White Death in Developing Countries: Evidence from a Tuberculosis Control Program in China

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Abstract

Despite decades of efforts, while tuberculosis (TB) is no longer prevalent in developed countries, it continues to pose a major public health concern in developing countries. This study evaluates the impacts of a TB control program in China. TB remained a public health threat in China in early 1990s, the Chinese Government introduced a comprehensive control program that incorporated the Directly Observed Treatment Short-Course across 13 provinces during 1992 and 2001. Our study demonstrates the program reduces TB infection rates. Results regarding sickness, child care provision, and employment exhibit a diverse contemporaneous pattern across different age groups and urban-rural heterogeneity. The effect of the program spillover to the subsequent generation by increasing high school completion rate. The cost-benefit analysis demonstrates the cost-effectiveness of the program. In conclusion, our findings illustrate the effectiveness of TB control efforts and offer valuable insights for other developing countries.

JEL Codes: H51, I12, I18
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1. Introduction

Tuberculosis (TB) had been the leading infectious killer for decades until the outbreak of COVID-19.[1] While economists have extensively studied infectious diseases such as malaria (Cutler et al., 2010; Kuecken et al., 2021; Tarozzi et al., 2014) and influenza (E.g., Almond, 2006; Heckman et al., 2013; Lin & Liu, 2014), surprisingly little attention has been given to TB—a fatal infectious disease with global prevalence that incurs significant economic consequences (Bloom et al., 2022). In fact, in 2019 alone, the estimated economic impact of TB ranged from 1,115 to 3,346 billion International Dollars, surpassing those attributed to either malaria or human immunodeficiency virus (HIV) (Bloom et al., 2022). Despite its historical prevalence in both developed and developing countries, TB is currently primarily concentrated in developing countries (WHO, 2023a). The distribution of individuals living on less than $2 mirrors the epidemiology of TB (Alsan et al., 2011), making it a substantial health threat to impoverished populations (Bütikofer & Salvanes, 2020). The negative health shocks caused by an epidemic can have a significantly detrimental impact on economic growth in developing countries, particularly low-income countries, either perpetuating stagnation or pushing the economy into a poverty trap (Bloom et al., 2022). Therefore, reducing the prevalence of TB in developing countries holds great importance. This study aims to investigate the benefits associated with reducing TB prevalence in a developing country - China.

In this paper, we examine the impact of a TB control program on the prevalence of TB and its contemporaneous as well as intergenerational effects in China. In the early 1990s, TB remained a significant public health concern with an infection rate reaching 611 per 100,000 population (Ministry of Public Health of the People's Republic of China, 1992).[2] Moreover, there were notable regional variations among provinces as depicted in Figure 1. From 1992 to 2001, in order to combat the TB epidemic, the Chinese government implemented a comprehensive TB control program ("TB program" hereafter) in 13 out of 31 provinces/autonomous regions/municipalities ("provinces" hereafter), utilizing funds from both the World Bank and the Chinese government.[3] The TB program mainly encompassed testing and provision of therapy, which was subsequently

[1] https://www.who.int/news-room/fact-sheets/detail/TB
[2] The 611 per 100,000 population is determined based on individuals who exhibit suspicious radiographs for TB.
[3] The fund from the World Bank and the Chinese government is 58.20 million dollars (0.305 billion RMB in 1991) and 70.78 million dollars (0.371 billion RMB in 1991), respectively.

recommended globally by the World Health Organization (WHO) as Directly Observed Treatment Short-Course (DOTS) in 1994 (WHO, 1994). Within provinces where DOTS was implemented under the TB program ("DOTS provinces" hereafter), as the coverage rate gradually reaches almost full coverage (refer to Figure 2), there was a notable reduction in TB prevalence compared to non-DOTS provinces over time (refer to Figure 3). Despite observing declining trends in both DOTS and non-DOTS provinces during the 1990s, DOTS provinces exhibited a greater decrease in their infection rates. By employing a Difference-in-Difference (DID) identification strategy that compares infection rates between DOTS and non-DOTS provinces in both 1990 and 2000, our findings indicate that the TB program significantly reduced TB infection rates by 38.34%.

In China, the incidence of TB increases with age, with children exhibiting a relatively lower infection rate compared to adults, and rural areas demonstrating a higher infection rate than urban areas (refer to Figure 4). Consequently, the implementation of the TB program would primarily impact individuals in rural areas. Therefore, we limit our sample for analysis exclusively to individuals from rural areas. Additionally, existing medical literature has extensively documented that prenatal exposure to TB leads to adverse birth outcomes (Jana et al., 1999; Salazar-Austin et al., 2018; Sugarman et al., 2014), which subsequently have negative implications on later-life outcomes (Behrman & Rosenzweig, 2004; Bharadwaj et al., 2018; Black et al., 2007; Figlio et al., 2014). Henceforth, we aim to examine both the contemporaneous and intergenerational effects of the TB program specifically on individuals from rural areas.

Leveraging the provincial variation between DOTS and non-DOTS provinces, as well as temporal variation across survey years, we employ a DID identification strategy to examine the contemporaneous effects of the TB program by utilizing the panel nature of the China Health Nutrition Studies (CHNS), which is a longitudinal data that spans from 1989 to 2015. We restrict our CHNS sample to individuals who were aged between 6 to 65 from the period of 1989 and 2000. For child-bearing age (aged 18-40) adults, we find the TB program reduces the incidence of sickness (*2.85 percentage points or 55.81%*). Due to the contagious nature of the TB, the TB program's treatment, which requires isolation from the public and staying away from healthy people, typically lasts for 6 to 16 months depending on drug resistance and failure (see section 2 for detail). Consequently, infected individuals are unable to engage in work activities or provide child care. We find the TB program reduces the probability of being currently employed (*4.90 percentage points or 5.32%*) and providing child care (*3.31 percentage points or 11.57%*). For older age (aged 41-65) adults, similar to the child-bearing age adults, we find the TB program reduces the probability of being currently employed (*8.86 percentage points or 10.41%*) and providing child care (*3.61 percentage points or 18.80%*). Due to the age-related deterioration of the immune system and bodily functions, older age adults infected with TB experience greater harm and face increased challenges in recovering from the infection (Gardner Toren et al., 2019; Hochberg & Horsburgh, 2013; Rajagopalan, 2001). Consequently, we do not observe any significant change in the incidence of sickness among older age adults. Additionally, we examine the impact of the TB program on school-age (aged 6-17) children and find null effects. The absence of findings regarding school-age children not only aligns with their low infection rates but also serves as a falsification check for our identification strategy.

The contemporaneous effects of the TB program on individuals from urban areas across all age groups were also examined, yielding null findings. These null findings not only align with the lower TB infection rates in urban areas compared to rural areas but also serve as a falsification check for our identification strategy.

Utilizing the birth provincial variation between DOTS and non-DOTS provinces, as well as the temporal variation among birth cohorts, we employ a cohort DID identification strategy to investigate the intergenerational effects of the TB program on adulthood outcomes using data from the 2015 wave of the CHNS. Specifically, our analysis focuses on individuals born between 1985 and 2000. Our findings indicate an increased likelihood of completing at least high school education. Additionally, we construct a sample from the 2015 1% Census to examine the intergenerational effects of the TB program, yielding qualitatively similar results to those obtained from utilizing the 2015 wave of the CHNS.

We also conduct a back-of-the-envelope cost-benefit analysis of the TB program. By considering the total funding allocated to the TB program and incorporating the potential income loss experienced by TB patients during their treatment, we calculate a per capita cost estimate of 1157.55 RMB (or 185.85 USD). Additionally, when factoring in the potential savings from reduced sickness likelihood and the increased income resulting from completing high school education or above, we arrive at a per capita benefit estimate of 9164.21 RMB (or 1471.36 USD). The benefits clearly outweigh the costs associated with implementing the TB program, thus indicating its positive outcome in terms of cost-benefit analysis.

This study contributes to several strands of literature: 1. Though there were numerous international programs to improve health, particularly curbing infectious diseases such as malaria, TB, and HIV/AIDS, especially beginning in the 2000s, most studies about the evaluations of the health effects of these international programs are primarily concentrated on demonstrating association (De Jongh et al., 2014). This paper adds to the literature by providing causal evidence of the effects of the TB program; 2. Only a few studies in the literature have examined the effects of reducing TB and uniformly focuses on developed countries (Bütikofer & Salvanes, 2020; Egedesø et al., 2020).[4] Given the systematical difference between developed and developing countries and high association between poverty and TB, reducing the prevalence of TB in developing countries is more likely to exert a positive and possibly greater impact. To the best of our knowledge, this is the first paper to examine the effects of TB prevalence reduction in a developing country; 3. Literature that examines the effects of in-utero and early life exposure to early life shocks primarily focuses on developed countries with a growing number of studies focusing on developing countries (Almond et al., 2018; Almond & Currie, 2011; Currie & Vogl, 2013). Our results of the intergenerational effects of the TB program adds to the literature by providing the evidence of the effects of reduced in-utero TB exposure in a developing country.

The rest of the article is structured as follows. The epidemiology of TB and the TB program are described in Section 2. Sections 3 and 4 describe the data and empirical strategy, respectively. The results are presented in Section 5 with robustness checks being presented in Section 6. In Section 7, we provide a back-of-the-envelope cost-benefit analysis of the TB program. Section 8 concludes.

2. Background

2.1. Tuberculosis

Tuberculosis (TB), which is currently one of the top ten global causes of death and world's second leading cause of death from a single infectious agent in 2022 (WHO, 2023a), has left traces of its impact on human populations for millennia (Hershkovitz et al., 2015). The origins of TB remained

[4] Anderson et al. (2019) and Clay et al. (2020) have examined the effects of public health intervention and found null effects on mortality. Though Bloom et al. (2012) have found that receiving vaccination for measles, polio, TB, Diphtheria, Pertussis, and Tetanus during early life (before age 2) improves cognition in Philippines, their exploration analysis indicates the results are more likely to be driven by the vaccination for measles.

shrouded in mystery until March 24, 1882, when Dr. Robert Koch unveiled his groundbreaking discovery of the causative agent—a bacillus later designated as *Mycobacterium TB* (Sakula, 1982). Transmission occurs when active TB patients aerosolize the bacterium through respiratory activities such as coughing.

TB manifests itself in either latent (asymptomatic and non-infectious) or active (various symptoms and infectious) forms (Jasmer et al., 2002), both of which involve the presence of *Mycobacterium TB* within the body. The latent form of TB, although not infectious, carries a high likelihood of progressing into active TB, which typically manifests symptoms such as persistent coughing, elevated body temperature, nocturnal perspiration, and unintended weight loss (Esmail et al., 2018). While TB primarily targets the lungs (pulmonary TB), it is capable of affecting other bodily regions as well (extrapulmonary TB) (Sharma et al., 2005). Long-term consequences of TB infection encompass permanent lung damage (Hnizdo, 2000), defects to the central nervous system and brain function (Rock et al., 2008), as well as damage to the circulatory system (Little et al., 2016), skin (Barbagallo et al., 2002), lymph nodes (Carter & Mates, 1994), cavity (Chang et al., 1996), heart (Lee et al., 2023), and joints and bones (Newton et al., 1982).

For older age adults infected with TB, comorbidities can complicate the effects of TB and increase the risk of medication reactions, leading to higher mortality rates (Chan-Yeung et al., 2002). These reactions may include drug-induced hepatitis and rash (Campbell et al., 2020; Pande et al., 1996), gastrointestinal intolerance (Teo et al., 2023), and other adverse event that necessitate hospitalization and discontinuation of medication (Lan et al., 2020; Yee et al., 2003).

The infection of TB also has detrimental effects on pregnant women and their offspring. Medical literature has demonstrated that TB infection during pregnancy is associated with adverse outcomes for both the pregnant women and their fetuses. For pregnant women, there is an increased risk of inadequate weight gain during gestation (WHO, 2023b), pre-eclampsia (Walles et al., 2024), preterm labor (El-Messidi et al., 2016), postpartum hemorrhage (Mathad & Gupta, 2012), and mortality (Sugarman et al., 2014). For the fetus, there is an elevated risk of spontaneous miscarriage (Zenner et al., 2012), small for date gestational age (Lin et al., 2010), low birth weight (Jana et al., 1999), and mortality (Sugarman et al., 2014).

Unlike the high infection rate among adults, children seem to be relatively protected against TB and enduring a lower infection rate (Basu Roy et al., 2019), as they can be protected from vaccines,[5] the Bacille Calmette-Guérin (BCG) vaccine, which was developed almost a century ago and remains the sole authorized vaccine for preventing TB in humans (Lange et al., 2022). The protective efficacy of BCG against TB, however, is limited to children and wanes over time (Rodrigues et al., 2011).

