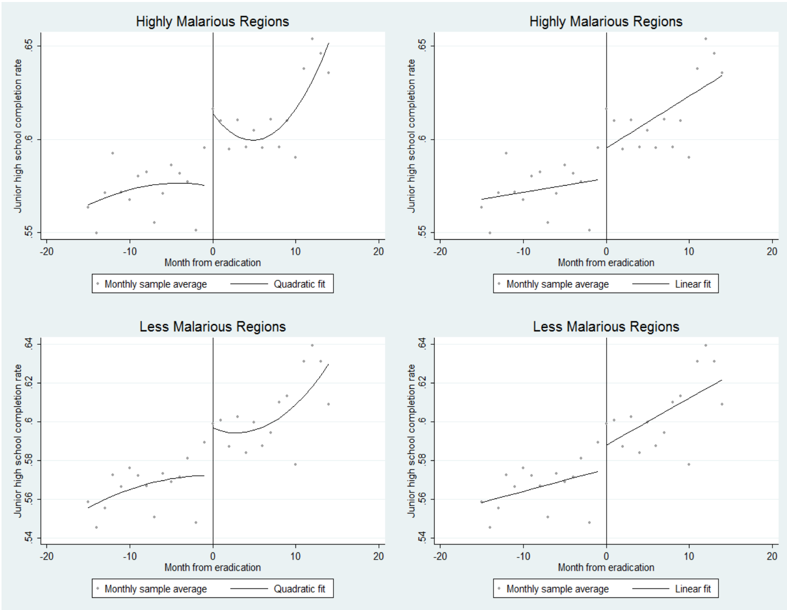
Figure 2.5

Discontinuity on Own Educational Attainment



Notes: (1) In all regressions, we use male sample born in July 1952 to December 1954. “Eradication” is the dummy variable of a post-eradication cohort born after October 1953. (2) We use the average of the difference in malaria spleen rate in each county as the baseline to classify each county into “Highly malarious” or “Less malarious” group. (3) “Linear fit” represents using the linear form of birth month in the regressions. “Quadratic fit” represents using the Quadratic form of birth month in the regressions.

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Table 2.1

Literature on Malaria: Summary

Author	Country	Method	Education	Economic outcome
Barreca (2010)	U.S. (M&F)	IV	Death rate ↑ 0.01 p. p.: Schooling ↓ 0.4 years	Death rate ↑ 0.01 p. p.: Poverty rate ↑ 3.8 p. p.
Lucas (2010)	Sri Lanka (F)	DID	Spleen rate ↑ 1p. p.: Schooling ↓ 0.4 year; High literacy ↓ 0.29 p. p.	
	Paraguay (F)	DID	Passive detection rates ↑ 1 p. p.: Schooling ↓ 0.13 year; High literacy ↓ 2.24 p. p.	
Barofsky et al. (2011)	Uganda (M&F)	DID	Being born both in district with eradication campaign and after the eradication: Schooling ↑ 0.29 year; Literacy ↑ 6.5 p. p.	
Cutler et al. (2010)	India (M&F)	DID	No effect	Malaria index (Spleen rate) ↑ 1 p. p.: Household expenditures ↓ 0.8 p. p. for men
Venkataramani (2012)	Mexico (M&F)	DID	No effect (on schooling)	Malaria death rate ↑ 0.1 p. p.: Consumption expenditures ↓ 6p. p. for men
Bleakley (2010)	U.S., Brazil, Colombia, Mexico (M)	DID		Probability of childhood malaria infection ↑ 1 p. p.: Income ↓ 4~6 p. p.

Notes: (1) "M" represents male data, "F" represents female data, and "M&F" represents both male and female data. (2) "p.p." represents percentage point.

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Table 2.2

Difference in Means

	Highly malarious			Less malarious			Differences
VARIABLES	Pre-Era	Post-Era	Increase	Pre-Era	Post -Era	Increase	in increase
Overall							
Own education							
Above high school	0.394	0.473	0.079	0.448	0.514	0.066	0.013
Above junior high	0.538	0.625	0.088	0.565	0.639	0.074	0.014
Observations	3,337	1,871		3,085	1,664		
Spouse's education							
Above high school	0.415	0.497	0.081	0.442	0.521	0.079	0.003
Above junior high	0.590	0.690	0.100	0.602	0.690	0.089	0.011
Observations	2,522	1,430		2,377	1,233		
Income							
Personal income	3.511	3.522	0.011	3.568	3.611	0.043	-0.032
Observations	2,192	1,293		2,034	1,113		
Family income	3.943	3.967	0.024	4.034	4.009	-0.025	0.049
Observations	2,389	1,396		2,256	1,219		
Male							
Own education							
Above high school	0.469	0.573	0.105	0.526	0.590	0.063	0.041
Above junior high	0.628	0.732	0.104	0.658	0.738	0.079	0.025
Observations	1,692	926		1,569	785		
Spouse's education							
Above high school	0.369	0.487	0.118	0.418	0.491	0.073	0.045
Above junior high	0.567	0.720	0.154	0.587	0.698	0.111	0.042
Observations	1,269	711		1,231	589		
Income							
Personal income	3.741	3.780	0.039	3.791	3.860	0.069	-0.030
Observations	1,296	728		1,217	618		
Family income	3.997	4.014	0.016	4.116	4.061	-0.055	0.071
Observations	1,246	697		1,151	575		
Female							
Own education							
Above high school	0.317	0.375	0.057	0.367	0.446	0.079	-0.022
Above junior high	0.444	0.521	0.076	0.469	0.551	0.082	-0.005
Observations	1,645	945		1,516	879		
Spouse's education							
Above high school	0.462	0.506	0.044	0.469	0.548	0.080	-0.035
Above junior high	0.615	0.661	0.046	0.683	0.683	0.065	-0.019
Observations	1,253	719		1,146	644		
Income							
Personal income	3.178	3.190	0.011	3.237	3.301	0.063	-0.052
Observations	896	565		817	495		
Family income	3.885	3.921	0.036	3.948	3.963	0.014	0.022
Observations	1,143	699		1,105	644		

Notes: (1) We use the average of the difference in the malaria spleen rate in each county as the baseline to classify each county into the "Highly malarious" or "Less malarious" group. (2) "Pre-Era" represents the Pre-Eradication group, which contains those born from 1950-1953. "Post-Era" represents the Post-Eradication group, which contains those born from 1954-1955. (3) In column 7, we subtract the values in column 6 from the values in column 3 to obtain "Differences in increase." (4) We use the CPI to deflate nominal personal and family income into real income, and then, we take the natural logarithm of the real income. In this paper, we chose 2011 as the base year.

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Table 2.3

Effects of Malaria Eradication on Own Educational Attainment

Sample	Overall	Male	Female
Panel A Independent variable: $\text{SpleenRateDif}_{county}(\%) \times \text{Era}$			
Own education level			
Above high school	0.0020*	0.0027**	0.0009
	[0.001]	[0.001]	[0.002]
Above junior high school	0.0022*	0.0021**	0.0023
	[0.001]	[0.001]	[0.002]
Observations	9,957	4,972	4,985
Panel B Independent variable: $\text{SpleenLevelDif}_{township}(1\sim5) \times \text{Era}$			
Own education level			
Above high school	0.0116	0.0377*	-0.0142
	[0.012]	[0.019]	[0.017]
Above junior high school	0.0051	0.0377**	-0.0232
	[0.013]	[0.019]	[0.019]
Observations	9,787	4,896	4,891

Notes: (1) In Panel A, we use the difference in the malaria spleen rate between 1953 and 1955 for each county to measure malaria intensity. "$\text{SpleenRateDif}_{county} \times \text{Era}$" represents the interaction term between the malaria intensity at the county level and the dummy variable of a post-eradication cohort born from 1954-1955. In Panel B, we use the difference in the level of the malaria spleen rate between 1953 and 1955 for each township. "$\text{SpleenLevelDif}_{township} \times \text{Era}$" represents the interaction term between the malaria intensity at the township level and the dummy variable of a post-eradication cohort. (2) The level of malaria spleen rates at the township level in 1953 and 1955 is a categorical variable that ranges from 1 to 5, hence the integer values of "$\text{SpleenLevelDif}_{township}$" range from -4 to 4. (3) The other controls not presented in this table include educational level and ethnicity of one's parents, regional fixed effects (county level in Panel A and township level in Panel B), birth year fixed effects, and dummy variables to categorize respondents by survey round. (4) Robust standard errors with regional clustering (county level in Panel A and township level in Panel B) are in brackets. (5) The high school completion rates for males born from 1950-1953 and those born from 1954-1955 are 49% and 58%, respectively. The junior high school completion rates for males born from 1950-1953 and those born from 1954-1955 are 64% and 73%, respectively. The high school completion rates for females born from 1950-1953 and those born from 1954-1955 are 34% and 41%, respectively. The junior high school completion rates for females born from 1950-1953 and those born from 1954-1955 are 46% and 54%, respectively. (6) Sampling weights are used in all regressions. (7) *** significant at 1 percent level. ** significant at 5 percent level. * significant at 10 percent level.

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Table 2.4

Effects of Malaria Eradication on Spouse's Educational Attainment

Sample	Overall		Male		Female	
Panel A Independent variable: $\text{SpleenRateDif}_{county}(\%) \times$ Era						
Spouse's education level						
Above high school	0.0021	0.0008	0.0035**	0.0031***	0.0011	-0.0009
	[0.002]	[0.001]	[0.001]	[0.001]	[0.002]	[0.002]
Above junior high school	0.0017	0.0004	0.0021	0.0013	0.0015	-0.0003
	[0.002]	[0.001]	[0.003]	[0.002]	[0.002]	[0.002]
Observations	7,562	7,562	3,800	3,800	3,762	3,762
Panel B Independent variable: $\text{SpleenLevelDif}_{township}(1\sim5) \times$ Era						
Spouse's education level						
Above high school	0.0144	0.0134	0.0304	0.0179	0.0035	0.0200
	[0.016]	[0.015]	[0.021]	[0.021]	[0.024]	[0.020]
Above junior high school	0.0045	0.0023	0.0351	0.0196	-0.0276	-0.0140
	[0.017]	[0.017]	[0.024]	[0.023]	[0.025]	[0.023]
Observations	7,437	7,437	3,743	3,743	3,694	3,694
Own education level	×	✓	×	✓	×	✓

Notes: (1) In Panel A, we use the difference in the malaria spleen rate between 1953 and 1955 for each county to measure malaria intensity. "$\text{SpleenRateDif}_{county}$ × Era" represents the interaction term between the malaria intensity at the county level and the dummy variable of a post-eradication cohort born from 1954-1955. In Panel B, we use the difference in the level of the malaria spleen rate between 1953 and 1955 for each township. "$\text{SpleenLevelDif}_{township}$ × Era" represents the interaction term between the malaria intensity at the township level and the dummy variable of a post-eradication cohort. (2) The level of malaria spleen rates at the township level in 1953 and 1955 is a categorical variable that ranges from 1 to 5, hence the integer values of "$\text{SpleenLevelDif}_{township}$" range from -4 to 4. (3) The other controls not presented in this table include educational level and ethnicity of one's parents, regional fixed effects (county level in Panel A and township level in Panel B), birth year fixed effects, dummy variables to categorize respondents by survey round, and own educational level in columns 2, 4, and 6. (4) Robust standard errors with regional clustering (county level in Panel A and township level in Panel B) are in brackets. (5) Sampling weights are used in all regressions. (6) *** significant at 1 percent level. ** significant at 5 percent level. * significant at 10 percent level.

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Table 2.5

Effects of Malaria Eradication on Income

	(1)	(2)	(3)	(4)	(5)
Outcome:	**Personal income**		**Family income**		
Panel A Independent variable: $\text{SpleenRateDif}_{county}(\%) \times$ Era					
Overall	-0.0005	-0.0008	0.0032***	0.0017	0.0007
	[0.003]	[0.003]	[0.001]	[0.001]	[0.001]
Observations	6,632	6,632	7,260	7,260	7,260
Male	0.0002	-0.0000	0.0070**	0.0058**	0.0047*
	[0.003]	[0.003]	[0.003]	[0.002]	[0.002]
Observations	3,859	3,859	3,669	3,669	3,669
Female	-0.0038	-0.0036	-0.0012	-0.0026	-0.0033
	[0.004]	[0.003]	[0.002]	[0.003]	[0.003]
Observations	2,773	2,773	3,591	3,591	3,591
Panel B Independent variable: $\text{SpleenLevelDif}_{township}(1\sim5)$ $\times$ Era					
Overall	-0.0330	-0.0120	-0.0067	-0.0023	0.0025
	[0.032]	[0.031]	[0.023]	[0.023]	[0.023]
Observations	6,529	6,529	7,135	7,135	7,135
Male	-0.0062	-0.0031	0.0168	0.0124	0.0145
	[0.034]	[0.034]	[0.037]	[0.037]	[0.037]
Observations	3,802	3,802	3,610	3,610	3,610
Female	-0.0497	-0.0119	-0.0241	-0.0114	-0.0007
	[0.046]	[0.046]	[0.035]	[0.033]	[0.033]
Observations	2,727	2,727	3,525	3,525	3,525
Own education level	×	✓	×	✓	✓
Education level of spouse			×	×	✓

Notes: (1) In columns 1 and 2, the dependent variable "Personal income" is a natural logarithm of deflated personal income. In columns 3-5, the dependent variable "Family income" is a natural logarithm of deflated family income. (2) In Panel A, we use the difference in the malaria spleen rate between 1953 and 1955 for each county to measure malaria intensity. "$\text{SpleenRateDif}_{county}\times$ Era" represents the interaction term between the malaria intensity at the county level and the dummy variable of a post-eradication cohort born from 1954-1955. In Panel B, we use the difference in the level of the malaria spleen rate between 1953 and 1955 for each township. "$\text{SpleenLevelDif}_{township}$ × Era" represents the interaction term between the malaria intensity at the township level and the dummy variable of a post-eradication cohort. (3) The level of malaria spleen rates at the township level in 1953 and 1955 is a categorical variable that ranges from 1 to 5, hence the integer values of "$\text{SpleenLevelDif}_{township}$" range from -4 to 4. (4) The other controls not presented in this table include: educational level and ethnicity of one's parents, regional fixed effects (county level in Panel A and township level in Panel B), birth year fixed effects, dummy variables to categorize respondents by survey round, one's own educational level in columns 2, 4, and 5, and spouse's educational attainment in column 5. (5) Robust standard errors with regional clustering (county level in Panel A and township level in Panel B) are in brackets. (6) Sampling weights are used in all regressions. (7) *** significant at 1 percent level. ** significant at 5 percent level. * significant at 10 percent level.

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Table 2.6

Effects of Malaria Eradication on Income:

Quantile Regression

Sample: Male	(1)	(2)	(3)	(4)	(5)
Outcome:	**Personal income**		**Family income**		
Independent variable: $\text{SpleenRateDif}_{county}(\%) \times$ Era					
OLS	0.0002	-0.0000	0.0070**	0.0058**	0.0047*
	[0.003]	[0.003]	[0.003]	[0.002]	[0.002]
Quantile:					
0.25	0.0014	0.0053	0.0113***	0.0095***	0.0075***
	[0.005]	[0.005]	[0.004]	[0.002]	[0.003]
0.40	0.0010	0.0022	0.0053*	0.0065*	0.0068***
	[0.003]	[0.002]	[0.003]	[0.004]	[0.003]
0.50	0.0027	0.0011	0.0037	0.0025	0.0039*
	[0.002]	[0.003]	[0.004]	[0.003]	[0.002]
0.60	0.0025	0.0008	0.0038	0.0013	0.0007
	[0.003]	[0.002]	[0.003]	[0.003]	[0.004]
0.75	-0.0007	-0.0013	0.0024	-0.0019	-0.0024
	[0.004]	[0.003]	[0.004]	[0.002]	[0.003]
Observations	3,859	3,859	3,669	3,669	3,669
Own education level	×	✓	×	✓	✓
Education level of spouse			×	×	✓

Notes: (1) In columns 1 and 2, the dependent variable "Personal income" is a natural logarithm of deflated personal income. In columns 3-5, the dependent variable "Family income" is a natural logarithm of deflated family income. (2) We use the difference in the malaria spleen rate between 1953 and 1955 for each county to measure malaria intensity. "$\text{SpleenRateDif}_{county} \times$ Era" represents the interaction term between the malaria intensity at the county level and the dummy variable of a post-eradication cohort born from 1954-1955. (3) The other controls not presented in this table include: educational level and ethnicity of one's parents, regional fixed effects (county level), birth year fixed effects, dummy variables to categorize respondents by survey round, one's own educational level in columns 2, 4, and 5, and spouse's educational attainment in column 5. (4) Robust standard errors with regional clustering at the county level are in brackets. (5) *** significant at 1 percent level. ** significant at 5 percent level. * significant at 10 percent level.

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Table 2.7

Robustness Check I: Effects of Malaria Eradication on Own and Spouse's Educational Attainment (Sample: 1951-1955)

Sample	Overall	Male	Female
Panel A Independent variable: $\text{SpleenRateDif}_{county}(\%) \times \text{Era}$			
Own education level			
Above high school	0.0026***	0.0036***	0.0014
	[0.001]	[0.001]	[0.002]
Above junior high school	0.0026**	0.0029***	0.0021
	[0.001]	[0.001]	[0.002]
Observations	8,497	4,215	4,282
Spouse's education level			
Above high school	0.0008	0.0027**	-0.0001
	[0.001]	[0.001]	[0.002]
Above junior high school	0.0001	-0.0001	0.0005
	[0.001]	[0.002]	[0.002]
Observations	6,424	3,210	3,214
Panel B Independent variable: $\text{SpleenLevelDif}_{township}(1\sim5) \times \text{Era}$			
Own education level			
Above high school	0.0082	0.0406*	-0.0201
	[0.013]	[0.021]	[0.017]
Above junior high school	0.0010	0.0367*	-0.0224
	[0.014]	[0.021]	[0.020]
Observations	8,358	4,158	4,200
Spouse's education level			
Above high school	0.0225	0.0174	0.0313
	[0.016]	[0.021]	[0.023]
Above junior high school	0.0032	0.0117	-0.0137
	[0.017]	[0.023]	[0.024]
Observations	6,325	3,170	3,155

Notes: (1) We use the difference in the malaria spleen rate between 1953 and 1955 for each county to measure malaria intensity in Panel A. "$\text{SpleenRateDif}_{county} \times \text{Era}$" represents the interaction term between the malaria intensity at the county level and the dummy variable of a post-eradication cohort born from 1954-1955. In Panel B, we use the difference in the level of malaria spleen rate between 1953 and 1955 for each township. "$\text{SpleenLevelDif}_{township} \times \text{Era}$" represents the interaction term between the malaria intensity at the township level and the dummy variable of a post-eradication cohort. (2) The level of malaria spleen rates at the township level in 1953 and 1955 is a categorical variable that ranges from 1 to 5, hence the values of "$\text{SpleenLevelDif}_{township}$" range from -4 to 4 (integer). (3) The other controls not presented here include parents' educational level and ethnicity, regional fixed effects (county level in Panel A and township level in Panel B), birth year fixed effects, dummy variables to categorize respondents by survey round, and one's own educational level as estimating the effects on the spouse's educational level. (4) Robust standard errors with regional clustering (county level in Panel A and township level in Panel B) are in brackets. (5) Sampling weights are used in all regressions. (6) *** significant at 1 percent level. ** significant at 5 percent level. * significant at 10 percent level.

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Table 2.8

Robustness Check I: Effects of Malaria Eradication on Income

(Sample: 1951-1955)

	(1)	(2)	(3)	(4)	(5)
Outcome:	**Personal income**		**Family income**		
Panel A Independent variable: $\text{SpleenRateDif}_{county}(\%) \times$ Era					
Overall	-0.0012	-0.0021	0.0033***	0.0014	0.0003
	[0.003]	[0.003]	[0.001]	[0.001]	[0.002]
Observations	5,695	5,695	6,196	6,196	6,196
Male	-0.0006	-0.0011	0.0064**	0.0049*	0.0036
	[0.004]	[0.004]	[0.003]	[0.003]	[0.003]
Observations	3,273	3,273	3,097	3,097	3,097
Female	-0.0057	-0.0064*	-0.0004	-0.0025	-0.0034
	[0.004]	[0.003]	[0.003]	[0.003]	[0.004]
Observations	2,422	2,422	3,099	3,099	3,099
Panel B Independent variable: $\text{SpleenLevelDif}_{township}(1\sim5) \times$ Era					
Overall	-0.0341	-0.0094	-0.0116	-0.0032	-0.0011
	[0.033]	[0.032]	[0.023]	[0.023]	[0.023]
Observations	5,612	5,612	6,096	6,096	6,096
Male	-0.0039	0.0014	0.0001	0.0124	0.0012
	[0.038]	[0.038]	[0.038]	[0.037]	[0.036]
Observations	3,232	3,232	3,055	3,610	3,055
Female	-0.0493	-0.0141	-0.0114	-0.0015	0.0063
	[0.050]	[0.051]	[0.038]	[0.035]	[0.035]
Observations	2,380	2,380	3,041	3,041	3,041
Own education level	×	✓	×	✓	✓
Education level of spouse			×	×	✓

Notes: (1) In columns 1 and 2, the dependent variable "Personal income" is a natural logarithm of deflated personal income. In columns 3-5, the dependent variable "Family income" is a natural logarithm of deflated family income. (2) In Panel A, we use the difference in the malaria spleen rate between 1953 and 1955 for each county to measure malaria intensity. "$\text{SpleenRateDif}_{county} \times$ Era" represents the interaction term between the malaria intensity at the county level and the dummy variable of a post-eradication cohort born from 1954-1955. In Panel B, we use the difference in the level of the malaria spleen rate between 1953 and 1955 for each township. "$\text{SpleenLevelDif}_{township} \times$ Era" represents the interaction term between the malaria intensity at the township level and the dummy variable of a post-eradication cohort. (3) The level of malaria spleen rates at the township level in 1953 and 1955 is a categorical variable that ranges from 1 to 5, hence the integer values of "$\text{SpleenLevelDif}_{township}$" range from -4 to 4. (4) The other controls not presented in this table include: educational level and ethnicity of one's parents, regional fixed effects (county level in Panel A and township level in Panel B), birth year fixed effects, dummy variables to categorize respondents by survey round, one's own educational level in columns 2, 4, and 5, and spouse's educational attainment in column 5. (5) Robust standard errors with regional clustering (county level in Panel A and township level in Panel B) are in brackets. (6) We use sampling weights all regressions. (7) *** significant at 1 percent level. ** significant at 5 percent level. * significant at 10 percent level.