Due to the highly infectious nature of TB, patients are required to undergo isolation from the public throughout the entire treatment process, which can last anywhere from 6 to 16 months depending on drug-resistance and failure.[6] The isolation from the public necessitates taking leave or terminating employment. Consequently, there is a potential reduction or complete loss of the household's income source (Meghji et al., 2021; Portnoy et al., 2023; Rajeswari et al., 1999; Tanimura et al., 2014). Moreover, the engagement of women in providing child care is significantly compromised when they contract TB and undergo treatment (Rajeswari et al., 1999).

The necessity of isolation from the public for treatment and its associated consequences often leads to a hesitancy among TB patients in seeking medical assistance, noncompliance with prescribed treatments, or even abandonment of treatment. In order to address the challenges associated with TB treatment, the WHO has advocated a comprehensive model for TB treatment known as "DOTS" (Directly Observed Treatment Short-Course). This model incorporates direct observed treatment (DOT) (Bayer & Wilkinson, 1995), and was recommended globally as the approach for combating TB in 1994. The WHO outlined five essential components for DOTS: 1. Political commitment to ensure effective treatment; 2. Guaranteed medication supply; 3. Sputum microscopy-based diagnosis;[7] 4. Implementation of a standardized recording and reporting system that allows assessment of treatment results and overall program performance; 5. Direct observation of treatment (DOT) (WHO, 1994).

Today, TB is prevalent primarily in developing countries and is a disease of poverty. In 2022, thirty countries, which are uniformly developing countries and characterized by a high burden of TB, collectively contributed to 87% of the new global TB cases (WHO, 2023a). The management

[5] The low TB incidence in children could also result from measurement error, children infected with TB may take 1-2 years to activate (Khan & Starke, 1995). Additionally, contemporary evidence has shown that some children with culture-confirmed TB remain asymptomatic and free of symptoms in the absence of treatment (Loveday et al., 2016).

[6] https://iris.who.int/bitstream/handle/10665/44165/9789241547833_eng.pdf

[7] Sputum test has two methods: culture examination and smear examination. Although culture examination boasts a higher sensitivity for the detection of tubercle bacilli compared to smear examination, its application is hindered by the significant time requirements and economic impracticalities, rendering it a less feasible routine method in the majority of developing countries (Devadatta et al., 1966). Smear results closely approximate culture results, making them technically feasible in low-income countries and an integral component of successful TB control programs (Wilkinson et al., 1994). Consequently, the sputum microscopy-based diagnosis in DOTS is based on smear results.

of TB in developing countries is confronted with unique challenges, including limited healthcare infrastructure, delays in diagnosis, a high burden of HIV-TB co-infection, drug-resistant TB, and social determinants of health that contribute to the transmission and morbidity of TB (Al-Worafi, 2024).

2.2. TB in China and the TB program

In 1990, TB remains a significant public health concern in China (see Figure 1). In order to tackle the TB prevalence induced public health concern, the Chinese Government implemented a comprehensive TB control program in 1992 ("the TB program" hereafter). The TB program adopted DOTS, was financed through a combination of World Bank loans and budgetary allocations from the Chinese government, and was implemented in 13 provinces ("DOTS provinces" hereafter) with a total population of 573 million, roughly half of China's population.[8] The 13 DOTS provinces were selected by the central government for meeting two criteria. First, they exhibited a high incidence of TB in 1990; Second, the local government committed to voluntarily applying for loans, along with the capability to repay, offer support, and undertake related initiatives.

The TB program mainly consists of two parts. First, testing. Health personnel (referred to as village doctors in rural areas) encouraged individuals displaying symptoms such as cough, expectoration, or hemoptysis to visit their nearby TB dispensary for a standardized diagnostic evaluation provided free of charge.[9] Individuals with positive sputum smear results were considered infected with TB and subsequently registered at the TB dispensary. Each patient was issued a TB treatment card and an identity card. Consequently, the health personnel who report, refer, or encourage individuals later confirmed to be infected with TB would receive monetary reward of 1 USD (in 1992 value) for each confirmed TB patient and an additional reward up to 6 USD for conducting follow-up visits to ensure the patients' compliance of the treatment. The monetary reward provides a strong incentive for healthcare personnel, particularly the underpaid

[8] The 13 provinces are Hebei, Liaoning, Heilongjiang, Shandong, Hubei, Hunan, Guangdong, Hainan, Chongqing, Sichuan, Gansu, Ningxia and Xinjiang. In 1996, Sichuan province split off a municipality called Chongqing. This increased the total number of DOTS provinces from 12 to 13.

[9] The TB dispensary, called TB Prevention and Control Institute, although prohibited from generating profits, is subsidized by the government. This ensures that salary and welfare remain on par with those of equivalent healthcare staff.

village doctors (Zhang & Unschuld, 2008), to actively seek out individuals displaying symptoms of TB and conduct follow-up visits.

Second, treatment. Newly diagnosed smear-positive patients would receive standard intermittent treatment consisting of streptomycin, isoniazid, pyrazinamide, and rifampicin. Smear-negative relapsing patients and those requiring retreatment (e.g. failures) were additionally prescribed ethambutol.[10] Subsequently, health personnel would conduct direct follow-up visits on patients who are on medication to ensure compliance of patients. The DOTS encompasses standardized regimens for six months (Cox et al., 2008). In the TB program, the treatment regimen for all new, relapse, and retreatment TB patients typically lasts between 6 to 8 months, while the duration of treatment maybe extended up to 16 months, depending on drug-resistance and failure. See (Zhao et al., 1996) for detailed description of the TB program.

The TB program achieved a coverage rate of 80% among the target population in DOTS provinces by 1994. Subsequently, the coverage rate remained consistently high until the end of the program (see Figure 2). By the end of the TB program, A total of 9,077,319 individuals with suspected symptoms of pulmonary TB was examined and 2,004,858 patients received treatment with 90.1% of them received the full regimen under DOT (Cai & Chen, 2003).

The TB program is successful. The proportion of previously treated cases among all smear-positive cases exhibited a progressive decline, diminishing from 19.7% in 1990 to 7.2% in 2000, while the prevalence of new smear-positive cases steadily ascended, nearly doubling the initial proportion, surging from 43.2% to 79.6% (Cai & Chen, 2003). These change can be largely attributed to the testing that screened out people who were unaware of their infection of TB and enhanced TB treatment in DOTS provinces (Zhao et al., 1996). Furthermore, as shown in Figure 3, there was a significant reduction of TB prevalence within DOTS provinces in compared to that of non-DOTS provinces between 1990 and 2000.

These temporal variation in TB prevalence and geographical variation between DOTS and non-DOTS provinces allow us to examine the effects of the TB program, which reduces not only the prevalence of TB but also the risk of infection for healthy people.

[10] Treatment failures are defined as patients who remain smear-positive at the conclusion of therapy. The failure rate for new smear-positive cases is 0.8%, and for relapse smear-positive cases, it is 3.1% (Cai & Chen, 2003).

3. Data

3.1. Diseases

To empirically examine the effects of the TB program on TB prevalence, we collect provincial TB infection rates in 1990 and 2000 from the 3rd and 4th national TB epidemiological surveys (Ministry of Public Health of the People's Republic of China, 1992, 2003), respectively.[11] In addition, in order to examine whether the TB program has any spillover effect on any other diseases, we collect the 1990 and 2000 provincial prevalence of Hepatitis (including all categories), dysentery, and measles from the Data-center of China Public Health Science.[12] Panel A of Table 1 presents the summary statistics of these four diseases.

3.2. China Health Nutrition Survey

We employ the China Health Nutrition Survey (CHNS) to examine the contemporaneous and intergenerational effects of the TB program. The CHNS is an ongoing open cohort, international collaborative project jointly conducted by the Carolina Population Center at the University of North Carolina at Chapel Hill and the National Institute for Nutrition and Health (NINH, formerly known as National Institute of Nutrition and Food Safety) at the Chinese Center for Disease Control and Prevention (CCDC). Covering a period from 1989 to 2015, the CHNS offers comprehensive data on individuals, households, and communities across 15 provinces in China.[13]

We exploit the panel nature of the CHNS to investigate the contemporaneous effect of the TB program. Our analysis focuses on individuals aged between 6 and 65 in the years 1989, 1991, 1993, 1997, and 2000 (referred to as "Panel Sample" hereafter). As depicted in Figure 4, rural areas exhibit a higher TB infection rate compared to urban areas. Consequently, it is highly probable that the TB program primarily affects individuals from rural areas. Therefore, we limit our panel sample exclusively to individuals from rural areas. Unless explicitly stated otherwise, all reported results are based on panel sample from rural areas. Moreover, to mitigate potential

[11] Due to data limitations, we are unable to obtain the provincial TB infection rate from 1991 to 1999. Consequently, we cannot employ the instrumental variable estimation method that utilizes the implementation of the TB program as an instrumental variable for the provincial TB infection rate in order to examine both contemporaneous and intergenerational effects of reducing TB prevalence. Although both culture- and smear-positive rates were obtained in both surveys, we have chosen to report only the culture-positive rates due to their higher precision.

[12] https://www.phsciencedata.cn/Share/en/index.jsp

[13] 8 provinces were surveyed between 1989 and 1997, the number of provinces increased to 9 in 2000.

sample selection issues arising from migration of individuals from rural to urban areas or from provinces with high TB infection rates to those with low rates during the period between 1989 and 2000, we exclude individuals whose province of residence or household registration status (urban or rural) changed within this period. Given that Figure 4 illustrates variations in TB infection rates across different age groups, we further divide our panel sample into three categories: school-age (aged 6-17) children, child-bearing age (aged 18-40) adults, and older age (aged 41-65) adults.

To investigate the intergenerational effects of the TB program on adulthood outcomes, we utilize data from the 2015 wave of the CHNS. Our analysis focuses specifically on individuals born between 1985 and 2000 in rural areas (referred to as "Cohort Sample" hereafter). Panels B to E in Table 1 provides the summary statistics of outcome and control variables within both panel and cohort samples.

We examine four outcomes for adults (aged 18 to 65). Due to the diverse range of symptoms associated with TB infection, we construct the first outcome: sickness indicator. Specifically, in each wave of the CHNS, respondents were asked whether they had been sick, injured, or diagnosed with any acute or chronic diseases over the past four weeks. Consequently, we use response to this question to construct the sickness indicator with 1 indicating that the respondent had been sick, injured, or diagnosed with any acute or chronic diseases over the past four weeks and 0 otherwise. As discussed in Section 2 regarding TB treatment requirements necessitating isolation from public spaces and avoidance of contact with healthy individuals, it is plausible that TB patients may discontinue employment or cease providing child care. Therefore, our second and third outcomes are employment status (where 1 represents current employment at the time of survey and 0 denotes unemployment) and child care provision (where 1 represents providing child care to children aged five years or younger either within one's own family or others' families during last week while 0 implies no such involvement). Considering limitations related to missing observations on individual income as well as challenges in distinguishing individual contributions towards household income specifically in rural households, we use household income per capita as our fourth outcome.

We investigate two outcomes for school-age children. The first outcome is the sickness indicator, which follows the same construction method as that for adult outcomes. In each wave of the CHNS, individuals were asked about their current enrollment status in school. Hence, the second outcome is a school enrollment indicator with a value of 1 denoting current enrollment and 0 indicating otherwise

For adulthood outcomes, we investigate two educational outcomes, which are years of education and high school completion (defined as years of education are greater than or equal to 12).

4. Empirical Strategy

4.1. Identification strategy

We adopt a Difference-in-Difference (DID) identification strategy, which leverages temporal difference between 1990 and 2000 as well as geographical difference between DOTS and non-DOTS provinces, to investigate the effect of the TB program on TB infection rate. The model is presented below.

$$Y_{st} = \alpha_0 + \alpha_1 * DOTS_s * Year_{2000} + \alpha_2 * Year_{2000} + \tau_s + \epsilon_{st} \quad (1)$$

Where Y_{st} is the infection rate of TB in province s in year t. $DOTS_s$ is an indicator of whether province s is a DOTS province. $Year_{2000}$ is a binary variable with 1 indicating the year 2000 and 0 indicating the year 1990. τ_s are province fixed effects. α_1 is the coefficient of interest that captures the effects of the TB program on TB infection rate.