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Table 2.9

Robustness Check II: Further Checks on Own Educational Attainment

	True intervention Sample: 1950-1955			Fake intervention I Sample: 1940-1945			Fake intervention II Sample: 1960-1965		
Sample	**Overall**	**Male**	**Female**	**Overall**	**Male**	**Female**	**Overall**	**Male**	**Female**
Independent variable: $\text{SpleenRateDif}_{county}(\%) \times \text{Era}$									
Panel A: Sample from TSCS									
Education level									
Above high school				0.0005	0.0017	0.0009	-0.0010	0.0003	-0.0022
				[0.002]	[0.003]	[0.002]	[0.001]	[0.002]	[0.002]
Above junior high				0.0018	-0.0011	0.0062	0.0003	0.0001	0.0006
				[0.002]	[0.003]	[0.004]	[0.001]	[0.001]	[0.001]
Observations				4,943	2,532	2,411	10,333	5,038	5,295
Panel B: Sample from 1980 Census									
Education level									
Above high school	0.0003	0.0005	0.0001	-0.0000	0.0001	-0.0003	0.0015	0.0014	0.0016
	[0.000]	[0.000]	[0.001]	[0.000]	[0.000]	[0.000]	[0.001]	[0.001]	[0.001]
Above junior high	0.0010***	0.0011***	0.0009*	0.0003	0.0002	0.0001	-0.0002	-0.0004	0.0000
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.001]	[0.001]	[0.000]	[0.001]
Observations	1,745,867	910,993	834,874	955,910	520,097	435,813	2,056,550	1,054,077	1,002,473

Notes: (1) We use the difference in the malaria spleen rate between 1953 and 1955 for each county to measure malaria intensity in all regressions. (2) In Panel A, we use the sample from the TSCS. In Panel B, we use the sample from the 1980 Census. (3) In columns 1-3, we use the sample born from 1950-1955. "$\text{SpleenRateDif}_{county} \times \text{Era}$" represents the interaction term between the malaria intensity and the dummy variable of a "true" post-eradication cohort born from 1954-1955. In columns 4-6, we use the sample born from 1940-1945. "$\text{SpleenRateDif}_{county} \times \text{Era}$" represents the interaction term between the malaria intensity and the dummy variable of a "fake" post-eradication cohort born from 1944-1945. In columns 7-9, we use the sample born from 1960-1965. "$\text{SpleenRateDif}_{county} \times \text{Era}$" represents the interaction term between the malaria intensity and the dummy variable of a "fake" post-eradication cohort born from 1964-1965. (4) The other controls not presented in this table include regional fixed effects at the county level and birth year fixed effects in all regressions, and educational level and ethnicity of one's parents and dummy variables to categorize respondents by survey round in Panel A. (5) Robust standard errors with regional clustering at the county level are in brackets. (6) Sampling weights are used in all regressions. (7) *** significant at 1 percent level. ** significant at 5 percent level. * significant at 10 percent level.

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Table 2.10

Robustness Check III: Further Checks on Own Educational Attainment

(Reduced Form of Fuzzy RD)

Sample: Male	Highly malarious		Less malarious	
Outcome: Above junior high	Linear	Quadratic	Linear	Quadratic
Eradication	0.0153***	0.0360***	0.0133**	0.0253*
	[0.004]	[0.011]	[0.004]	[0.011]
Observations	192,046	192,046	194,407	194,407

Notes: (1) In all regressions, we use the male sample born from July 1952 to December 1954. "Eradication" is the dummy variable of a post-eradication cohort born after October 1953. (2) We use the average of the difference in the malaria spleen rate in each county as the baseline to classify each county into the "Highly malarious" or "Less malarious" group. (3) In the "Linear" columns, we use the linear form of the birth month in the regressions. In the "Quadratic" columns, we use the quadratic form of the birth month in the regressions. (4) In all regressions, we include regional fixed effects at the county level. (5) Robust standard errors with regional clustering at the county level are in brackets. (6) *** significant at 1 percent level. ** significant at 5 percent level. * significant at 10 percent level.

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Chapter 3

The Impact of Air Pollution on Infant Health in Taiwan

3.1 Introduction

Over the past few decades, research has indicated that health conditions in early life could have long-lasting impacts on various developmental outcomes into adulthood (Case et al., 2005; Almond and Currie, 2011a). Early-life health conditions predetermine one's health capital later in life, and health capital is a crucial element of economic competence throughout one's life. However, epidemiologists used to believe that the placenta was an impeccable filter in the 1950s; hence, it was acceptable for pregnant women to smoke or drink (Almond and Currie, 2011b).

Barker (1992) first formalized this conjecture by proposing the fetal origins hypothesis. The fetal origins hypothesis posits that "certain chronic conditions later in life can be traced to the course of fetal development." Therefore, certain chronic health conditions such as diabetes and cardiovascular diseases in middle or old age can be traced back to the fetal environment. Extensive evidence in the medical field supports this hypothesis. Langley-Evans (2001) and Brown et al. (2004) find that poor early fetal conditions led to increase in the risks of vascular resistance, hypertension, and schizophrenia. Furthermore, a series of epidemiological studies show that cohorts in utero during the Dutch famine succumbed to coronary heart disease morbidity and other health problems in middle age (Roseboom et al., 2000; Roseboom et al., 2001;

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Ravelli et al., 2005). This evidence shows a strong relationship between the in utero environment and long-term outcomes.

Nevertheless, it is not easy to demonstrate the causality between health conditions in early life and outcomes later in life. The main problem with estimating the effect of early-life health is mainly caused by omitted confounders, such as socioeconomic conditions. To address this identification concern, researchers have established ingenious methods to mitigate potential bias. For example, Almond (2006) uses the sudden and unexpected attribute of the 1918 influenza pandemic as a natural experiment to test the fetal origins hypothesis. Comparing long-term outcomes for cohorts born during the 1918 influenza epidemic to the outcomes of cohorts born one year before or after the epidemic, he finds large negative long-term consequences from exposure to the 1918 influenza virus, such as lower educational attainment and socioeconomic status and higher disability rates. Similarly, Chen and Zhou (2007) indicate that cohorts exposed to the China's Great Famine in early life were significantly shorter, worked fewer hours and earned less income in adulthood. Lee (2014) also finds that prenatal exposure to the Korean War resulted in lower educational attainment and labor market performance and higher disability rates.

In recent years, research has examined the impact of exposure to air pollution in early-life both on near-term and long-term outcomes. In California in the 1990s, air pollution resulted in asthma for children aged from 1 to 18 as well as had a significant effect on infant mortality (Neidell, 2004; Currie and Neidell, 2005). Using the Clean Air Act, the recessions, or other unexpected events as natural/quasi experiments, researchers also find that air pollution led to negative health effects on newborn babies as well as academic performance later in life. For example, Chay and Greenstone (2003a,c) find that reductions in air pollution induced by the 1970 Clean Air Act Amendments (CAAA) and the 1981 – 1982 recession in the U.S led to decrease in the infant mortality rate. Using Chernobyl fallout in Sweden as a natural experiment, Almond et al. (2009) find that students born in regions with higher fallout performed

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worse in school. Currie and Walker (2011) indicate that the implementation of E-ZPass could reduce the probability of prematurity as well as low birth weight.

Another series of studies employs the instrumental-variable (IV) strategy to deal with the identification problem of estimating the impact of exposure to air pollution. Using the existence of thermal inversions (a meteorological phenomenon) as an instrumental variable for pollution levels, Arceo-Gomez et al. (2016) find that increases in pollution levels resulted in increases in infant mortality in Mexico City. Schlenker and Walker (2014) utilize airport ground congestion as an instrumental variable and show that air pollution led to hospital admissions for respiratory problems and heart disease in California.

Based on the aforementioned literature, this study investigates the health effects of air pollution on newborn babies in Taiwan in the first decade of the 21st century. However, the estimation could suffer from endogenous problems such as omitted variables and measurement errors. Using the birth data and data on atmospheric condition (including pollution and weather) collected by the government, we examine the effects of air pollution on early-life health through appropriate empirical strategy. Specifically, we utilize the instrumental-variable strategy to investigate the health impact of air pollution on newborn babies in Taiwan. We use variation in climatic factors such as temperature, humidity, and rainfall to instrument for in utero exposure to air pollution.

Taiwan's economy grew rapidly in the past decades. However, the rapid economic growth has led to higher level of air pollutants which might affect infant health. This study will provide suggestions for the establishment of health policies. If the health condition around the time of birth (in utero and postnatal) is the most crucial determinant for developmental outcomes later in life, health policies that target pregnant women and infants may have higher returns than those policies that target wider age groups. This study will provide more abundant evidence to clarify the importance of early-life health conditions.

Our results indicate that increases in particulate matter 10 micrometers (PM10)

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during pregnancy would lead to prematurity, low birth weight, and being born in bad health. Moreover, exposure to sulfur dioxide (SO2) and nitrogen dioxide (NO2) during pregnancy would result in prematurity and low birth weight for those born between 37 and 44 weeks of gestation. Our results suggest that there were negative and significant effects of in utero exposure to air pollution on infant health in Taiwan.

This paper proceeds as follows. Section 3.2 describes the literature review. Section 3.3 introduces the data used in this paper. Section 3.4 presents the empirical specification. Section 3.5 discusses the estimation results, and section 3.6 concludes the paper.

3.2 Literature Review

In the 1990s, Barker (1992) proposed the fetal origins hypothesis, which posits that ”certain chronic conditions later in life can be traced to the course of fetal development.” Inadequate in utero nutrition could ”program” a fetus to prioritize brain growth at the expense of other organs and tissues. Consequently, certain chronic health conditions such as stroke, diabetes, and heart problems in middle or old age can be traced back to the fetal environment.

An abundance of evidence in the medical literature supports the fetal origins hypothesis. Langley-Evans (2001) indicates that poor early fetal conditions result in increased vascular resistance and hypertension. Brown et al. (2004) also suggest that poor early fetal conditions increase the risk of schizophrenia. Ozanne and Hales (2004) find that the lifespan of experimental mice is significantly shortened if the postnatal period of growth is accelerated to compensate for reduced growth in utero. Besides, epidemiological studies of famine episodes are noticeable. These studies on famine show that cohorts in utero during the Dutch famine suffered from coronary heart disease morbidity and various other health deteriorations in their middle age (Roseboom et al., 2000; Roseboom et al., 2001; Ravelli et al., 2005).

The fetal origins hypothesis has not only attracted medical scientists; it has also

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attracted the interest of economists. In addition to health conditions in adulthood, economists are curious about the association between a person's early-life health conditions and socioeconomic outcomes later in life. Case, Fertig, and Paxson (2005) show that a low birth weight and mother's smoking during pregnancy are associated with poor academic achievement and poor health in adulthood. Furthermore, health in childhood is related to adult socioeconomic status.

The aforementioned evidence confirms a strong correlation between health conditions in early-life and later outcomes. Nevertheless, it is not easy to determine the causality between them. The main challenge in estimating the effect of early-life health conditions is mainly due to omitted confounders, such as social and economic conditions. To deal with this identification problem, Almond (2006) investigates the long-term impact of the 1918 influenza pandemic in the United States. The author uses the abrupt and unexpected attribute of the 1918 influenza pandemic as a natural experiment to test the fetal origins hypothesis. He shows that compared with those born just before or after the epidemic, cohorts in utero during the peak of the influenza pandemic presented lower educational attainment, lower income, lower socioeconomic status, higher disability rates, and higher transfer payments. Schwandt (2014) also shows that in utero exposure to seasonal influenza in Denmark is associated with worse health at birth, a lower labor market participation rate and earnings, and higher rates of welfare dependence later in life.

In addition to use the influenza to estimate the effects of early-life health shocks, research has estimated the impacts of early-life exposure to other diseases such as malaria. Barreca (2010) uses the instrumental-variable strategy and finds that cohorts exposed to malaria in their year of birth had significantly lower levels of educational attainment as adults. Using malaria eradication campaigns as quasi-experiments, Lucas (2010) also suggests that there were negative and significant effects of malaria on educational attainment in Paraguay and Sri Lanka.

Rather than using diseases as early-life health shocks, there is evidence examining

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the impact of early-life exposure to air pollution both on near-term health and long-term outcomes. Neidell (2004) shows that carbon monoxide (CO) led to asthma for children aged from 1 to 18 in California in the 1990s. Furthermore, Neidell finds that the impact of pollution is larger for children with lower socio-economic status. Subsequently, Currie and Neidell (2005) indicate that reductions in CO could also save approximately 1000 infant lives in California over the same period. Liu (2007) indicates that reductions in PM10, SO2, and NO2 in Taiwan resulted in positive health effects on newborn babies. Currie et al. (2009) show that not only CO, but also PM10 and ozone have negative effects on infant health such as birth weight and infant mortality, especially among smoking mothers.

Another series of studies examines the effects of air pollution using the Clean Air Act or unexpected events around the world as quasi or natural experiments. For example, Chay and Greenstone (2003a) find that a one percent decrease in total suspended particulates (TSPs) induced by the 1970 Clean Air Act Amendments (CAAA) led to a 0.5 percent decrease in the infant mortality rate in the U.S. However, they find there is no effect on adult mortality (Chay and Greenstone, 2003b). Chay and Greenstone (2003c) also show that air pollution reductions caused by the 1981 – 1982 recession in the U.S led to declines in infant mortality.

Using Chernobyl fallout in Sweden as a natural experiment, Almond et al. (2009) find that students born in regions with higher fallout performed worse in secondary school, particularly in mathematics. Currie and Walker (2011) exploit the introduction of electronic toll collection (E-ZPass) in New Jersey and Pennsylvania, which significantly reduced traffic congestion and vehicle emissions, to examine the effects of pollution through the difference-in-differences method. Comparing the infant health outcomes of those living near an electronic toll plaza before and after implementation of E-ZPass to those living further away from a toll plaza (but still near a major highway), they find that the implementation of E-ZPass could reduce the probability of prematurity as well as low birth weight. Utilizing the natural experiment created

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by the mandated desulfurization at powerplants in Germany, Luechinger (2014) shows that infant mortality decreases with reductions in SO2 concentration due to desulfurization.

Recently, researchers employ the instrumental-variable (IV) strategy as an alternative way to deal with the identification problem of estimating the effects of air pollution. Utilizing the existence of thermal inversions (a meteorological phenomenon) as an instrumental variable for pollution levels, Arceo-Gomez et al. (2016) find that increases in both CO and PM10 resulted in increases in infant mortality in Mexico City. Schlenker and Walker (2014) use airport ground congestion as an instrumental variable for levels of pollution and show that air pollution led to hospital admissions for respiratory problems and heart disease in California. Furthermore, they find that there is no impact of airport ground congestion on diagnoses unrelated to air pollution such as stroke or appendicitis.

The afore-stated evidence shows that exposure to air pollution early in life is deleterious to near-term health, and that early-life health might influence health and human capital later in life. However, previous literature mainly focused on people in the western countries. To provide more abundant evidence of the importance of early-life health conditions in Asian countries, we investigate the health effects of air pollution on newborn babies (such as birth weight and premature birth) in Taiwan. Using the birth data and data on atmospheric condition (including pollution and weather) collected by the government, we utilize the instrumental-variable strategy to mitigate potential biases caused by omitted variables and measurement errors. In the next section, we introduce the data used in our analysis.

3.3 Data

3.3.1 Pollution and Weather

Detailed data on atmospheric pollution and weather conditions come from the air monitoring stations constructed by Taiwan's Environmental Protection Administration.

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There are 71 monitoring stations across the country. We concentrate on the set of monitors with hourly measures for PM10, SO2, NO2, temperature, rainfall, and humidity (relative humidity) in the years 2000-2011. We construct monthly measures of air pollution and weather conditions for each township which has an air monitoring station nearby. In order to do this, we calculate a monthly level of pollution and weather conditions for each monitoring station taking the average of the hourly values. In townships with two or more monitoring stations nearby, we take the average of monthly measures of all stations.

3.3.2 Birth Data

Data on infant health come from Taiwan's National Health Insurance Administration (NHIA) for 2001 to 2011. The NHIA provides a very rich source of data that cover all births in Taiwan. The data contain detailed information about the infant, including birth year and month, gender, birth weight, gestation, the Apgar scores at 1 minute and 5 minutes after birth.[1] Like most of previous studies of infant health, we define *Prematurity* as gestation less than 37 weeks, *Low Birth Weight* as birth weight less than 2,500 grams, and $LowBirthWeight_{37-44weeks}$ as birth weight less than 2,500 grams and born between 37 and 44 weeks' gestation. We also define $ApgarScore1_{good}$ and $ApgarScore5_{good}$ as the Apgar score of 7 – 10 at 1 minute and 5 minutes after birth (i.e., the newborn is in good health), respectively.

Furthermore, the NHIA provide background information about the mother, including maternal age, parity, residence in township level, and health problems during pregnancy. Because these characteristics are potential confounding factors when examining birth outcomes, they are included as control variables in the analysis. All of these variables are dummy variables. The categories of maternal age are 20 or below, 21-25,

[1] The Apgar score provides an accepted and convenient method for reporting the status of the newborn infant immediately after birth. The Apgar score of 7-10 is defined as reassuring, a score of 4-6 is defined as moderately abnormal, and a score of 0-3 is defined as low in the term infant and late-preterm infant (source: *The Apgar Score*, 2015).

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26-30, 31-35, and so on.[2] We define the indicator variable, *Health Prob in Preg* $= 1$ if the mother has at least one health problem during pregnancy.

3.3.3 Township's Characteristics

Since socio-economic characteristics of townships may be important determinants of pollution levels but could also have independent effects on infant health, we include household income and population density for 2000 to 2011 as additional controls in our analysis. The Financial and Taxation Data Processing and Examination Center in Taiwan provides the annual average household income in each township. Data on population density for each township come from the Department of Household Registration in Taiwan. Population density is the number of people per unit of area. The unit in the data is per square Kilometer. The two sets of data are provided annually. In order to control these characteristics during pregnancy, we calculate a weighted average of household income and population density if the gestation period spans across two years, using the fraction of the gestation period in each year as the weight. Below we introduce our empirical strategy and the instrumental variables in detail.

3.4 Empirical Strategy

3.4.1 OLS

Our baseline OLS model examines the relationship between air pollution and infant health. The estimated equation is as follows:

$$y_{izt} = \alpha + \sum_{n=1}^{9} \beta_n P_{iztn} + \gamma X_{izt} + \phi Z_{izt} + \lambda_t + \varepsilon_{izt}, \tag{3.1}$$

where i indicates individual infant, z is the mother's residence in township level, and t is the infant's birth year and month. y_{izt} is the infant's health outcomes. The outcomes of interest include prematurity, low birth weight, the Apgar scores at 1 minute and 5 minutes after birth. P_{iztn} indicates measures of air pollution levels in each month of the

[2] We limit the sample to those born to mothers aged below 55.

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mother's pregnancy, denoted by n ranging from 1 to 9, using the monitoring station closest to the mother's residence. X_{izt} are controls for individual characteristics of the mother and child, including infant's gender, birth order, maternal age, and mother's health problems during pregnancy. Furthermore, we control for birth weight as the birth outcome is prematurity, control for gestation as the outcome is low birth weight, and control for both birth weight and gestation as the outcomes are the Apgar scores. Z_{izt} are characteristics of the township, including weighted average of household income and population density during pregnancy, and the township fixed effect. λ_t is the birth year fixed effect.

3.4.2 IV

The main challenges in identifying the impacts of air pollution are from endogenous problems such as omitted variables, simultaneity (reverse causality), and measurement error. If endogeneity is ignored, a bias occurs in the estimated results, which may distort the casual relationship. For example, families with higher incomes may be more likely to live in regions with better air quality. In addition, these families are also more likely to have access to better prenatal care. The estimations may be biased upward if these confounders are omitted from the analysis. Alternatively, economic growth will tend to increase pollution levels, but also may be correlated with increases in income levels and access to health care. Omitting these factors would result in a downward bias in the estimated effects of pollution. Therefore, the overall direction of bias is ambiguous. To address these endogeneity problems, we use the two-stage least-squares (2SLS) estimation of the instrumental-variable (IV) strategy. The first task is to develop an appropriate IV for resolving estimation bias.

A suitable IV must satisfy two conditions. The first condition is correlation. The IV should be significantly associated with air pollution. This association can be tested using the first-stage weak IV F test. The second condition is exogeneity. Exogeneity cannot be detected using statistical tools; therefore, we will employ detailed theory and

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evidence to demonstrate exogeneity.