As discussed in Section 2, adults exhibit a significantly higher infection rate compared to children. Therefore, we utilize the panel nature of the CHNS and employ a Difference-in-Differences (DID) identification strategy. This approach allows us to harness both temporal variation across survey years and geographical variation between DOTS and non-DOTS provinces. Our aim is to investigate the contemporaneous effects of the TB program on adults, particularly those in their child-bearing age who typically play a crucial role as primary caregivers for both elderly individuals and children within families, especially in developing countries like China. The model is shown below.

$$Y_{ist} = \beta_0 + \beta_1 * DOTS_s * Post_t + X' * \eta + \gamma_i + \omega_t + \tau_s + TB\_Trend_{st} + \epsilon_{ist} \quad (2)$$

Where Y_{ist} is the outcome of individual i who lives in province s in survey year t. $DOTS_s$ is an indicator of whether provinces are DOTS provinces.[14] $Post_t$ is a binary variable with 1 indicating survey year is 1994, 1997, or 2000 and 0 indicating survey year is 1989 or 1991. X' is a vector of dummies of age. γ_i, ω_t, and τ_s are individual, survey year, and province fixed effects, respectively. TB_Trend_{st} is a province-specific TB trend, which is an interaction between survey year and 1990 provincial TB infection rate. The coefficient of interest in equation (2) is β_1, which captures the effects of the TB program on child-bearing age adults.[15]

Given the adverse consequences induced by TB infection during pregnancy, as discussed in section 2, we also investigate the intergenerational effects of the TB program. Following Bleakley (2007) and Bütikofer & Salvanes (2020), we adopt a cohort DID identification strategy. Specifically, we leverage both variation across birth cohorts and geographical difference between DOTS and non-DOTS provinces to investigate the intergenerational effects of the TB program on adulthood outcomes. The model is presented below.

$$Y_{isc} = \sigma_0 + \sigma_1 * DOTS_s * Post_c + X' * \eta + \omega_c + \tau_s + TB\_Trend_{sc} + \epsilon_{isc} \qquad (3)$$

Where Y_{ist} is the outcome of individual i who was born in province s in year c. $DOTS_s$ is an indicator of whether province s implemented the TB program. $Post_c$ is a binary variable with 1 indicating the child was born in 1992 or onward and 0 indicating 1991 or earlier. X' is a vector of child characteristics, which includes age dummies, gender dummies, and han ethnic group indicator. ω_c, and τ_s are birth year and birth province fixed effects, respectively. TB_Trend_{cs} is a birth province-specific TB trend, which is an interaction between birth year and 1990 provincial TB infection rate. σ_1 , which is the coefficient of interest in equation (3), captures the intergenerational effects of the TB program on adulthood outcomes.

[14] The 13 provinces are Hebei, Liaoning, Heilongjiang, Shandong, Hubei, Hunan, Guangdong, Hainan, Gansu, Ningxia, Xinjiang, Sichuan, and Chongqing.

[15] We are aware that the individual fixed effects and province fixed effects are perfectly collinear in equation (2). Dropping province fixed effects does not affect our estimation of the contemporaneous effects of the TB program at all. The inclusion of province fixed effects and subscripts in other variables aims to enhance readers' understanding of both DOTS provinces assignment and subsequent robustness checks.

4.2. Threats

The underlying assumption of our identification strategy is that, in the absence of the TB program, the outcomes between DOTS and non-DOTS provinces would have evolved parallelly. We conduct event-study estimation using child-bearing age adults sample and cohort sample. The results are presented in Figure 5 and Figure A.2. in the Appendix, where all coefficients before 1992 exhibit statistical insignificance across all outcomes, indicating no violation of the parallel trend assumption. There are also several major concerns that threats our identification of the effects of the TB program. 1. The timing of the TB program may be non-random. In equations (2) and (3), (birth) province fixed effects accounts for all the time-invariant differences across (birth) provinces while survey year (birth year) fixed effects controls for all the unobserved factors that varied uniformly across survey years (birth years). However, it is still possible that there are province-time-specific factors that correlates with both the timing of the TB program and outcomes for individuals as well as their descendants; 2. Another concern arises from the fact that only 13 out of 31 provinces were selected by the central government to implement the TB program based on their higher infection rates, willingness, and capability to repay loans from the World Bank. This raises concern about potential systematic difference between DOTS and non-DOTS provinces; 3. The estimated contemporaneous and intergenerational effects of the TB program might simply be an artifact of mean reversion (Bleakley, 2003, 2007; Bütikofer & Salvanes, 2020; Kuecken et al., 2021).

To address these concerns, in addition to the inclusion of (birth) province fixed effects, we also include (birth) province-specific TB trend which is an interaction between (birth) survey year and 1990 provincial TB infection rate. Furthermore, we empirically examine whether there is a systematical difference between DOTS and non-DOTS provinces. The results are presented in Figure A.1 in the Appendix, where no significant difference between DOTS and non-DOTS provinces before 1992 is observed. Additionally, we conduct several robustness checks to ensure the validity of our findings; detailed information can be found in Section 6.

5. Results

5.1. Effects on TB prevalence

Though Figure 3 suggests the TB program reduces TB prevalence, this association is merely a correlation rather than causation. We use equation (1) to empirically examine the causal effects of the TB program on TB prevalence. The results are presented in Table 2. As shown in Column (1), the TB program reduces the infection rate of TB by 63.34 people per 100k people (about 38.34 %).

Columns (2) – (4) present the effects of the TB program on the prevalence of Hepatitis, dysentery, and measles, respectively. Across all three diseases, the estimated coefficients of the TB program interaction term are uniformly statistically insignificant, suggesting the TB program did not have any spillover effects on other diseases.

5.2. Contemporaneous effects on adults

In this subsection, we estimate the contemporaneous effects of the TB program on adults' outcomes using equation (2) with a focus on child-bearing age adults.

The results are presented in Table 3. As shown in Panel A, the incidence of sickness over the past four weeks reduces by 2.85 percentage (about 55.81%). The reduced incidence of sickness suggest that the TB program successfully improves the health condition of the rural population and also corroborates with the fact that TB infection rate reduces following the TB program implementation. Furthermore, the probability of employment and providing child care also reduces by 4.90 (about 5.32%) and 3.31 (about 11.57%) percentage points, respectively. The significant effects on employment and child care provision aligns with the medical requirement for curation of TB and further corroborates the reduced sickness probability. However, we do not observe any significant effect on household income.

Panels B and C present the results of the TB program for males and females, respectively. The incidence of sickness decreases for both genders. Regarding employment and child care provision, the findings suggest distinct gender roles within families. Specifically, there is a decrease in the probability of employment for men, while women experience a reduction in their likelihood of providing child care. Similar statistically insignificant effects on household income are observed among both men and women.

We also examine the contemporaneous effects of the TB program on older age adults. The results are presented in Table 4. We observe that the probability of employment and providing child care reduces with null effects on the incidence of sickness and household income with similar effects for both men and women. Though the null finding on household income and significant findings on employment and child care among older age adults are similar to that of child-bearing age adults, the incidence of sickness is statistically insignificant for older age adults while it is statistically significant for child-bearing age adults. The difference in the significance of incidence of sickness between these two age groups is attributable to the aging induced immune system and body function deterioration, which, consequently would enables the TB to generate a greater, or even irreversible, harm on the older age adults in compared to child-bearing age adults (Hochberg & Horsburgh, 2013).

The reduction in employment and child care provision among adults of both child-bearing age and older age may initially appear counterintuitive, given that the TB program is expected to improve employment and child care provision. We will use employment status as an example to explain the rationale behind the observed effects. Prior to 1992, adults who contracted TB but remained undiagnosed and lived in DOTS provinces had similar employment patterns as adults in non-DOTS provinces. However, after the implementation of the TB program in 1992, those who were previously undiagnosed from DOTS provinces could be diagnosed anytime between 1992 and 2001, leading to their isolation for TB treatment. If a previously undiagnosed adult from DOTS provinces was diagnosed and subsequently received TB treatment in 1993, their employment status would become unemployed. Considering the high success rate of TB treatment, there was a high likelihood that these individuals would be fully cured and able to return to the labor market by 1994, following a similar pattern as before 1992. Consequently, the mean employment rate during 1992-2001 would be lower than before 1992 due to this temporary unemployment period. On the other hand, for adults in non-DOTS provinces, their employment patterns after 1992 would continue unchanged from before that year. Therefore, any difference in mean employment status before and after 1992 for adults in non-DOTS provinces can simply be attributed to general trends (non-DOTS difference), while for adults in DOTS provinces it represents both the effects of the TB program and trend differences (DOTS difference). By subtracting the non-DOTS difference from DOTS difference we can isolate specifically how much reduced employment is attributable to the impact of the TB program itself. Similarly, this reasoning can also apply when considering child care provision.

The null finding on household income among adults of all age groups may seem contradicting to the significant findings on decreased probability of employment and providing child care at first glance. However, this null finding can be reasonably explained as follows: In rural areas, individuals often possess their own farmland and engage in farming activities. During the 1990s, many males, especially child-bearing age male, farmers sought job opportunities in urban areas within their province due to higher wages compared to farming at home with their wife, female farmers, remain at home to care for their young children and tend to their farmland (Mu & Van De Walle, 2011; Zhao, 1999). If these male farmers contracted TB, they were required to isolate themselves from the public for treatment purposes. Although they had to temporarily leave their jobs in urban areas during treatment, they could still tend to their farmland alone and generate income by selling crops. While this income might be lower than what they earned in urban areas, it could partially offset the loss incurred from temporarily leaving their jobs there. The female farmers, even if they contracted TB and had to stay away from their children, it did not hinder them from farming their land. The agricultural nature of farmland cultivation in China is likely responsible for the lack of significant findings regarding household income among rural populations.

Our null finding on household income contrast with that of Egedesø et al. (2020) who found that the opening of TB dispensary in the early 20th century in Denmark increases income. The difference is attributable to the systematical difference between developed and developing countries.

5.3. Contemporaneous effects on school-age children

In this subsection, we also estimate the impact of the TB program on school-age children, and these findings are presented in Table 5. Across all outcomes, the estimated coefficients are statistically insignificant. The absence of significant effects on school-age children is consistent with their relatively lower infection rate and serves as a falsification test for our identification strategy.

The null findings on school-age children differ from those of Bütikofer & Salvanes (2020), who examined the effects of a nationwide TB testing and vaccination program implemented in

Norway in the late 1940s and found that school-age children had reduced absences from school. The discrepancy is most likely due to the difference in TB infection rates among all age groups between China and Norway prior to the implementation of their respective policies. As depicted in Figure 4, in 1990, the TB infection rate increased with age in China, with adults having the highest infection rate while that of children was much lower. The low infection rate among children in China can be attributed to the implementation of a nationwide mandatory vaccination program starting in 1978, which includes Bacillus Calmette-Guérin (BCG) and targets all newborns (Pan et al., 2021). In contrast, prior to Norway's nationwide TB testing and vaccination program implemented in the late 1940s, school-age children had the highest infection rates (Bütikofer & Salvanes, 2020).

The results of the effects of the TB program on individuals from all age groups and urban areas are presented in Table A.1 in the Appendix. Across all outcomes, the estimated coefficients exhibit no statistical significance. The absence of significant effects for urban individuals not only aligns with the low infection rate observed in urban areas but also serves as a falsification test for our identification strategy.

5.4. Intergenerational effects

We investigate the intergenerational impacts of TB programs on adulthood outcomes using equation (3), and the findings are presented in Columns (1) of Table 6. Consistent with Bütikofer & Salvanes (2020), we observe an improvement in educational attainment. Specifically, as illustrated in Panel A, individuals born in DOTS provinces from 1992 onwards exhibit a higher likelihood of completing at least high school education (an increase of 8.10 percentage points or 46.96%) compared to those born in non-DOTS provinces. Panels B and C present the results for men and women, respectively. Women have higher probability of completing at least high school education, while null effects are observed for men.

Because the 2015 wave of the CHNS only surveys 15 provinces, we therefore use sample constructed from the 2015 1% census to re-run equation (3).[16] The estimated coefficient for high school completion is presented in Column (2) and are qualitatively similar but quantitively smaller in compared to those in Column (1). This reduction in magnitude can likely be attributed to

[16] Data can be accessed through the Microdata of the National Bureau of Statistics. Visit https://microdata.stats.gov.cn/#/ for more information.

measurement errors associated with assigning birth province in the census sample. Unfortunately, the 2015 1% Census does not provide information regarding respondents' province of birth. Therefore, we have used their current province of household registration as a proxy for their province of birth. However, it should be noted that over the past decades, many individuals within prime working age would migrate to coastal provinces or municipalities such as Beijing, Tianjin, and Shanghai due to better opportunities and higher wages (Facchini et al., 2019; Tombe & Zhu, 2019). As depicted in Figure 1, among all coastal provinces, only Guangdong and Hainan implemented the TB program between 1992 and 2001. Consequently, using current province of household registration as a proxy for province of birth may introduce measurement errors since some individuals who were actually born in DOTS provinces might have been misclassified as being born in non-DOTS provinces. As a result, these measurement errors related to province of birth could potentially bias downward our estimation regarding the true intergenerational effect of the TB program; thus our estimated coefficient obtained from analyzing data from the 2015 1% census sample serves as a conservative lower bound estimate for this effect. Table A.2. in the Appendix presents the summary statistics of outcome and control variables of the cohort sample constructed from the 2015 1% census. We acknowledge that the estimated intergenerational effects of the TB program using the 2015 wave of the CHNS may be an overestimation due to potential sampling issues, as only 19 out of 31 birth provinces were included (7 DOTS provinces and 12 non-DOTS provinces). Among individuals born in the 12 non-DOTS provinces in the 2015 CHNS, approximately 27% were born in Guizhou and Yunnan, where average educational attainment has consistently remained at the lower end compared to other provinces in China. The mean high school completion rate in non-DOTS provinces is influenced by individuals from Guizhou and Yunnan, resulting in a relatively small value. Therefore, it is reasonable to observe such significant intergenerational effects of the TB program using the 2015 wave of the CHNS. Consequently, these identified intergenerational effects can largely be considered an upper bound estimate rather than reflecting true effects.