We use variation in climatic data such as temperature, humidity, and rainfall collected by Taiwan's Environmental Protection Administration to instrument for in utero exposure to air pollution. At first stage, we estimate:

$$P_{izt} = \delta + \pi W_{izt} + \Gamma C_{izt} + \upsilon_{izt}. \tag{3.2}$$

P_{izt} is $(P_{izt1}, P_{izt2}, ..., P_{izt9})$', presenting air pollution levels in each month of the mother's pregnancy. W_{izt} is $(W_{izt1}, W_{izt2}, ..., W_{izt9})$', indicating our instruments. The instruments include temperature, humidity, and rainfall during pregnancy. C_{izt} are remaining control variables which are identical to those of the OLS regression equation. The first-stage regression indicates the predicted values of pollution levels obtained using the IV.

Regression analysis is then performed on the infant's health outcomes, which is the second stage of the estimation. The model is presented as follows:

$$y_{izt} = \alpha + \sum_{n=1}^{9} \beta_n \hat{P_{iztn}} + \gamma X_{izt} + \phi Z_{izt} + \lambda_t + \varepsilon_{izt}, \tag{3.3}$$

where $\hat{P_{iztn}}$ represents the first-stage predicted values of pollution levels. In this equation, the predicted values obtained from the estimations in the first stage was used to substitute P_{iztn}. Below we discuss whether the IVs used in this study satisfy the correlation and exogeneity requirements.

3.4.3 Relevance of the Instrumental Variables

We first address correlation. Meteorological research has revealed a strong relationship between weather conditions and air pollution. The washout effect, which is the removal of air pollutants by falling precipitation, has attracted the interest of researchers. Similarly, relative humidity could also reduce air pollutants. Ravindra et al. (2003) report that the oncentration of TSP, SO2, and NO2 decreased by 40 – 45% during rainfall in India. Giri et al. (2008) indicate that the increase in rainfall and relative humidity has

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negative correlation with PM10 concentration in Nepal. Huo et al. (2011) show significant negative correlations between air pollutants (NO2 and SO2) and rainfall as well as humidity in China. Plaude et al. (2012) indicate that rainfall negatively correlates with aerosol particles concentration in Russia. Similarly, Yoo et al. (2014) find significant negative correlations between pollutant concentrations and rainfall for PM10, SO2, NO2, and CO. Afzali et al. (2014) also show a negative correlation between PM10 and relative humidity in Malaysia (Johor).

On the other hand, research has shown temperature might increase the chemical reaction in the atmosphere resulting in the formation of pollutants. Braniš and Větvička (2010) find temperature has positive correlation with PM10 concentration in Beijing. Bralić et al. (2012) indicate that high level of SO2 are associated with low humidity and high temperature in Croatia. Vanos et al. (2015) also find that high temperature is coincided with high air pollution concentrations of NO2, O3, and SO2 in Canada.

In summary, the evidence sets support our assumption that weather conditions are significantly correlated with air pollution. Therefore, the weather conditions used as our IVs might meet the correlation requirement.

3.4.4 Exogeneity of the Instrumental Variables

The key exclusion restriction for weather conditions to be good instruments is that weather conditions should not affect infant health, holding all other determinants of infant health constant (i.e., weather must affect infant health only through the channel of air pollution). In addition to air pollution, there might be other channels linking weather conditions to infant health. The most critical concern is that rainfall might affect infant health through the channel of agricultural production and household income (Maccini and Yang, 2009). During our sample period (2001 – 2011), average employment in agriculture is 6% of total employment in Taiwan, which implies that few people would be affected by this channel. Furthermore, the IV model contains all other controls of the OLS specification, including characteristics of townships such as

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household income and population density. Therefore, these potential channels could not confound our analysis. Overall, our instruments could satisfy the exclusion restriction. Moreover, we could use alternative specification in our analysis. That is, we only use temperature and humidity as instruments to reanalysis the impacts of air pollution, and compare the results of the two different specifications.

3.5 Estimation Results

3.5.1 Descriptive Statistics

Table 3.1 presents descriptive statistics for infant health outcomes, pollution measures, and weather conditions. This is the sample from townships with air monitoring stations nearby and data on household income and population density. The top rows of the table presents infants and mothers' characteristics. The probability of prematurity is about 10%. The probability of birth weight below 2,500 grams is about 9%, while the probability of birth weight below 2,500 grams for those born between 37 and 44 weeks' gestation is lower, roughly 4%. The probabilities of the Apgar score being 7 – 10 at 1 and 5 mins after birth are 97.1% and 98.9%, implying that most newborns are in good health. The next set of rows shows average concentrations of PM10, SO2, and NO2, and the rest of the table presents average temperature, rainfall, and humidity.

3.5.2 First Stage Estimates

In our instrumental-variable (IV) strategy, we use weather conditions to instrument for in utero exposure to air pollution, including temperature, humidity, and rainfall. We start by examining the relationship between the weather conditions and each of the three pollutants (PM10, SO2, and NO2), which composes the first stage of our IV strategy. The first column of Table 3.2 shows the first-stage IV F statistics using temperature, humidity, and rainfall as IVs. All the F statistics are considerably large, especially for PM10. In the second column, we only use temperature and humidity as IVs, and the results are similar to the results shown in the first column. The coefficients

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are generally displayed the predicted sign (results not reported). They are consistent with the results of previous research. The results indicate that temperature, humidity, and rainfall are significantly associated with PM10, SO2, and NO2, implying that our IVs might meet the correlation requirements.

3.5.3 Results

Table 3.3 presents the effects of air pollution on prematurity. The first column is the results of the OLS model, the second column is the results of the IV model using temperature, humidity, and rainfall as IVs, and the results of the IV model using only temperature and humidity as IVs are shown in the remaining columns with different controls. In all the estimations, we control infant's gender, birth order, birth weight, maternal age, and township and birth year fixed effects. The remaining controls are demonstrated in the table. The first column of Table 3.3 shows that the effects of air pollution are ambiguous in the OLS model. Most coefficients of interest are negative, while a few of them are positive. However, the coefficients of the IV models are positive with the same controls, which are consistent with our expectation that air pollution would harm infant health. Specifically, increases in PM10 during pregnancy would lead to increases in the probability of prematurity. On the other hand, increases in SO2 and NO2 would result in prematurity, especially during the 2nd and 3rd trimester.

Table 3.4 shows the effects of air pollution on low birth weight. The coefficients of PM10 are insignificant in the OLS model, while the coefficients of the IV model using temperature and humidity as IVs are positive and significant. Increases in PM10 during pregnancy would increase the probability of low birth weight during the 1st trimester. The effects of SO2 and NO2 on low birth weight are ambiguous.

In Table 3.5, we examine the effects on low birth weight for those born between 37 and 44 weeks of gestation. The results are ambiguous in the OLS model, while the results of the IV model (using temperature and humidity) are positive and significant for SO2 and NO2. Increases in SO2 and NO2 during the 1st and the 2nd trimester

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would lead to low birth weight for those born between 37 and 44 weeks of gestation.

Table 3.6 and Table 3.7 present the effects of air pollution on the Apgar score, which reports the status of the newborn infant immediately after birth. Specifically, we examine the effects on the probability of the Apgar score being 7 – 10 at 1 and 5 mins after birth (i.e., the newborn is in good health). The results of the Apgar score at 1 min after birth are presented in Table 3.6, which shows that the effects of air pollution on the Apgar score at 1 min are insignificant. In contrast, the effect of PM10 on the Apgar score at 5 mins is significant, which is shown in Table 3.7. The coefficients of PM10 levels during the third month of pregnancy in the IV models are significantly negative, implying that increases in PM10 during pregnancy would cause infants to be born in bad health. However, the effects of SO2 and NO2 are ambiguous. A possible explanation for the differences between the Apgar score at 1 and 5 mins is that previous studies have found a stronger correlation between the Apgar score at 5 min of age and infant health, such as neonatal mortality (Finster and Wood, 2005). Therefore, the Apgar score at 5 mins after birth might be a more appropriate measure for infant health.

In summary, our estimates indicate that exposure to PM10 during pregnancy could lead to prematurity, low birth weight, and being born in bad health, especially during the first trimester. In addition, exposure to SO2 and NO2 could also result in prematurity and low birth weight for those born between 37 and 44 weeks of gestation. The results show that there were negative and significant effects of in utero exposure to air pollution on infant health in Taiwan.

3.6 Conclusions

This study examines the health effects of air pollution on newborn babies in Taiwan in the first decade of the 21st century. Using the birth data and data on atmospheric condition (including pollution and weather), we utilize the instrumental-variable strategy to mitigate potential biases. Using weather conditions such as temperature and

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humidity to instrument for in utero exposure to air pollution, we find that increases in PM10 during pregnancy would lead to prematurity, low birth weight, and being born in bad health. Moreover, exposure to SO2 and NO2 during pregnancy would result in prematurity and low birth weight for those born between 37 and 44 weeks of gestation. Our estimates suggest that there were negative effects of in utero exposure to air pollution on infant health in Taiwan.

Over the past few decades, economic growth was exceptionally rapid around the world. However, air pollution also increased substantially at the same time. This study suggests that air pollution might affect infant health. If the health condition around the time of birth is a crucial determinant for developmental outcomes later in life, health policies that target pregnant women and infants would deliver appreciably higher returns for society.

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Tables

Table 3.1

Descriptive Statistics

	Mean
Infant and mother's characteristics	
Prematurity	0.0958
Low weight (below 2500g)	0.0923
Low weight (37-44weeks)	0.0367
Birth weight (g)	3,059
Apgar_1_good	0.971
Apgar_5_good	0.989
Gestation	38.17
Maternal age	30.00
Pollution	
PM10 (μg/m^3)	59.76
SO2 (ppb)	5.170
NO2 (ppb)	20.61
Weather	
Temperature (℃)	23.77
Relative humidity (%)	73.47
Rainfall (mm)	0.255

Note: The sample is from townships with air monitoring station nearby.

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Table 3.2

First-Stage Weak IV Test

First-stage weak IV test	(1) IV(Temp RH Rain)	(2) IV(Temp RH)
Trimester pollution: PM10		
9th month	147.326	182.267
8th month	238.091	239.101
7th month	313.785	206.882
6th month	392.682	282.658
5th month	229.343	159.789
4th month	251.195	210.438
3rd month	218.258	140.993
2nd month	233.528	158.754
1st month	134.606	101.036
Observations	533,837	534,439
Trimester pollution: SO2		
9th month	51.8729	40.0411
8th month	45.6957	27.5532
7th month	35.4345	21.5349
6th month	31.3976	24.0915
5th month	30.7583	26.2295
4th month	49.9912	32.14
3rd month	75.2846	30.373
2nd month	56.846	33.1332
1st month	42.676	24.883
Observations	532,359	532,961
Trimester pollution: NO2		
9th month	98.2095	105.5
8th month	115.091	90.7185
7th month	94.9634	98.2466
6th month	68.6904	87.0039
5th month	62.8511	77.4781
4th month	73.3134	70.2105
3rd month	79.4097	80.4722
2nd month	89.0437	87.1089
1st month	67.4106	86.3549
Observations	533,679	534,281
Household income	✓	✓
Population density	✓	✓
Mother's health during pregnancy	✓	✓

Notes: (1) Column 1 presents the First-stage F statistics using temperature (Temp), humidity (relative humidity, RH), and rainfall (Rain) as IVs. (2) Column 2 presents the First-stage F statistics using temperature and humidity as IVs.