We also examine whether the estimated effects of the TB program are influenced by another TB control project (referred to as "93 program" hereafter), which also implemented DOTS and was solely funded by the Chinese government (with a total of 24 million RMB or 4.35 million USD in 1992 value) in 15 out of 18 non-DOTS provinces from 1993 to 2000. To provide suggestive evidence on the potential bias induced by the 93 program, we utilize equation (3) and the cohort sample.[17] Specifically, we construct an interaction term of the 93 program in the same manner as that of the TB program and add the 93 program interaction term to equation (3). The results are presented in Table A.3. in the Appendix. The estimated coefficients of the TB program interaction term are higher than those reported in Column (1) of Table 6, indicating that implementation of the 93 program leads to an underestimation of true effects of the TB program. However, these difference in the estimated coefficients of the TB interaction term do not accurately reflect the actual level of bias for the following reasons. 1. Unlike the TB program, which encompasses the entire population within the DOTS provinces, the 93 program only covers a mere 29.1% of the population (approximately 160 million individuals) in the 15 non-DOTS provinces. Consequently, it is plausible that the observed effects of the 93 program may incorporate certain sub-provincial level governmental policies; 2. The total funding allocated to the 93 program amounts to 24 million RMB (equivalent to approximately 4.35 million USD in terms of its value in 1992), while that of the TB program reaches a substantial sum of 129.7 million USD. Hence, it is reasonable to suspect that some unobserved factors could potentially confound or influence the identified effects of the 93 program presented in Table A.3 in the Appendix. In sum, the difference in the estimated coefficients of the TB interaction term provide suggestive evidence of potential bias resulted from the 93 program but should be interpreted with caution. Consequently, given the potential bias resulted from the 93 program, the identified effects of the TB program on TB prevalence, individuals, and their descendants should be considered as a conservative lower bound of the true effects.

We are aware that there is a potential sampling issue of the CHNS and the potential bias induced by the 93 program. Nevertheless, we can still conclude that there is evidence of spillover effects from the TB program into subsequent generations through increased high school completion rates.

6. Robustness Checks

In addition to the previously discussed event study estimation method results and systematic difference check, this subsection presents an additional range of robustness checks.

[17] Due to the limited availability of data in the panel sample, which encompasses the years 1989, 1991, 1993, 1997, and 2000, employing both equation (2) and the panel sample for assessing the bias induced by the 93 program on estimated TB program effects would result in a high collinearity problem between the interaction term of the TB program and that of the 93 program.

We perform permutation test by randomly assigning provinces as DOTS provinces (Rosenbaum, 2007). To estimate the "placebo" treatment effect of implementing the TB program, we employ equation (2) and perform 999 random assignments using the child-bearing age adults sample. The resulting distribution of 999 coefficients representing the effects of "placebo" treatments is illustrated in Figure A.3 in the Appendix. Importantly, for all outcomes that are statistically significant in Table 3, the proportions of these coefficients that are smaller than the absolute value of the estimated coefficients presented in Table 3 uniformly remain below 0.01.

We also conduct a placebo test by assuming that the TB program was implemented in 1991 and construct the placebo interaction term in the same manner as Equation (2) using the child-bearing age adults sample. To address any potential systematic overlap, we include both the actual and placebo interaction terms in Equation (2) and present the results in Panel A of Table 7. Across all outcomes, the coefficients of the actual interaction term remain robust, while those of the placebo interaction term are either statistically insignificant or exhibit an opposite sign. The findings from our permutation tests and placebo test further strengthen our identification strategy.

From 1992 to 2001, the Chinese government implemented an additional project aimed at combating schistosomiasis, an infectious disease (Chen et al., 2005). Similar to the TB program, funding for the schistosomiasis project was sourced from both the Chinese government and a loan from the World Bank. The implementation of this project took place in 8 provinces that were endemic to schistosomiasis.[18] Some of DOTS provinces also implemented the schistosomiasis project. This raises concerns regarding potential confounding effects between the identified impacts of the TB program and those of the schistosomiasis project. To address this concern, we introduce an interaction term into equation (2) which captures whether or not provinces implemented the schistosomiasis project and whether or not survey years fall after 1992. We then re-run regressions on all outcomes using the child-bearing age adults sample. The results are presented in Panel B of Table 7 and are generally robust.[19]

As discussed in earlier sections, the infection rate of TB has been following a decreasing trend over time, regardless of the TB program. Furthermore, as discussed earlier, the choice of DOTS provinces is determined by the willingness as well as capability to repay the loan from the World Bank and the TB infection rate in the national epidemiological survey of TB 1990.

[18] The 8 provinces are Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Sichuan, and Yunnan.
[19] The employment status becomes marginally insignificant with a p value being 0.104.

However, even though we have included (birth) province fixed effects and province-specific TB trend, it is still possible that the choice is determined by some unobservable factors. Following Deng & Lindeboom (2022), we add region-specific time trend to equation (2). The results obtained from using the child-bearing age adults sample are presented in Panel C of Table 7 and are robust.

We calculate wild-cluster bootstrap p-values with clustering at province-survey year level. The results are presented in Panel D of Table 7 and are robust.

We also use equation (3) to perform Permutation tests and other robustness checks that were performed using equation (2). The results are presented in Figure A.4. and Table A.5. in the Appendix and are robust.

7. Cost-Benefit Analysis

Given the observed above findings, it is important to assess whether the TB program is cost-beneficial. Therefore, we conduct a back-of-the-envelope cost-benefit analysis.

The cost of the TB program consists of two parts, costs associated with the discovery and treatment of TB patients, and income loss due to receiving TB treatment. For costs associated with the TB patients' discovery and treatment, we use data from the Cai & Chen (2003). Specifically, the per capita cost for discovery, treatment of new TB patients, and treatment of relapse TB patients, are 83 RMB, 537 RMB, and 759 RMB, respectively. Among all TB patients that received the TB treatment, 71.95% of them are new TB patients while that of the relapse TB patients are 28.05%. Consequently, the per capita cost for discovery and treatment of TB patients is 685.08 RMB (83 + 537 * 0.7195 + 769 * 0.2805), adjusting to the 2015 value leads to 970.79 RMB.[20] For income loss due to receiving TB treatment, we first calculate the average individual income (adjusted to 2015 value) during 1992 and 2000, 5817.43 RMB. Because most TB patients recovered after six months of treatment, we therefore proxy the duration of not working as half of a year. We further calculate the effects of the TB program on employment by aggregating samples of adults across both child-bearing age and older age. The estimated coefficient is -0.0651. Consequently, we could obtain the per capita income loss due to receiving TB treatment, 186.76 RMB ($0.0651 * \frac{180}{365} * 5817.43$).

[20] Another method to calculate the per capita cost of recovery and treatment of TB patients is to use the total fund of the TB program, 0.1297 billion USD (around 0.676 billion RMB) divided by the total number of TB patients discovered during 1992 and 2001, 2,004,858 people. This gives us per capita cost of discovery and treatment being 447.8 RMB (in 2015 value).

In sum, the estimated total per capita cost is 1157.55 RMB (970.79 + 186.76), which is equivalent to 185.85 USD (in 2015 value).

The benefit of the TB program consists of the income saved from reduced sickness and the extra income from increased completion of at least high school education. For income saved from reduced sickness, we first obtain the relationship between income and sickness, 16.1%, by regressing individual income on sickness indicator using the 1989-2000 waves of the CHNS.[21] Given the duration of TB treatment usually last for half a year, the TB program was implemented for 10 years, people who recovered from TB infection were likely to maintain a health status for 9.5 years. Given the coefficient of the effect of the TB program on sickness is -0.0285 and the average individual income (adjusted to 2015 value) during 1992 and 2000 is 5817.43 RMB, we could obtain the per capita income saved from reduced sickness, 253.59 RMB (0.161 * 0.0285 * 5817.43 * 9.5). To calculate the benefit of completing at least high school education, we first obtain the income gap between high school education and below, 18.2 %, from (Lee & Malin, 2013). Following Bütikofer & Salvanes (2020), we use average personal income at age 37 as a proxy for an adult's average lifetime annual income, 26472.97. The average personal income at age 37 is calculated from the individuals who were aged 37 in the 2015 of the CHNS. In addition, we also account for the discount rate (Bütikofer & Salvanes, 2020; Zhang et al., 2023). Following Zhang et al. (2023), we use 0.03 as the discount rate. Assuming an adult with at least high school education works from 19 to 55 and starts working at age 19 in 2015, given the coefficient of the intergenerational effect of the TB program on completing at least high school education is 0.0810, the benefit of completing at least high school is 8910.62 RMB ($\sum_{t=0}^{36} 0.182 * 0.0810 * \frac{26472.97}{(1+0.03)^t}$). In sum, the estimated total per capita benefit of the TB program is 9164.21 RMB (253.59 + 8910.62), which is equivalent to 1471.36 USD (in 2015 value). The ratio of cost-benefit is 1:7.92. Therefore, the benefit outweighs the cost of the TB program, suggesting the TB program is a cost-effective intervention.

[21] The control variables include age dummies, survey year fixed effect and province fixed effect.

8. Conclusion

This paper examines the effects of a comprehensive TB control program, which was implemented during 1992 and 2001 in 13 out 31 provinces, and funded by the World Bank and the Chinese government, on TB prevalence and its contemporaneous as well as intergenerational effects in China. We find the TB program not only reduces TB prevalence but also concurrently improves the health condition among child-bearing age adults within DOTS provinces. The findings on reduced probability of employment and child care provision for both child-bearing age adults and older age adults corroborates the findings on reduced TB prevalence and are align with the medical requirement for TB curation. We also find the effects of the TB program spillover to the next generations. Specifically, we find people who were born in DOTS provinces in 1992 or later are more likely to have completed at least high school education. Our back-of-the-envelope cost-benefit analysis indicates the benefit of the TB program outweighs its cost, suggesting the TB program passes a cost-benefit analysis.

This paper holds significant implications for other developing countries currently grappling with the TB and possibly other epidemics. In many developing countries, a considerable number of TB cases remain undiagnosed or unreported due to challenges in accessing healthcare and diagnostic services (Al-Worafi, 2024). The success of the TB program implemented in rural areas of China can be largely attributed to the strategic placement of TB dispensaries, which provide diagnostic and treatment facilities. Additionally, village doctors were incentivized financially to identify suspected patients displaying symptoms of TB, inform them about the availability of free diagnostic and treatment options, subsequently encourage them to visit nearby TB dispensaries, and conduct follow-up visits on identified TB patients to ensure treatment compliance. The establishment of these dispensaries and monetary incentives for village doctors significantly enhance healthcare access and diagnostics respectively. Therefore, this exemplary TB program serves as a valuable model for other developing countries facing similar epidemics.

Additionally, when China decided to implement the subsequent TB program in 1991, its GDP per capita stood at 359.2 USD (in current value), while the global average GDP per capita amounted to 4,446.3 USD.[22] Unlike the study of Egedesø et al. (2020) and Bütikofer & Salvanes (2020), which rely solely on government funding for their public health intervention against TB,

[22] https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=CN

the TB program serves as a commendable example of utilizing external funds and potentially government budgetary allocations for developing countries that often face financial constraints in controlling infectious diseases.

Furthermore, considering the remarkable success of the tuberculosis (TB) program and its enduring benefits across generations in China, coupled with the alarming fact that 99% of newly diagnosed TB cases are concentrated in low- and middle-income countries (LIMCs) which face a significant shortfall in available funding for 2022 (WHO, 2023a), this paper strongly advocates for increased financial support from the international community to effectively combat TB.

Reference

Almond, D. (2006). Is the 1918 influenza pandemic over? Long-term effects of in utero influenza exposure in the post-1940 US population. Journal of Political Economy, 114(4), 672–712.