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Table 3.3

Effects of Air Pollution on Prematurity

Outcome: **Prematurity**	(1) OLS	(2) IV(Temp RH Rain)	(3) IV(Temp RH)	(4) IV(Temp RH)	(5) IV(Temp RH)
Trimester pollution: PM10					
9th month	-7.71e-05***	-8.44e-06	-1.49e-05	-1.14e-05	-1.55e-05
	(2.59e-05)	(5.21e-05)	(4.93e-05)	(5.58e-05)	(5.44e-05)
8th month	7.07e-05*	5.15e-05	3.22e-05	4.51e-05	4.47e-05
	(3.76e-05)	(5.25e-05)	(5.48e-05)	(5.68e-05)	(5.57e-05)
7th month	1.77e-05	0.000109**	7.87e-05	0.000105*	0.000105*
	(3.31e-05)	(5.43e-05)	(6.02e-05)	(6.03e-05)	(5.88e-05)
6th month	-1.07e-05	-2.41e-05	-2.36e-05	-4.06e-05	-4.14e-05
	(2.78e-05)	(4.75e-05)	(4.44e-05)	(4.69e-05)	(4.70e-05)
5th month	9.07e-05***	9.39e-05*	0.000102**	9.28e-05*	9.33e-05*
	(2.94e-05)	(5.16e-05)	(4.84e-05)	(5.42e-05)	(5.39e-05)
4th month	-8.65e-05***	-5.88e-05	-6.18e-05	-5.86e-05	-6.56e-05
	(2.81e-05)	(4.64e-05)	(4.23e-05)	(4.91e-05)	(4.85e-05)
3rd month	-6.68e-05**	-5.26e-05	-7.53e-05**	-6.27e-05	-6.14e-05
	(3.09e-05)	(4.04e-05)	(3.69e-05)	(4.04e-05)	(4.03e-05)
2nd month	3.42e-05	-8.28e-06	-5.92e-06	-1.40e-05	-2.09e-05
	(2.83e-05)	(4.67e-05)	(4.65e-05)	(5.08e-05)	(5.04e-05)
1st month	4.62e-05	0.000170**	0.000142*	0.000157**	0.000157**
	(3.42e-05)	(6.92e-05)	(7.70e-05)	(7.57e-05)	(7.39e-05)
Observations	533,837	533,837	585,087	534,439	534,439
Trimester pollution: SO2					
9th month	0.000190	0.00132	-0.000466	-0.00102	-0.00123
	(0.000361)	(0.00106)	(0.00183)	(0.00222)	(0.00238)
8th month	-0.000106	0.00171	0.00440	0.00496*	0.00541*
	(0.000318)	(0.00136)	(0.00281)	(0.00262)	(0.00280)
7th month	3.50e-05	5.67e-05	0.00417	0.00487	0.00524
	(0.000280)	(0.00177)	(0.00329)	(0.00360)	(0.00372)
6th month	0.000330	-0.00167	0.000926	0.000461	0.000589
	(0.000330)	(0.00126)	(0.00198)	(0.00233)	(0.00247)
5th month	0.000296	0.00172	0.000531	-6.73e-05	-0.000276
	(0.000341)	(0.00137)	(0.00158)	(0.00200)	(0.00205)
4th month	-0.000267	-0.000365	-0.00220	-0.00305	-0.00331
	(0.000391)	(0.00123)	(0.00158)	(0.00205)	(0.00212)
3rd month	-0.000632**	0.000531	0.000748	0.00102	0.00121
	(0.000264)	(0.00135)	(0.00196)	(0.00220)	(0.00234)
2nd month	0.000344	0.000550	0.00399	0.00390	0.00415
	(0.000315)	(0.00166)	(0.00296)	(0.00282)	(0.00303)
1st month	5.33e-05	0.000234	0.00474	0.00530	0.00571
	(0.000259)	(0.00186)	(0.00363)	(0.00387)	(0.00397)
Observations	532,359	532,359	583,609	532,961	532,961

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Table 3.3－Continued					
Trimester pollution: NO2					
9th month	-0.000196*	0.000586	0.000299	0.000236	0.000262
	(0.000107)	(0.000535)	(0.000554)	(0.000613)	(0.000603)
8th month	0.000336***	0.000749*	0.000913*	0.00117**	0.00118**
	(0.000108)	(0.000439)	(0.000521)	(0.000527)	(0.000527)
7th month	-0.000217*	-0.000297	-0.000304	-0.000374	-0.000368
	(0.000118)	(0.000554)	(0.000478)	(0.000526)	(0.000536)
6th month	0.000494***	0.000402	3.08e-05	-3.47e-05	-4.76e-05
	(0.000136)	(0.000540)	(0.000559)	(0.000565)	(0.000577)
5th month	-4.48e-05	0.000812	0.00136**	0.00113	0.00122*
	(0.000130)	(0.000690)	(0.000603)	(0.000708)	(0.000705)
4th month	-0.000352**	-0.000153	-0.000885	-0.000384	-0.000456
	(0.000147)	(0.000680)	(0.000572)	(0.000762)	(0.000730)
3rd month	-9.91e-05	-0.000228	0.000113	-0.000530	-0.000425
	(0.000174)	(0.000662)	(0.000552)	(0.000921)	(0.000879)
2nd month	0.000157	0.000269	0.000312	0.000875	0.000720
	(0.000123)	(0.000781)	(0.000597)	(0.000939)	(0.000923)
1st month	0.000251**	0.00127*	0.00103	0.000810	0.000947
	(0.000120)	(0.000665)	(0.000669)	(0.000768)	(0.000766)
Observations	533,679	533,679	584,929	534,281	534,281
Household income	✓	✓	×	✓	✓
Population density	✓	✓	×	✓	✓
Mother's health during pregnancy	✓	✓	×	×	✓

Notes: (1) We define "Prematurity" as gestation less than 37 weeks. (2) Column 1 presents the results of the OLS model. (3) Column 2 presents the results of the IV model using temperature (Temp), humidity (relative humidity, RH), and rainfall (Rain) as IVs. (4) Columns 3 to 5 present the results of the IV model using only temperature and humidity as IVs. (5) In all the estimations, we control infant's gender, birth order, birth weight, maternal age, and township and birth year fixed effects. (6) Robust standard errors with regional clustering are in brackets. (7) *** significant at 1 percent level. ** significant at 5 percent level. * significant at 10 percent level.

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Table 3.4

Effects of Air Pollution on Low Weight

Outcome: **Low weight (below 2500g)**	(1) OLS	(2) IV(Temp RH Rain)	(3) IV(Temp RH)	(4) IV(Temp RH)	(5) IV(Temp RH)
Trimester pollution: PM10					
9th month	-4.08e-05	1.25e-05	3.35e-05	4.38e-05	4.10e-05
	(2.79e-05)	(5.22e-05)	(4.56e-05)	(5.20e-05)	(5.20e-05)
8th month	-2.72e-05	3.40e-05	3.18e-05	6.07e-05	6.04e-05
	(2.62e-05)	(5.99e-05)	(5.47e-05)	(6.34e-05)	(6.32e-05)
7th month	-4.37e-06	8.23e-07	1.35e-05	1.46e-05	1.58e-05
	(2.71e-05)	(5.25e-05)	(4.75e-05)	(5.62e-05)	(5.58e-05)
6th month	9.94e-06	-2.40e-05	2.22e-05	-2.70e-06	-3.35e-06
	(2.92e-05)	(4.05e-05)	(3.84e-05)	(4.35e-05)	(4.37e-05)
5th month	-1.39e-06	9.59e-06	-3.79e-06	2.04e-05	2.09e-05
	(3.12e-05)	(5.01e-05)	(3.79e-05)	(4.87e-05)	(4.90e-05)
4th month	1.37e-06	5.13e-05	3.08e-05	5.50e-05	4.93e-05
	(2.56e-05)	(5.34e-05)	(4.97e-05)	(5.41e-05)	(5.43e-05)
3rd month	-4.18e-06	6.52e-05	9.52e-05**	8.08e-05	8.16e-05*
	(2.40e-05)	(5.11e-05)	(4.46e-05)	(5.01e-05)	(4.96e-05)
2nd month	4.68e-05	6.74e-05	0.000106**	0.000113**	0.000107**
	(3.45e-05)	(4.75e-05)	(4.75e-05)	(4.74e-05)	(4.82e-05)
1st month	-2.40e-05	-3.74e-06	8.79e-06	1.96e-05	1.97e-05
	(2.93e-05)	(7.49e-05)	(7.42e-05)	(8.38e-05)	(8.32e-05)
Observations	533,837	533,837	585,087	534,439	534,439
Trimester pollution: SO2					
9th month	-0.000573**	0.00103	0.00102	0.00254	0.00239
	(0.000240)	(0.00155)	(0.00162)	(0.00206)	(0.00201)
8th month	0.000178	-0.000227	-0.00167	-0.00178	-0.00142
	(0.000267)	(0.00159)	(0.00243)	(0.00230)	(0.00223)
7th month	3.45e-05	0.000127	-0.00130	-0.00220	-0.00190
	(0.000292)	(0.00135)	(0.00301)	(0.00337)	(0.00331)
6th month	0.000642*	0.000168	3.55e-05	-0.00114	-0.00105
	(0.000326)	(0.00121)	(0.00178)	(0.00214)	(0.00208)
5th month	-0.000639**	0.00112	0.000892	0.00224	0.00208
	(0.000271)	(0.00125)	(0.00125)	(0.00170)	(0.00167)
4th month	8.78e-05	0.000196	0.000645	0.00158	0.00138
	(0.000269)	(0.00180)	(0.00182)	(0.00240)	(0.00238)
3rd month	0.000311	0.00233	0.00183	0.00230	0.00245
	(0.000282)	(0.00165)	(0.00162)	(0.00173)	(0.00171)
2nd month	0.000211	-0.000232	-0.000939	-0.00178	-0.00159
	(0.000325)	(0.00154)	(0.00244)	(0.00252)	(0.00245)
1st month	-2.44e-05	0.00104	-0.00116	-0.00164	-0.00131
	(0.000304)	(0.00156)	(0.00329)	(0.00338)	(0.00334)
Observations	532,359	532,359	583,609	532,961	532,961