Almond, D., & Currie, J. (2011). Killing Me Softly: The Fetal Origins Hypothesis. Journal of Economic Perspectives, 25(3), 153–172. https://doi.org/10.1257/jep.25.3.153

Almond, D., Currie, J., & Duque, V. (2018). Childhood Circumstances and Adult Outcomes: Act II. Journal of Economic Literature, 56(4), 1360–1446. https://doi.org/10.1257/jel.20171164

Alsan, M. M., Westerhaus, M., Herce, M., Nakashima, K., & Farmer, P. E. (2011). Poverty, Global Health, and Infectious Disease: Lessons from Haiti and Rwanda. Infectious Disease Clinics of North America, 25(3), 611–622. https://doi.org/10.1016/j.idc.2011.05.004

Al-Worafi, Y. M. (2024). Tuberculosis Management in Developing Countries. In Y. M. Al-Worafi (Ed.), Handbook of Medical and Health Sciences in Developing Countries: Education, Practice, and Research (pp. 1–40). Springer International Publishing. https://doi.org/10.1007/978-3-030-74786-2_52-1

Anderson, D. M., Charles, K. K., Olivares, C. L. H., & Rees, D. I. (2019). Was the First Public Health Campaign Successful? American Economic Journal: Applied Economics, 11(2), 143–175. https://doi.org/10.1257/app.20170411

Barbagallo, J., Tager, P., Ingleton, R., Hirsch, R. J., & Weinberg, J. M. (2002). Cutaneous Tuberculosis: Diagnosis and Treatment. American Journal of Clinical Dermatology, 3(5), 319–328. https://doi.org/10.2165/00128071-200203050-00004

Basu Roy, R., Whittaker, E., Seddon, J. A., & Kampmann, B. (2019). Tuberculosis susceptibility and protection in children. The Lancet Infectious Diseases, 19(3), e96–e108. https://doi.org/10.1016/S1473-3099(18)30157-9

Bayer, R., & Wilkinson, D. (1995). Directly observed therapy for tuberculosis: History of an idea. The Lancet, 345(8964), 1545–1548.

Behrman, J. R., & Rosenzweig, M. R. (2004). Returns to Birthweight. Review of Economics and Statistics, 86(2), 586–601. https://doi.org/10.1162/003465304323031139

Bharadwaj, P., Lundborg, P., & Rooth, D.-O. (2018). Birth Weight in the Long Run. Journal of Human Resources, 53(1), 189–231. https://doi.org/10.3368/jhr.53.1.0715-7235R

Black, S. E., Devereux, P. J., & Salvanes, K. G. (2007). From the cradle to the labor market? The effect of birth weight on adult outcomes. The Quarterly Journal of Economics.

Bleakley, H. (2003). Disease and Development: Evidence from the American South. Journal of the European Economic Association, 1(2–3), 376–386. https://doi.org/10.1162/154247603322391017

Bleakley, H. (2007). Disease and Development: Evidence from Hookworm Eradication in the American South. The Quarterly Journal of Economics, 122(1), 73–117.

Bloom, D. E., Canning, D., & Shenoy, E. S. (2012). The effect of vaccination on children's physical and cognitive development in the Philippines. Applied Economics, 44(21), 2777–2783. https://doi.org/10.1080/00036846.2011.566203

Bloom, D. E., Kuhn, M., & Prettner, K. (2022). Modern Infectious Diseases: Macroeconomic Impacts and Policy Responses. Journal of Economic Literature, 60(1), 85–131. https://doi.org/10.1257/jel.20201642

Bütikofer, A., & Salvanes, K. G. (2020). Disease Control and Inequality Reduction: Evidence from a Tuberculosis Testing and Vaccination Campaign. The Review of Economic Studies, 87(5), 2087–2125. https://doi.org/10.1093/restud/rdaa022

Cai, J., & Chen, X. (2003). A Model of Tuberculosis Control in China. People's Medical Publishing House.

Campbell, J. R., Trajman, A., Cook, V. J., Johnston, J. C., Adjobimey, M., Ruslami, R., Eisenbeis, L., Fregonese, F., Valiquette, C., Benedetti, A., & Menzies, D. (2020). Adverse events in adults with latent tuberculosis infection receiving daily rifampicin or isoniazid: Post-hoc safety analysis of two randomised controlled trials. The Lancet Infectious Diseases, 20(3), 318–329. https://doi.org/10.1016/S1473-3099(19)30575-4

Carter, E. J., & Mates, S. (1994). Sudden Enlargement of a Deep Cervical Lymph Node During and After Treatment for Pulmonary Tuberculosis. Chest, 106(6), 1896–1898. https://doi.org/10.1378/chest.106.6.1896

Chang, J. C., Wysocki, A., Tchou-Wong, K. M., Moskowitz, N., Zhang, Y., & Rom, W. N. (1996). Effect of Mycobacterium tuberculosis and its components on macrophages and the release of matrix metalloproteinases. Thorax, 51(3), 306–311. https://doi.org/10.1136/thx.51.3.306

Chan-Yeung, M., Noertjojo, K., Tan, J., Chan S, L., Tam C, M., & others. (2002). Tuberculosis in the elderly in Hong Kong. The International Journal of Tuberculosis and Lung Disease, 6(9), 771–779.

Chen, X., Wang, L., Cai, J., Zhou, Xiaonong, Zheng, J., Guo, J., Wu, X., D, E., & Chen, M. (2005). Schistosomiasis control in China: The impact of a 10-year World Bank Loan Project (1992–2001). Bulletin of the World Health Organization.

Clay, K., Egedesø, P. J., Hansen, C. W., Jensen, P. S., & Calkins, A. (2020). Controlling tuberculosis? Evidence from the first community-wide health experiment. Journal of Development Economics, 146, 102510. https://doi.org/10.1016/j.jdeveco.2020.102510

Cox, H. S., Morrow, M., & Deutschmann, P. W. (2008). Long term efficacy of DOTS regimens for tuberculosis: Systematic review. BMJ, 336(7642), 484–487. https://doi.org/10.1136/bmj.39463.640787.BE

Currie, J., & Vogl, T. (2013). Early-Life Health and Adult Circumstance in Developing Countries. Annual Review of Economics, 5(1), 1–36. https://doi.org/10.1146/annurev-economics-081412-103704

Cutler, D., Fung, W., Kremer, M., Singhal, M., & Vogl, T. (2010). Early-life Malaria Exposure and Adult Outcomes: Evidence from Malaria Eradication in India. American Economic Journal: Applied Economics, 2(2), 72–94. https://doi.org/10.1257/app.2.2.72

De Jongh, T. E., Harnmeijer, J. H., Atun, R., Korenromp, E. L., Zhao, J., Puvimanasinghe, J., & Baltussen, R. (2014). Health impact of external funding for HIV, tuberculosis and malaria: Systematic review. Health Policy and Planning, 29(5), 650–662. https://doi.org/10.1093/heapol/czt051

Deng, Z., & Lindeboom, M. (2022). A bit of salt, a trace of life: Gender norms and the impact of a salt iodization program on human capital formation of school aged children. Journal of Health Economics, 83, 102614. https://doi.org/10.1016/j.jhealeco.2022.102614

Devadatta, S., Radhakrishna, S., Fox, W., Mitchison, D., Rajagopalan, S., Sivasubramanian, S., & Stott, H. (1966). Comparative value of sputum smear examination and culture examination in assessing the progress of tuberculous patients receiving chemotherapy. Bulletin of the World Health Organization, 34(4), 573.

Egedesø, P. J., Hansen, C. W., & Jensen, P. S. (2020). Preventing the White Death: Tuberculosis Dispensaries. The Economic Journal, 130(629), 1288–1316. https://doi.org/10.1093/ej/ueaa014

El-Messidi, A., Czuzoj-Shulman, N., Spence, A. R., & Abenhaim, H. A. (2016). Medical and obstetric outcomes among pregnant women with tuberculosis: A population-based study of 7.8 million births. American Journal of Obstetrics and Gynecology, 215(6), 797-e1.

Esmail, H., Dodd, P. J., & Houben, R. M. G. J. (2018). Tuberculosis transmission during the subclinical period: Could unrelated cough play a part? The Lancet Respiratory Medicine, 6(4), 244–246. https://doi.org/10.1016/S2213-2600(18)30105-X

Facchini, G., Liu, M. Y., Mayda, A. M., & Zhou, M. (2019). China's "Great Migration": The impact of the reduction in trade policy uncertainty. Journal of International Economics, 120, 126–144. https://doi.org/10.1016/j.jinteco.2019.04.002

Figlio, D., Guryan, J., Karbownik, K., & Roth, J. (2014). The Effects of Poor Neonatal Health on Children's Cognitive Development. American Economic Review, 104(12), 3921–3955. https://doi.org/10.1257/aer.104.12.3921

Gardner Toren, K., Spitters, C., Pecha, M., Bhattarai, S., Horne, D. J., & Narita, M. (2019). Tuberculosis in Older Adults: Seattle and King County, Washington. Clinical Infectious Diseases, ciz306. https://doi.org/10.1093/cid/ciz306

Heckman, J., Pinto, R., & Savelyev, P. (2013). Understanding the Mechanisms through Which an Influential Early Childhood Program Boosted Adult Outcomes. American Economic Review, 103(6), 2052–2086. https://doi.org/10.1257/aer.103.6.2052

Hershkovitz, I., Donoghue, H. D., Minnikin, D. E., May, H., Lee, O. Y.-C., Feldman, M., Galili, E., Spigelman, M., Rothschild, B. M., & Bar-Gal, G. K. (2015). Tuberculosis origin: The Neolithic scenario. Tuberculosis, 95, S122–S126.

Hnizdo, E. (2000). Chronic pulmonary function impairment caused by initial and recurrent pulmonary tuberculosis following treatment. Thorax, 55(1), 32–38. https://doi.org/10.1136/thorax.55.1.32

Hochberg, N. S., & Horsburgh, C. R. (2013). Prevention of Tuberculosis in Older Adults in the United States: Obstacles and Opportunities. Clinical Infectious Diseases, 56(9), 1240–1247. https://doi.org/10.1093/cid/cit027

Jana, N., Vasishta, K., Saha, S. C., & Ghosh, K. (1999). Obstetrical Outcomes among Women with Extrapulmonary Tuberculosis. New England Journal of Medicine, 341(9), 645–649. https://doi.org/10.1056/NEJM199908263410903

Jasmer, R. M., Nahid, P., & Hopewell, P. C. (2002). Latent tuberculosis infection. New England Journal of Medicine, 347(23), 1860–1866.

Khan, E. A., & Starke, J. R. (1995). Diagnosis of tuberculosis in children: Increased need for better methods. Emerging Infectious Diseases, 1(4), 115.

Kuecken, M., Thuilliez, J., & Valfort, M.-A. (2021). Disease and Human Capital Accumulation: Evidence from the Roll Back Malaria Partnership in Africa. The Economic Journal, 131(637), 2171–2202. https://doi.org/10.1093/ej/ueaa134

Lan, Z., Ahmad, N., Baghaei, P., Barkane, L., Benedetti, A., Brode, S. K., Brust, J. C. M., Campbell, J. R., Chang, V. W. L., Falzon, D., Guglielmetti, L., Isaakidis, P., Kempker, R.

R., Kipiani, M., Kuksa, L., Lange, C., Laniado-Laborín, R., Nahid, P., Rodrigues, D., … Menzies, D. (2020). Drug-associated adverse events in the treatment of multidrug-resistant tuberculosis: An individual patient data meta-analysis. The Lancet Respiratory Medicine, 8(4), 383–394. https://doi.org/10.1016/S2213-2600(20)30047-3

Lange, C., Aaby, P., Behr, M. A., Donald, P. R., Kaufmann, S. H., Netea, M. G., & Mandalakas, A. M. (2022). 100 years of Mycobacterium bovis bacille Calmette-Guérin. The Lancet Infectious Diseases, 22(1), e2–e12.

Lee, H., Yoo, J., Choi, H., Han, K., Lim, Y.-H., Lee, H., & Shin, D. W. (2023). Tuberculosis and the Risk of Ischemic Heart Disease: A Nationwide Cohort Study. Clinical Infectious Diseases, 76(9), 1576–1584. https://doi.org/10.1093/cid/ciac946

Lee, S., & Malin, B. A. (2013). Education's role in China's structural transformation. Journal of Development Economics, 101, 148–166. https://doi.org/10.1016/j.jdeveco.2012.10.006

Lin, H.-C., Lin, H.-C., & Chen, S.-F. (2010). Increased risk of low birthweight and small for gestational age infants among women with tuberculosis. BJOG: An International Journal of Obstetrics & Gynaecology, 117(5), 585–590.