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Table 3.4－Continued					
Trimester pollution: NO2					
9th month	-0.000211**	0.000377	0.000293	5.90e-05	8.03e-05
	(0.000104)	(0.000583)	(0.000592)	(0.000643)	(0.000653)
8th month	-3.67e-05	0.000272	0.000187	0.000499	0.000511
	(0.000138)	(0.000446)	(0.000408)	(0.000447)	(0.000446)
7th month	0.000116	-0.000287	-0.000342	-0.000387	-0.000380
	(0.000166)	(0.000461)	(0.000427)	(0.000496)	(0.000498)
6th month	4.27e-05	0.000746	0.000985*	0.000981	0.000970
	(0.000157)	(0.000588)	(0.000561)	(0.000644)	(0.000641)
5th month	-4.19e-05	-0.00147*	-0.00136**	-0.00193**	-0.00186**
	(0.000162)	(0.000766)	(0.000545)	(0.000838)	(0.000843)
4th month	-8.50e-05	0.00137**	0.000458	0.00126	0.00120
	(0.000147)	(0.000642)	(0.000614)	(0.000770)	(0.000754)
3rd month	0.000188	-0.000279	0.000609	-0.000612	-0.000533
	(0.000115)	(0.000732)	(0.000743)	(0.000973)	(0.000953)
2nd month	4.11e-05	0.00136*	0.00106	0.00247**	0.00235**
	(0.000157)	(0.000780)	(0.000763)	(0.00107)	(0.00105)
1st month	-4.28e-05	-0.000821	-0.000897	-0.00174	-0.00163
	(0.000130)	(0.000663)	(0.000942)	(0.00106)	(0.00106)
Observations	533,679	533,679	584,929	534,281	534,281
Household income	✓	✓	×	✓	✓
Population density	✓	✓	×	✓	✓
Mother's health during pregnancy	✓	✓	×	×	✓

Notes: (1) We define “Low weight” as birth weight less than 2,500 grams. (2) Column 1 presents the results of the OLS model. (3) Column 2 presents the results of the IV model using temperature (Temp), humidity (relative humidity, RH), and rainfall (Rain) as IVs. (4) Columns 3 to 5 present the results of the IV model using only temperature and humidity as IVs. (5) In all the estimations, we control infant's gender, birth order, gestation, maternal age, and township and birth year fixed effects. (6) Robust standard errors with regional clustering are in brackets. (7) *** significant at 1 percent level. ** significant at 5 percent level. * significant at 10 percent level.

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Table 3.5

Effects of Air Pollution on Low Weight (37 – 44 weeks)

Outcome: **Low weight (37-44 weeks)**	(1) OLS	(2) IV(Temp RH Rain)	(3) IV(Temp RH)	(4) IV(Temp RH)	(5) IV(Temp RH)
Trimester pollution: PM10					
9th month	-7.58e-06	3.82e-07	5.99e-06	7.66e-08	-8.11e-07
	(2.17e-05)	(3.97e-05)	(3.41e-05)	(3.96e-05)	(3.96e-05)
8th month	-2.88e-05	1.60e-05	2.69e-05	3.18e-05	3.17e-05
	(2.19e-05)	(3.69e-05)	(3.34e-05)	(3.74e-05)	(3.75e-05)
7th month	9.57e-06	-6.60e-06	-2.83e-06	-1.14e-05	-1.14e-05
	(2.56e-05)	(4.27e-05)	(3.87e-05)	(4.39e-05)	(4.38e-05)
6th month	3.78e-06	-1.93e-05	7.23e-06	-7.34e-06	-7.47e-06
	(2.50e-05)	(3.44e-05)	(3.38e-05)	(3.42e-05)	(3.42e-05)
5th month	-2.14e-06	2.69e-05	-7.51e-06	1.96e-05	1.95e-05
	(2.66e-05)	(3.74e-05)	(2.83e-05)	(3.71e-05)	(3.72e-05)
4th month	-4.77e-06	8.69e-06	5.70e-06	8.52e-06	7.05e-06
	(2.43e-05)	(3.60e-05)	(3.42e-05)	(3.74e-05)	(3.75e-05)
3rd month	1.96e-05	4.02e-05	5.41e-05*	4.38e-05	4.39e-05
	(2.33e-05)	(3.97e-05)	(3.19e-05)	(3.78e-05)	(3.77e-05)
2nd month	1.23e-05	-1.98e-06	3.04e-05	1.60e-05	1.44e-05
	(2.53e-05)	(3.24e-05)	(3.43e-05)	(3.39e-05)	(3.41e-05)
1st month	1.57e-05	4.39e-05	2.48e-05	3.64e-05	3.60e-05
	(1.75e-05)	(5.86e-05)	(5.57e-05)	(6.09e-05)	(6.09e-05)
Observations	533,837	533,837	585,087	534,439	534,439
Trimester pollution: SO2					
9th month	-0.000447*	0.00114	0.00137	0.00198	0.00194
	(0.000259)	(0.00106)	(0.00114)	(0.00131)	(0.00131)
8th month	0.000247	-5.85e-05	0.000416	-0.000185	-8.73e-05
	(0.000280)	(0.00116)	(0.00194)	(0.00191)	(0.00188)
7th month	-0.000277	-0.000770	-0.000897	-0.00195	-0.00187
	(0.000227)	(0.00112)	(0.00214)	(0.00242)	(0.00240)
6th month	-9.96e-05	-0.000179	-0.000168	-0.000843	-0.000817
	(0.000270)	(0.000839)	(0.00130)	(0.00142)	(0.00140)
5th month	-0.000128	0.00107	8.89e-05	0.00127	0.00122
	(0.000227)	(0.000950)	(0.00103)	(0.00142)	(0.00141)
4th month	8.60e-05	8.42e-05	0.000504	0.000844	0.000794
	(0.000272)	(0.00117)	(0.00118)	(0.00151)	(0.00151)
3rd month	0.000417*	0.00191	0.00240*	0.00240*	0.00244*
	(0.000219)	(0.00121)	(0.00125)	(0.00137)	(0.00136)
2nd month	-0.000149	-0.000886	-0.000281	-0.00150	-0.00145
	(0.000273)	(0.00114)	(0.00196)	(0.00205)	(0.00203)
1st month	-6.33e-06	0.000841	8.83e-05	-0.000456	-0.000375
	(0.000204)	(0.00131)	(0.00248)	(0.00254)	(0.00252)
Observations	532,359	532,359	583,609	532,961	532,961

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Table 3.5－Continued					
Trimester pollution: NO2					
9th month	-0.000116	5.83e-05	0.000552	0.000298	0.000305
	(0.000102)	(0.000406)	(0.000415)	(0.000459)	(0.000460)
8th month	-0.000103	0.000176	9.57e-05	0.000146	0.000147
	(0.000124)	(0.000312)	(0.000318)	(0.000341)	(0.000340)
7th month	9.48e-05	-4.22e-05	-5.07e-05	-0.000143	-0.000141
	(0.000109)	(0.000324)	(0.000290)	(0.000314)	(0.000316)
6th month	-0.000169	0.000593	0.000856*	0.000944*	0.000938*
	(0.000132)	(0.000495)	(0.000466)	(0.000492)	(0.000489)
5th month	4.43e-05	-0.000785	-0.000762*	-0.000930	-0.000911
	(0.000145)	(0.000587)	(0.000402)	(0.000612)	(0.000616)
4th month	-2.71e-05	0.000740	0.000263	0.000555	0.000540
	(0.000137)	(0.000481)	(0.000493)	(0.000587)	(0.000587)
3rd month	0.000137	-0.000426	0.000632	-7.08e-05	-4.75e-05
	(0.000115)	(0.000542)	(0.000522)	(0.000683)	(0.000682)
2nd month	-8.23e-05	0.000779	0.000381	0.000868	0.000832
	(0.000134)	(0.000594)	(0.000559)	(0.000755)	(0.000753)
1st month	-5.28e-05	-1.40e-05	0.000220	-5.34e-05	-2.43e-05
	(9.53e-05)	(0.000568)	(0.000681)	(0.000790)	(0.000791)
Observations	533,679	533,679	584,929	534,281	534,281
Household income	✓	✓	×	✓	✓
Population density	✓	✓	×	✓	✓
Mother's health during pregnancy	✓	✓	×	×	✓

Notes: (1) We define "Low weight (37-44 weeks)" as birth weight less than 2,500 grams and born between 37 and 44 weeks' gestation. (2) Column 1 presents the results of the OLS model. (3) Column 2 presents the results of the IV model using temperature (Temp), humidity (relative humidity, RH), and rainfall (Rain) as IVs. (4) Columns 3 to 5 present the results of the IV model using only temperature and humidity as IVs. (5) In all the estimations, we control infant's gender, birth order, maternal age, and township and birth year fixed effects. (6) Robust standard errors with regional clustering are in brackets. (7) *** significant at 1 percent level. ** significant at 5 percent level. * significant at 10 percent level.

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Table 3.6

Effects of Air Pollution on Apgar Score at 1 Minute After Birth

Outcome: **Apgar_1_good**	(1) OLS	(2) IV(Temp RH Rain)	(3) IV(Temp RH)	(4) IV(Temp RH)	(5) IV(Temp RH)
Trimester pollution: PM10					
9th month	8.65e-06	4.80e-06	2.24e-05	-1.70e-06	-4.47e-07
	(1.57e-05)	(3.46e-05)	(3.80e-05)	(3.81e-05)	(3.83e-05)
8th month	-1.64e-05	3.69e-05	3.59e-05	2.77e-05	2.78e-05
	(1.61e-05)	(3.10e-05)	(3.14e-05)	(3.19e-05)	(3.20e-05)
7th month	-2.22e-05	-2.97e-07	5.39e-06	1.44e-06	8.53e-07
	(1.71e-05)	(2.33e-05)	(2.25e-05)	(2.44e-05)	(2.43e-05)
6th month	1.05e-05	-6.68e-07	-4.38e-06	1.86e-06	2.43e-06
	(1.76e-05)	(2.37e-05)	(2.68e-05)	(2.63e-05)	(2.56e-05)
5th month	-1.03e-05	-3.03e-05	-1.40e-05	-3.37e-05	-3.42e-05
	(1.79e-05)	(3.09e-05)	(2.92e-05)	(3.14e-05)	(3.14e-05)
4th month	-2.36e-05	6.98e-06	7.37e-06	2.60e-06	5.11e-06
	(1.77e-05)	(2.65e-05)	(2.61e-05)	(2.81e-05)	(2.80e-05)
3rd month	1.18e-05	-1.33e-05	-2.23e-05	-1.73e-05	-1.78e-05
	(1.90e-05)	(2.70e-05)	(2.58e-05)	(2.72e-05)	(2.72e-05)
2nd month	-8.46e-06	2.36e-05	3.35e-05	1.13e-05	1.36e-05
	(1.88e-05)	(3.67e-05)	(3.64e-05)	(3.79e-05)	(3.77e-05)
1st month	2.30e-05	4.37e-05	4.66e-05	4.45e-05	4.46e-05
	(1.76e-05)	(4.46e-05)	(4.79e-05)	(5.04e-05)	(5.10e-05)
Observations	530,944	530,944	582,055	531,542	531,542
Trimester pollution: SO2					
9th month	0.000271	0.00135	0.00102	0.000127	0.000196
	(0.000243)	(0.000924)	(0.00122)	(0.00161)	(0.00155)
8th month	-9.95e-05	0.000427	0.00139	0.00198	0.00183
	(0.000251)	(0.000992)	(0.00157)	(0.00152)	(0.00149)
7th month	-0.000301	-0.00135	-7.11e-05	0.000875	0.000739
	(0.000205)	(0.00105)	(0.00146)	(0.00171)	(0.00168)
6th month	-0.000180	-0.000866	-0.000261	0.000528	0.000490
	(0.000192)	(0.000823)	(0.00108)	(0.00141)	(0.00138)
5th month	-1.70e-05	-9.54e-05	-0.000324	-0.00112	-0.00107
	(0.000210)	(0.000834)	(0.000834)	(0.00108)	(0.00106)
4th month	-0.000278*	0.00103	0.000408	-0.000180	-8.18e-05
	(0.000163)	(0.000753)	(0.000782)	(0.00109)	(0.00106)
3rd month	0.000363*	0.000268	0.000334	0.000405	0.000332
	(0.000184)	(0.00105)	(0.00142)	(0.00150)	(0.00147)
2nd month	-0.000317*	0.000437	0.00171	0.00208	0.00200
	(0.000168)	(0.00113)	(0.00150)	(0.00152)	(0.00149)
1st month	-4.11e-06	-0.000646	0.000620	0.00175	0.00160
	(0.000170)	(0.00118)	(0.00169)	(0.00209)	(0.00207)
Observations	529,489	529,489	580,600	530,087	530,087