Lin, M.-J., & Liu, E. M. (2014). Does in utero exposure to Illness matter? The 1918 influenza epidemic in Taiwan as a natural experiment. Journal of Health Economics, 37, 152–163. https://doi.org/10.1016/j.jhealeco.2014.05.004

Little, M. P., Zablotska, L. B., Brenner, A. V., & Lipshultz, S. E. (2016). Circulatory disease mortality in the Massachusetts tuberculosis fluoroscopy cohort study. European Journal of Epidemiology, 31(3), 287–309. https://doi.org/10.1007/s10654-015-0075-9

Loveday, M., Sunkari, B., Marais, B. J., Master, I., & Brust, J. C. M. (2016). Dilemma of managing asymptomatic children referred with 'culture-confirmed' drug-resistant tuberculosis. Archives of Disease in Childhood, 101(7), 608–613. https://doi.org/10.1136/archdischild-2015-310186

Mathad, J. S., & Gupta, A. (2012). Tuberculosis in Pregnant and Postpartum Women: Epidemiology, Management, and Research Gaps. Clinical Infectious Diseases, 55(11), 1532–1549. https://doi.org/10.1093/cid/cis732

Meghji, J., Gregorius, S., Madan, J., Chitimbe, F., Thomson, R., Rylance, J., Banda, N. P., Gordon, S. B., Corbett, E. L., Mortimer, K., & Squire, S. B. (2021). The long term effect of pulmonary tuberculosis on income and employment in a low income, urban setting. Thorax, 76(4), 387–395. https://doi.org/10.1136/thoraxjnl-2020-215338

Ministry of Public Health of the People's Republic of China. (1981). Nationwide random survey for the epidemiology of tuberculosis in 1979. People's Medical Publishing House.

Ministry of Public Health of the People's Republic of China. (1992). Nationwide random survey for the epidemiology of tuberculosis in 1990. People's Medical Publishing House.

Ministry of Public Health of the People's Republic of China. (2003). Report on nationwide random survey for the epidemiology of tuberculosis in 2000. People's Medical Publishing House.

Mu, R., & Van De Walle, D. (2011). Left behind to farm? Women's labor re-allocation in rural China. Labour Economics, 18, S83–S97. https://doi.org/10.1016/j.labeco.2011.01.009

Newton, P., Sharp, J., & Barnes, K. L. (1982). Bone and Joint tuberculosis in Greater Manchester 1969-79. Annals of the Rheumatic Diseases, 41(1), 1–6. https://doi.org/10.1136/ard.41.1.1

Pan, J., Wang, Y., Cao, L., Wang, Y., Zhao, Q., Tang, S., Gong, W., Guo, L., Liu, Z., Wen, Z., Zheng, B., & Wang, W. (2021). Impact of immunization programs on 11 childhood

vaccine-preventable diseases in China: 1950–2018. The Innovation, 2(2), 100113. https://doi.org/10.1016/j.xinn.2021.100113
Pande, J., Singh, S., Khilnani, G., Khilnani, S., & Tandon, R. (1996). Risk factors for hepatotoxicity from antituberculosis drugs: A case-control study. Thorax, 51(2), 132–136.
Portnoy, A., Yamanaka, T., Nguhiu, P., Nishikiori, N., Baena, I. G., Floyd, K., & Menzies, N. A. (2023). Costs incurred by people receiving tuberculosis treatment in low-income and middle-income countries: A meta-regression analysis. The Lancet Global Health, 11(10), e1640–e1647.
Rajagopalan, S. (2001). Tuberculosis and Aging: A Global Health Problem. Clinical Infectious Diseases, 33(7), 1034–1039. https://doi.org/10.1086/322671
Rajeswari, R., Balasubramanian, R., Muniyandi, M., Geetharamani, S., Thresa, X., & Venkatesan, P. (1999). Socio-economic impact of tuberculosis on patients and family in India. The International Journal of Tuberculosis and Lung Disease, 3(10), 869–877.
Rock, R. B., Olin, M., Baker, C. A., Molitor, T. W., & Peterson, P. K. (2008). Central Nervous System Tuberculosis: Pathogenesis and Clinical Aspects. Clinical Microbiology Reviews, 21(2), 243–261. https://doi.org/10.1128/CMR.00042-07
Rodrigues, L. C., Mangtani, P., & Abubakar, I. (2011). How does the level of BCG vaccine protection against tuberculosis fall over time? BMJ, 343(sep29 2), d5974–d5974. https://doi.org/10.1136/bmj.d5974
Rosenbaum, P. R. (2007). Interference between Units in Randomized Experiments. Journal of the American Statistical Association, 102(477), 191–200.
Sakula, A. (1982). Robert Koch: Centenary of the discovery of the tubercle bacillus, 1882. Thorax, 37(4), 246–251.
Salazar-Austin, N., Hoffmann, J., Cohn, S., Mashabela, F., Waja, Z., Lala, S., Hoffmann, C., Dooley, K. E., Chaisson, R. E., Martinson, N., & TSHEPISO Study Team. (2018). Poor Obstetric and Infant Outcomes in Human Immunodeficiency Virus-Infected Pregnant Women With Tuberculosis in South Africa: The Tshepiso Study. Clinical Infectious Diseases, 66(6), 921–929. https://doi.org/10.1093/cid/cix851
Sharma, S. K., Mohan, A., Sharma, A., & Mitra, D. K. (2005). Miliary tuberculosis: New insights into an old disease. The Lancet Infectious Diseases, 5(7), 415–430.
Sugarman, J., Colvin, C., Moran, A. C., & Oxlade, O. (2014). Tuberculosis in pregnancy: An estimate of the global burden of disease. The Lancet Global Health, 2(12), e710–e716. https://doi.org/10.1016/S2214-109X(14)70330-4
Tanimura, T., Jaramillo, E., Weil, D., Raviglione, M., & Lonnroth, K. (2014). Financial burden for tuberculosis patients in low- and middle-income countries: A systematic review. European Respiratory Journal, 43(6), 1763–1775. https://doi.org/10.1183/09031936.00193413
Tarozzi, A., Mahajan, A., Blackburn, B., Kopf, D., Krishnan, L., & Yoong, J. (2014). Micro-Loans, Insecticide-Treated Bednets, and Malaria: Evidence from a Randomized Controlled Trial in Orissa, India. American Economic Review, 104(7), 1909–1941. https://doi.org/10.1257/aer.104.7.1909
Teo, A. K. J., Morishita, F., Islam, T., Viney, K., Ong, C. W. M., Kato, S., Kim, H., Liu, Y., Oh, K. H., Yoshiyama, T., Ohkado, A., Rahevar, K., Kawatsu, L., Yanagawa, M., Prem, K., Yi, S., Tran, H. T. G., & Marais, B. J. (2023). Tuberculosis in older adults: Challenges

and best practices in the Western Pacific Region. The Lancet Regional Health - Western Pacific, 36, 100770. https://doi.org/10.1016/j.lanwpc.2023.100770
Tombe, T., & Zhu, X. (2019). Trade, Migration, and Productivity: A Quantitative Analysis of China. American Economic Review, 109(5), 1843–1872. https://doi.org/10.1257/aer.20150811
Walles, J., Winqvist, N., Hansson, S. R., Sturegård, E., Baqir, H., Westman, A., Kjerstadius, T., Schön, T., & Björkman, P. (2024). Pregnancy Outcomes in Women Screened for Tuberculosis Infection in Swedish Antenatal Care. Clinical Infectious Diseases, 78(1), 125–132.
WHO. (1994). WHO tuberculosis programme: Framework for effective tuberculosis control (Vol. 94). World Health Organization.
WHO. (2023a). Global tuberculosis report 2023. World Health Organization.
WHO. (2023b). Management of moderate undernutrition in individuals with active tuberculosis. World Health Organization.
Wilkinson, D., Moore, D., & Millard, J. (1994). Tuberculosis treatment programmes in low-income countries. The Lancet, 344(8917), 259–260.
Yee, D., Valiquette, C., Pelletier, M., Parisien, I., Rocher, I., & Menzies, D. (2003). Incidence of Serious Side Effects from First-Line Antituberculosis Drugs among Patients Treated for Active Tuberculosis. American Journal of Respiratory and Critical Care Medicine, 167(11), 1472–1477. https://doi.org/10.1164/rccm.200206-626OC
Zenner, D., Kruijshaar, M. E., Andrews, N., & Abubakar, I. (2012). Risk of Tuberculosis in Pregnancy: A National, Primary Care–based Cohort and Self-controlled Case Series Study. American Journal of Respiratory and Critical Care Medicine, 185(7), 779–784. https://doi.org/10.1164/rccm.201106-1083OC
Zhang, D., & Unschuld, P. U. (2008). China's barefoot doctor: Past, present, and future. The Lancet, 372(9653), 1865–1867. https://doi.org/10.1016/S0140-6736(08)61355-0
Zhang, L., Xie, L., & Zheng, X. (2023). Across a few prohibitive miles: The impact of the Anti-Poverty Relocation Program in China. Journal of Development Economics, 160, 102945. https://doi.org/10.1016/j.jdeveco.2022.102945
Zhao, F., Christopher, M., Sergio, S., Karel, Styblo, & Jaap, Broekmans. (1996). Results of directly observed short-course chemotherapy in 112 842 Chinese patients with smear-positive tuberculosis. The Lancet, 347(8998), 358–362.
Zhao, Y. (1999). Leaving the Countryside: Rural-to-Urban Migration Decisions in China. American Economic Review, 89(2), 281–286. https://doi.org/10.1257/aer.89.2.281

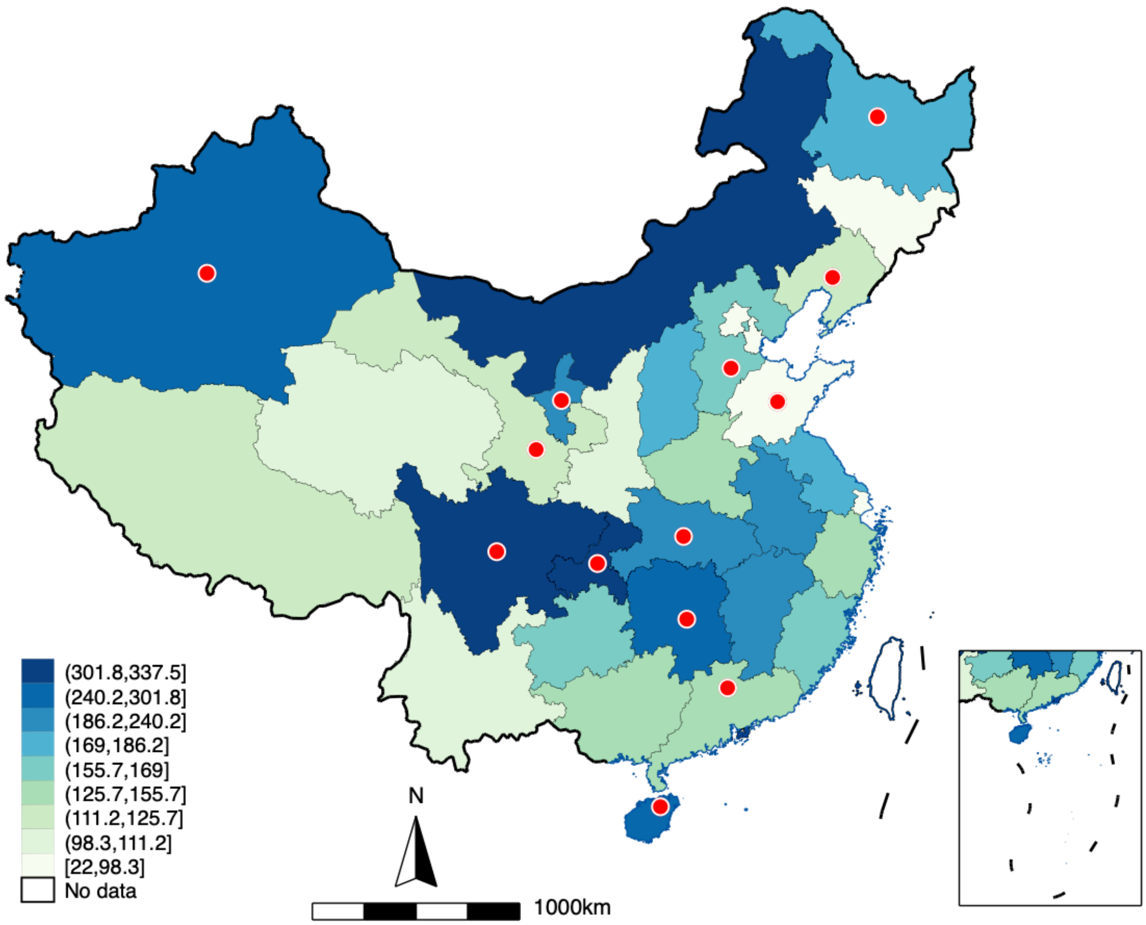


Figure 1: Spatial distribution of tuberculosis prevalence in 1990

Notes: This figure illustrates the smear-positive rates (per 100,000 population) of provinces in 1990, with red dots indicating provinces that implemented the TB program in 1992. *Data Source:* The 3rd national epidemiological tuberculosis survey in China (Ministry of Public Health of the People's Republic of China, 1992)

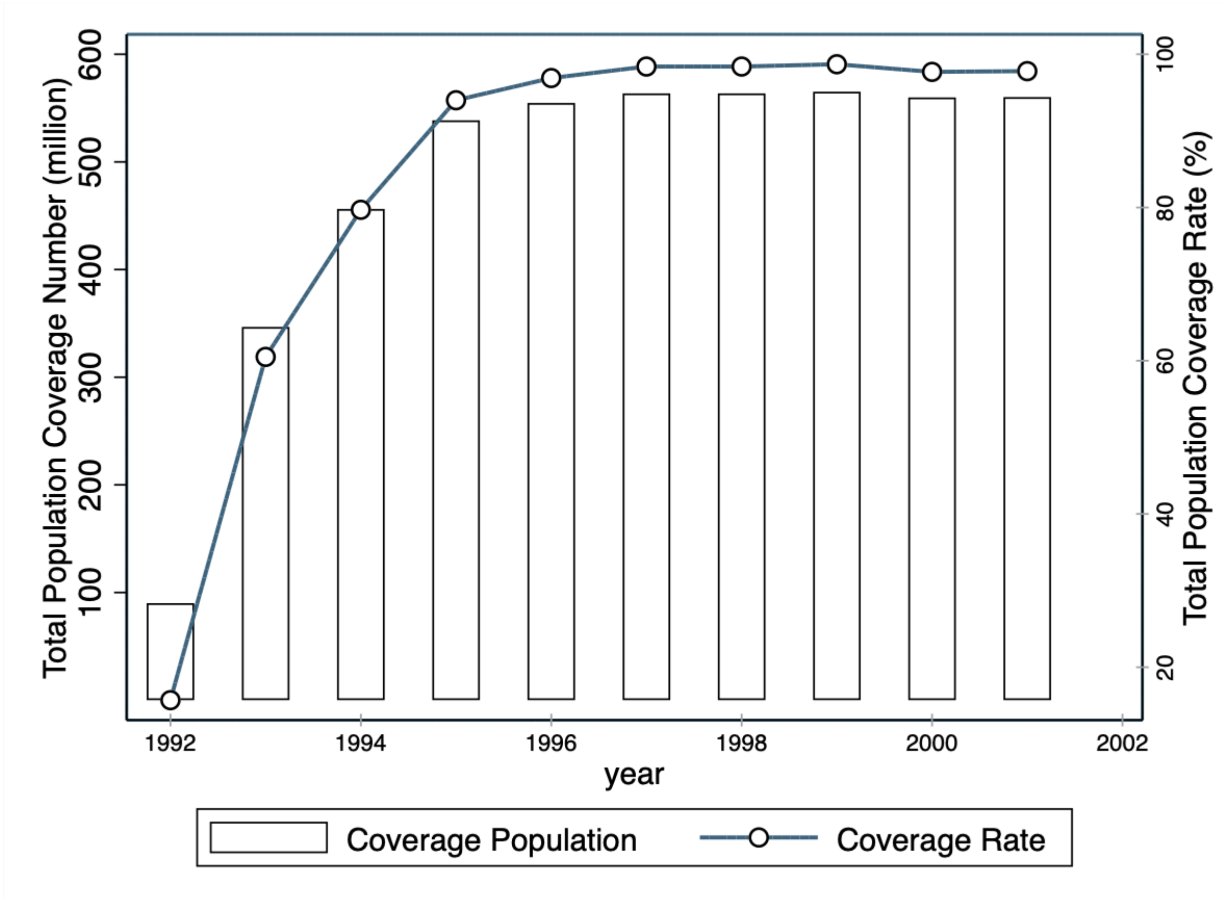


Figure 2: Time trend of coverage rate within DOTS provinces

Notes: This figure illustrates the rate and population of coverage of the TB program within DOTS provinces from 1992 to 2001. Data Source: Cai & Chen (2003).

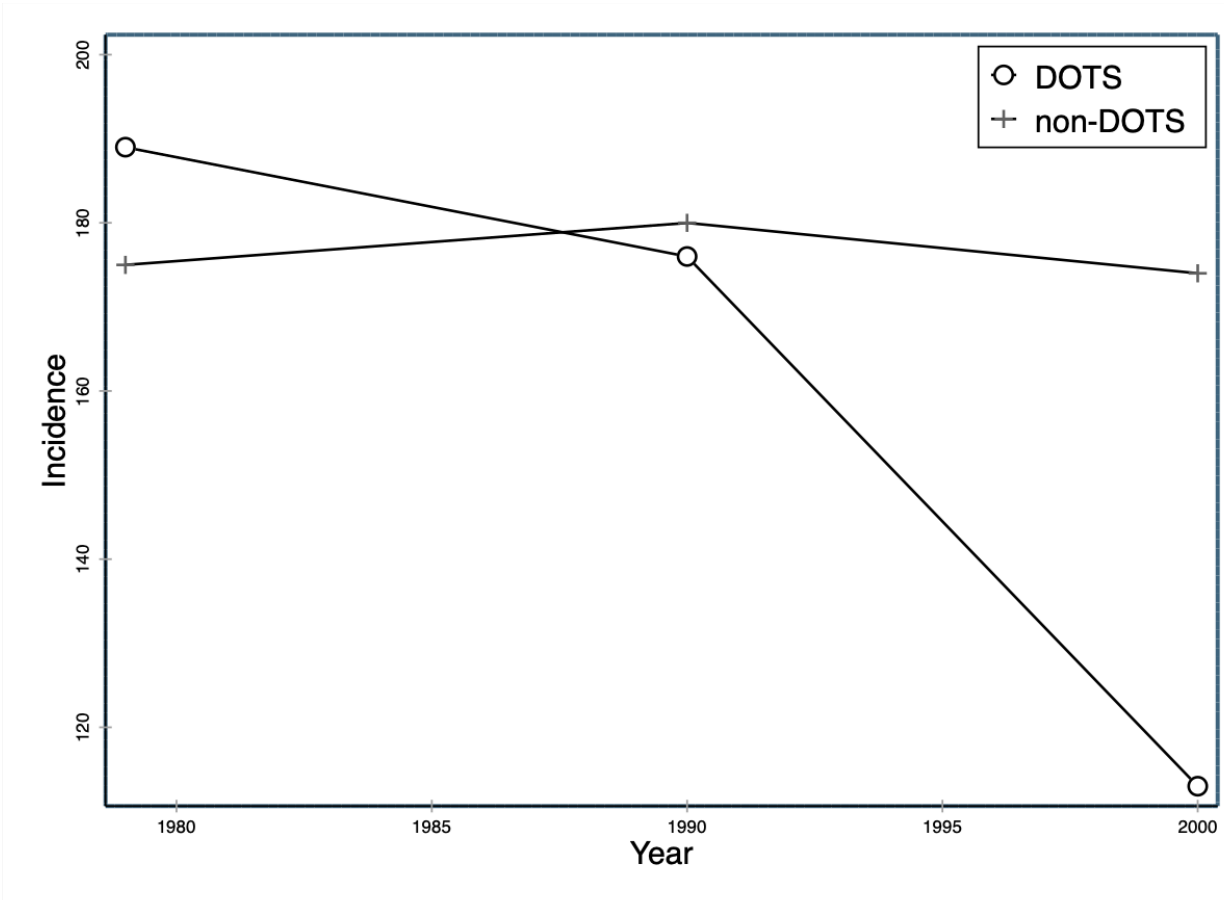


Figure 3: Time trend of tuberculosis prevalence between DOTS and non-DOTS provinces

Notes: This figure illustrates the smear-positive rates (per 100,000 population) between DOTS and non-DOTS provinces in 1978, 1990, and 2000. The 2nd national epidemiological tuberculosis survey conducted in 1985 was limited to only 22 provinces, unlike the 1st, 3rd, and 4th surveys. Due to this regional restriction, the collected information may lack national representativeness. Consequently, we have decided not to use data from the second survey. Data Source: The 1st, 3rd and 4th national epidemiological tuberculosis surveys in China (Ministry of Public Health of the People's Republic of China, 1981, 1992, 2003).

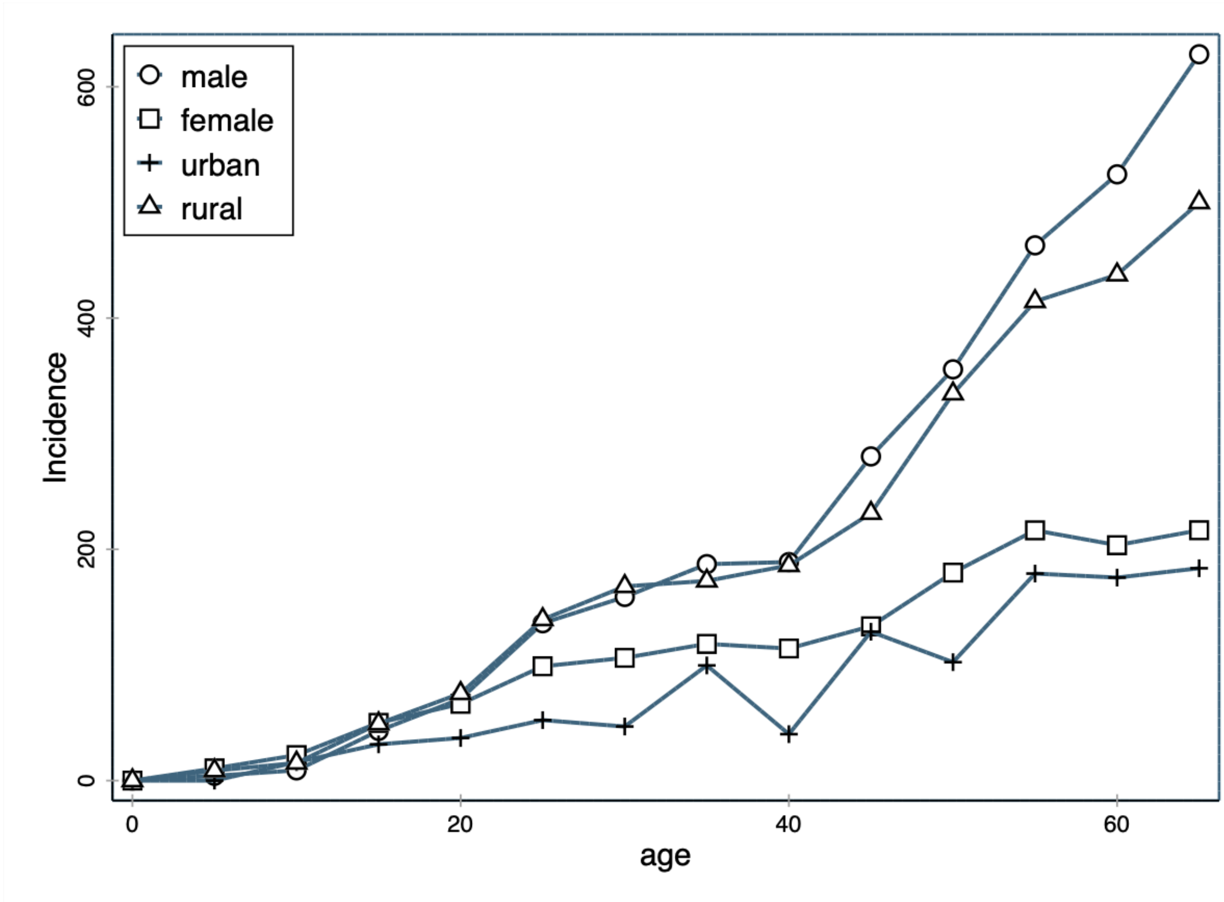
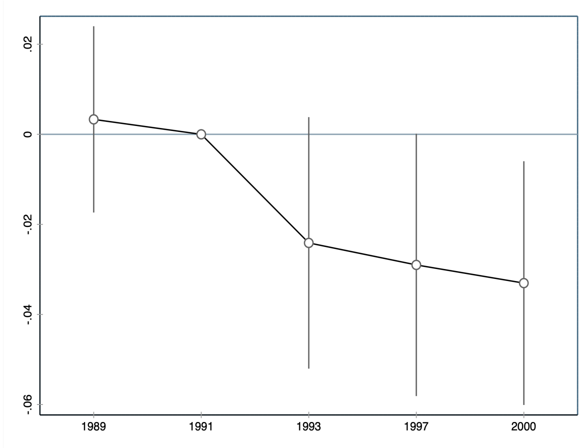


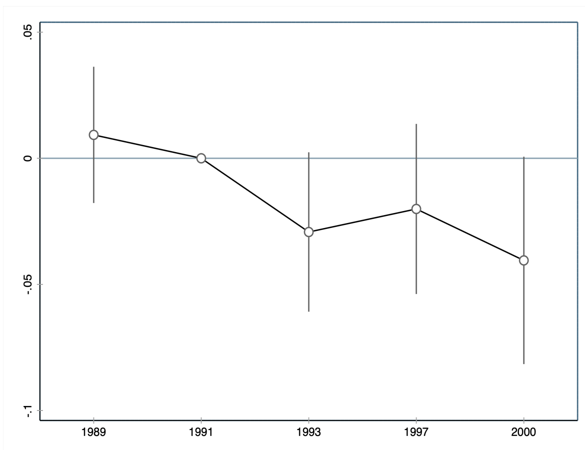
Figure 4: Age distribution of tuberculosis infection rate by gender and rural and urban areas

Notes: This figure illustrates the gender and rural-urban disparities in smear-positive rates (per 100,000 population) distribution across different age groups in 1990. However, due to data limitation, we are unable to present the smear-positive rates of urban men, urban women, rural-men, and rural women across different age groups in 1990. Data Source: The 3rd national epidemiological tuberculosis survey in China (Ministry of Public Health of the People's Republic of China, 1992).