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Table 3.6－Continued					
Trimester pollution: NO2					
9th month	0.000141	0.000167	0.000474	0.000341	0.000335
	(8.77e-05)	(0.000345)	(0.000472)	(0.000487)	(0.000488)
8th month	-5.76e-05	0.000186	0.000377	0.000234	0.000226
	(0.000107)	(0.000229)	(0.000266)	(0.000272)	(0.000270)
7th month	-8.83e-05	8.83e-06	-0.000110	-7.22e-05	-7.39e-05
	(8.15e-05)	(0.000306)	(0.000289)	(0.000321)	(0.000322)
6th month	4.87e-05	0.000441	0.000233	0.000509	0.000516
	(8.29e-05)	(0.000300)	(0.000365)	(0.000343)	(0.000341)
5th month	3.59e-05	-0.000360	0.000110	-8.16e-05	-0.000111
	(8.10e-05)	(0.000373)	(0.000321)	(0.000395)	(0.000393)
4th month	-0.000103	0.000239	-7.28e-05	-9.23e-05	-6.73e-05
	(7.16e-05)	(0.000348)	(0.000336)	(0.000386)	(0.000389)
3rd month	6.50e-05	-0.000570	-0.000116	-0.000124	-0.000158
	(8.48e-05)	(0.000499)	(0.000553)	(0.000654)	(0.000655)
2nd month	-2.53e-05	0.000976*	0.000902**	0.000661	0.000709
	(9.03e-05)	(0.000504)	(0.000456)	(0.000550)	(0.000551)
1st month	0.000135	9.90e-05	0.000168	0.000396	0.000354
	(8.14e-05)	(0.000489)	(0.000538)	(0.000544)	(0.000555)
Observations	530,794	530,794	581,905	531,392	531,392
Household income	✓	✓	×	✓	✓
Population density	✓	✓	×	✓	✓
Mother's health during pregnancy	✓	✓	×	×	✓

Notes: (1) We define "Apgar_1_good" as the Apgar score of 7 -- 10 at 1 minute after birth (i.e., the newborn is in good health). (2) Column 1 presents the results of the OLS model. (3) Column 2 presents the results of the IV model using temperature (Temp), humidity (relative humidity, RH), and rainfall (Rain) as IVs. (4) Columns 3 to 5 present the results of the IV model using only temperature and humidity as IVs. (5) In all the estimations, we control infant's gender, birth order, birth weight, gestation, maternal age, and township and birth year fixed effects. (6) Robust standard errors with regional clustering are in brackets. (7) *** significant at 1 percent level. ** significant at 5 percent level. * significant at 10 percent level.

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Table 3.7

Effects of Air Pollution on Apgar Score at 5 Minutes After Birth

Outcome: **Apgar_5_good**	(1) OLS	(2) IV(Temp RH Rain)	(3) IV(Temp RH)	(4) IV(Temp RH)	(5) IV(Temp RH)
Trimester pollution: PM10					
9th month	-6.08e-06	3.45e-06	-4.51e-06	-9.11e-06	-9.18e-06
	(9.60e-06)	(1.80e-05)	(1.84e-05)	(1.88e-05)	(1.88e-05)
8th month	4.25e-06	4.65e-06	5.10e-06	-3.46e-06	-3.46e-06
	(1.25e-05)	(2.61e-05)	(2.59e-05)	(2.71e-05)	(2.70e-05)
7th month	-6.23e-06	-3.91e-06	-1.62e-05	-1.14e-05	-1.14e-05
	(1.05e-05)	(1.75e-05)	(1.87e-05)	(1.83e-05)	(1.83e-05)
6th month	1.98e-05**	1.17e-05	7.08e-06	7.58e-06	7.55e-06
	(8.51e-06)	(1.55e-05)	(1.40e-05)	(1.67e-05)	(1.67e-05)
5th month	-2.90e-05***	-2.34e-05	-1.69e-05	-2.75e-05	-2.75e-05
	(1.05e-05)	(1.65e-05)	(1.47e-05)	(1.69e-05)	(1.69e-05)
4th month	-3.24e-08	1.90e-05	2.15e-05	1.35e-05	1.33e-05
	(1.25e-05)	(2.11e-05)	(2.11e-05)	(2.19e-05)	(2.20e-05)
3rd month	-9.23e-06	-3.70e-05*	-5.36e-05***	-4.32e-05**	-4.32e-05**
	(1.00e-05)	(1.98e-05)	(1.99e-05)	(2.13e-05)	(2.13e-05)
2nd month	5.06e-06	1.69e-05	1.05e-05	6.95e-06	6.82e-06
	(1.02e-05)	(2.14e-05)	(1.96e-05)	(2.10e-05)	(2.10e-05)
1st month	1.08e-05	1.72e-05	1.53e-05	4.77e-06	4.77e-06
	(1.16e-05)	(2.35e-05)	(2.53e-05)	(2.67e-05)	(2.67e-05)
Observations	530,958	530,958	582,070	531,556	531,556
Trimester pollution: SO2					
9th month	0.000152*	0.000788	0.000323	0.000125	0.000122
	(8.84e-05)	(0.000592)	(0.000651)	(0.000756)	(0.000759)
8th month	3.26e-05	-5.64e-05	0.00112	0.00102	0.00103
	(0.000148)	(0.000542)	(0.00101)	(0.00103)	(0.00103)
7th month	-0.000185	-0.000884	0.000280	0.000541	0.000548
	(0.000115)	(0.000647)	(0.000911)	(0.00106)	(0.00106)
6th month	-1.64e-05	-0.000224	0.000480	0.000458	0.000460
	(8.77e-05)	(0.000490)	(0.000534)	(0.000707)	(0.000709)
5th month	-0.000112	-0.000296	-0.000657	-0.000961	-0.000965
	(8.94e-05)	(0.000425)	(0.000563)	(0.000717)	(0.000717)
4th month	6.74e-05	0.00107*	0.000659	0.000343	0.000338
	(0.000113)	(0.000615)	(0.000565)	(0.000729)	(0.000730)
3rd month	-2.29e-05	-0.000781	-0.000620	-0.000417	-0.000414
	(0.000126)	(0.000627)	(0.000782)	(0.000780)	(0.000781)
2nd month	1.31e-05	0.000710	0.00182*	0.00171	0.00171
	(0.000110)	(0.000520)	(0.000977)	(0.00104)	(0.00104)
1st month	-3.22e-05	-0.000801	0.000757	0.000737	0.000745
	(8.81e-05)	(0.000677)	(0.000884)	(0.00101)	(0.00101)
Observations	529,503	529,503	580,615	530,101	530,101

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Table 3.7－Continued					
Trimester pollution: NO2					
9th month	-1.49e-05	0.000102	0.000315	0.000268	0.000269
	(4.52e-05)	(0.000239)	(0.000272)	(0.000271)	(0.000272)
8th month	3.80e-05	-2.56e-05	6.80e-06	-9.28e-05	-9.23e-05
	(5.88e-05)	(0.000153)	(0.000174)	(0.000189)	(0.000189)
7th month	7.15e-06	1.50e-05	-2.25e-05	3.80e-05	3.81e-05
	(5.87e-05)	(0.000182)	(0.000177)	(0.000173)	(0.000173)
6th month	8.52e-05*	0.000249	0.000252	0.000325	0.000325
	(4.84e-05)	(0.000188)	(0.000222)	(0.000228)	(0.000228)
5th month	-0.000172***	-0.000211	-1.16e-05	-3.09e-05	-2.93e-05
	(4.39e-05)	(0.000244)	(0.000177)	(0.000217)	(0.000218)
4th month	2.43e-05	0.000257	0.000285	0.000133	0.000132
	(4.90e-05)	(0.000261)	(0.000260)	(0.000256)	(0.000257)
3rd month	-6.81e-06	-0.000698**	-0.000606*	-0.000481	-0.000479
	(5.05e-05)	(0.000335)	(0.000333)	(0.000373)	(0.000374)
2nd month	6.72e-05	0.000826**	0.000674*	0.000539	0.000537
	(4.60e-05)	(0.000403)	(0.000346)	(0.000406)	(0.000407)
1st month	2.62e-05	-0.000130	0.000174	0.000237	0.000239
	(3.81e-05)	(0.000300)	(0.000297)	(0.000316)	(0.000316)
Observations	530,807	530,807	581,919	531,405	531,405
Household income	✓	✓	×	✓	✓
Population density	✓	✓	×	✓	✓
Mother's health during pregnancy	✓	✓	×	×	✓

Notes: (1) We define “Apgar_5_good” as the Apgar score of 7 -- 10 at 5 minutes after birth (i.e., the newborn is in good health). (2) Column 1 presents the results of the OLS model. (3) Column 2 presents the results of the IV model using temperature (Temp), humidity (relative humidity, RH), and rainfall (Rain) as IVs. (4) Columns 3 to 5 present the results of the IV model using only temperature and humidity as IVs. (5) In all the estimations, we control infant's gender, birth order, birth weight, gestation, maternal age, and township and birth year fixed effects. (6) Robust standard errors with regional clustering are in brackets. (7) *** significant at 1 percent level. ** significant at 5 percent level. * significant at 10 percent level.

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