Panel A: Sickness

Panel B: employment



Panel C: Child care provision

Panel D: Household income per capita

Figure 5: Event Study for all outcomes using the child-bearing age adults sample

Notes: This figure presents the event study estimation results of the estimated contemporaneous effects of the TB program using child-bearing age adults sample. The vertical and horizontal axis represent coefficients and year, respectively. Panels A, B, C, and D present the event study estimation results for sickness, employment, child care provision, and household income per capita, respectively. All models include individual fixed effects, province fixed effects, survey year fixed effects, age dummies, and interaction between survey year and 1990 provincial TB infection rate. Robust standard errors are clustered at province-survey year level. Data Source: CHNS 1989 – 2000.

Table 1: Summary Statistics

	Overall		Treated Group		Control Group		Men				Women			
							Treated Group		Control Group		Treated Group		Control Group	
	Obs	Mean	Obs	Mean	Obs	Mean	Obs	Mean	Obs	Mean	Obs	Mean	Obs	Mean
Panel A: Diseases														
Culture-positive	62	165.223	26	187.608	36	149.056								
Hepatitis	62	89.883	26	88.693	36	90.742								
Diarrhea	62	112.755	26	92.695	36	127.243								
Measles	62	6.942	26	5.353	36	8.090								
Panel B: Childbearing age adults (18-40)														
Sickness	14936	0.053	6805	0.043	8131	0.061	3442	0.043	4342	0.052	3363	0.044	3789	0.070
Employment	14935	0.935	6784	0.911	8151	0.955	3431	0.937	4372	0.959	3353	0.885	3779	0.951
Child care provision	17252	0.288	7693	0.298	9559	0.280	3811	0.192	4863	0.173	3882	0.403	4696	0.390
Household income per capita	17793	3303.278	7979	3310.443	9814	3297.453	3901	3375.805	4966	3306.739	4078	3247.917	4848	3287.942
Age	17929	28.257	8061	28.995	9868	27.653	3934	28.976	4998	27.502	4127	29.013	4870	27.809
Panel C: Older age adults (41-65)														
Sickness	10438	0.089	4103	0.064	6335	0.105	2029	0.067	3146	0.094	2074	0.061	3189	0.116
Employment	10453	0.858	4105	0.791	6348	0.901	2038	0.872	3153	0.926	2067	0.712	3195	0.876
Child care provision	10733	0.189	4213	0.151	6520	0.214	2086	0.091	3242	0.129	2127	0.210	3278	0.298
Household income per capita	10764	3540.413	6540	3506.931	4224	3592.253	2101	3513.917	3267	3463.666	2123	3669.776	3273	3550.116
Age	10842	51.263	4267	51.170	6575	51.323	2121	51.044	3281	51.378	2146	51.295	3294	51.268
Panel D: School-age children (6-17)														
Sickness	9420	0.033	4188	0.027	5232	0.038	2170	0.031	2774	0.037	2018	0.023	2458	0.038
School attendance	8499	0.803	3740	0.809	4759	0.798	1941	0.826	2542	0.813	1799	0.791	2217	0.781
Age	9859	11.677	4386	11.548	5473	11.781	2297	11.554	2924	11.756	2089	11.541	2549	11.811
Panel E: Cohort sample														
High School	3206	0.172	1414	0.238	1792	0.121	730	0.244	925	0.114	684	0.231	867	0.129
Age	3206	24.047	1414	24.454	1792	23.727	730	23.821	925	22.728	684	25.130	867	24.792
Han	3206	0.998	1414	0.997	1792	0.999	730	0.995	925	0.999	684	1.000	867	1.000

Data Sources: Panel A: The Data-center of China Public Health Science, 3rd and 4th national epidemiological tuberculosis surveys. Panels B-D: CHNS 1989 – 2000. Panel E: CHNS 2015.

Table 2: Effects of the TB program on tuberculosis prevalence

	Tuberculosis	Hepatitis	Diarrhea	Measles
	(1)	(2)	(3)	(4)
Dots*post	-63.3436*	17.2336	40.2316	-0.5151
	(33.6691)	(20.0799)	(32.0384)	(3.2414)
Observations	62	62	62	62

Notes: All models include province fixed effects and year fixed effects. *** p<0.01, ** p<0.05, * p<0.1. Data Source: CHNS 1989 – 2000.

Table 3. Contemporaneous effects of the TB program on child-bearing age adults

	Sickness	Employment	Child care provision	Household income per capita
	(1)	(2)	(3)	(4)
Panel A: Whole sample				
Dots*post	-0.0285**	-0.0490*	-0.0331**	133.5782
	(0.0119)	(0.0248)	(0.0131)	(265.0708)
Observations	14,936	14,935	17,252	17,793
Panel B: Male				
Dots*post	-0.0271*	-0.0461**	-0.0078	134.6969
	(0.0141)	(0.0185)	(0.0168)	(299.3064)
Observations	7,784	7,803	8,674	8,867
Panel A: Female				
Dots*post	-0.0289*	-0.0506	-0.0528**	112.4066
	(0.0152)	(0.0335)	(0.0196)	(246.7797)
Observations	7,152	7,132	8,578	8,926

Notes: All models include individual fixed effects, province fixed effects, survey year fixed effects, age dummies, and interaction between survey year and 1990 provincial TB infection rate. Robust standard errors are clustered at province-survey year level. *** p<0.01, ** p<0.05, * p<0.1. Data Source: CHNS 1989 – 2000.

Table 4. Contemporaneous effects of the TB program on older age adults

	Sickness	Employment	Child care provision	Household income per capita
	(1)	(2)	(3)	(4)
Panel A: Whole sample				
Dots*post	-0.0101	-0.0886***	-0.0361**	72.1355
	(0.0233)	(0.0228)	(0.0156)	(329.2091)
Observations	10,438	10,453	10,733	10,764
Panel B: Male				
Dots*post	-0.0199	-0.0740***	-0.0269**	25.2044
	(0.0264)	(0.0211)	(0.0120)	(336.0459)
Observations	5,175	5,191	5,328	5,368
Panel A: Female				
Dots*post	-0.0007	-0.1008***	-0.0481*	98.9995
	(0.0268)	(0.0314)	(0.0249)	(330.8438)
Observations	5,263	5,262	5,405	5,396

Notes: All models include individual fixed effects, province fixed effects, survey year fixed effects, age dummies, and interaction between survey year and 1990 provincial TB infection rate. Robust standard errors are clustered at province-survey year level. *** p<0.01, ** p<0.05, * p<0.1. Data Source: CHNS 1989 - 2000

Table 5. Contemporaneous effects of the TB program on school-age children

	Sickness	School enrollment
	(1)	(2)
Panel A: Whole sample		
Dots*post	0.0170	0.0074
	(0.0166)	(0.0260)
Observations	9,420	8,499
Panel B: Male		
Dots*post	0.0138	0.0171
	(0.0177)	(0.0284)
Observations	4,944	4,483
Panel A: Female		
Dots*post	0.0201	-0.0014
	(0.0199)	(0.0377)
Observations	4,476	4,016

Notes: All models include individual fixed effects, province fixed effects, survey year fixed effects, age dummies, and interaction between survey year and 1990 provincial TB infection rate. Robust standard errors are clustered at province-survey year level. *** p<0.01, ** p<0.05, * p<0.1. Data Source: CHNS 1989 – 2000.

Table 6. Intergenerational effects of the TB program using cohort sample and census sample

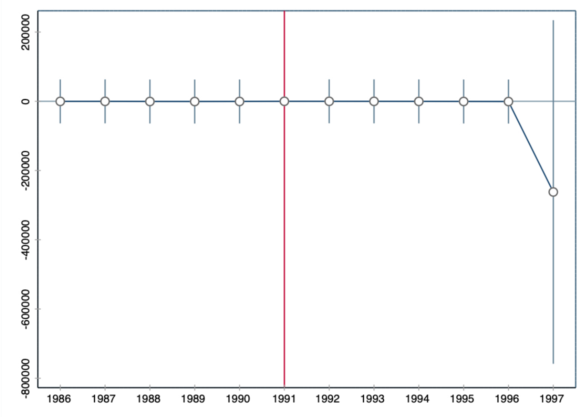
	High school (CHNS) (1)	High school (Census) (2)
Panel A: Whole sample		
Dots*cohort	0.0810***	0.0163**
	(0.0292)	(0.0080)
Observations	3,206	94,724
Panel B: Male		
Dots*cohort	0.0351	0.0108
	(0.0331)	(0.0121)
Observations	1,655	50,200
Panel C: Female		
Dots*cohort	0.1537***	0.0218**
	(0.0441)	(0.0109)
Observations	1,551	44,524

Notes: All models include birth province fixed effects, birth year fixed effects, age dummies, gender dummies, han ethnic group indicator, and interaction between birth year and 1990 provincial TB infection rate. Robust standard errors are clustered at province-year of birth level. *** p<0.01, ** p<0.05, * p<0.1. Data Source: CHNS 2015 and 2015 1% Census.

Table 7. Robustness checks using child-bearing age adults sample

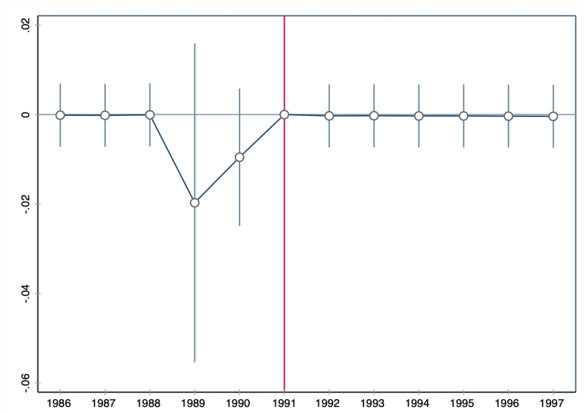
	Sickness	Employment	Child care provision	Household income
	(1)	(2)	(3)	(4)
Panel A: Placebo test				
Dots*post	-0.0270**	-0.0570*	-0.0290*	-63.1009
	(0.0110)	(0.0283)	(0.0144)	(299.1433)
Dots*placebo post	-0.0033	0.0177	-0.0093	449.0234
	(0.0102)	(0.0291)	(0.0134)	(269.5573)
Observations	14,936	14,935	17,252	17,793
Panel B: Schistosomiasis				
Dots*post	-0.0210*	-0.0474	-0.0337**	208.6123
	(0.0112)	(0.0285)	(0.0138)	(273.9665)
Observations	14,936	14,935	17,252	17,793
Panel C: Region-time trend				
Dots*post	-0.0243*	-0.0612**	-0.0298**	-54.9046
	(0.0132)	(0.0236)	(0.0114)	(265.5567)
Observations	14,936	14,935	17,252	17,793
Panel D: Wild-cluster bootstrap				
Original p-value	0.0217	0.0558	0.0153	0.6172
Wild-cluster bootstrap p-value	0.0260	0.0240	0.0200	0.6306
Observations	14,936	14,935	17,252	17,793

Notes: All models include individual fixed effects, province fixed effects, survey year fixed effects, age dummies, and interaction between survey year and 1990 provincial TB infection rate. Robust standard errors are clustered at province-survey year level. *** p<0.01, ** p<0.05, * p<0.1. Data Source: CHNS 1989 – 2000.

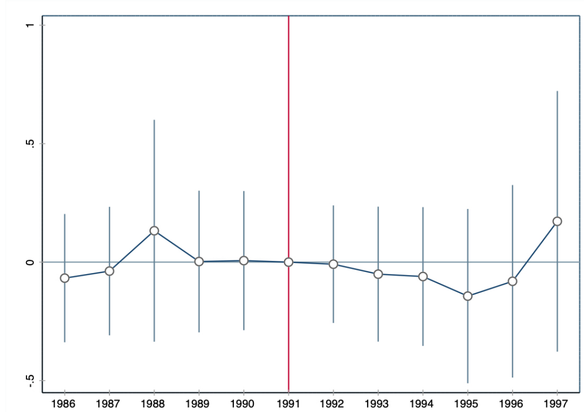


Panel A: GDP per capita

Panel B: Medical personnel per 10k people



Panel C: Health care facilities bed per 10k people



Panel D: health care facilities per 10k people

Figure A.1: Systematical difference check between DOTS and non-DOTS provinces

Notes: This figure presents the event study estimation results of the effects of the TB program on provincial characteristics. The vertical and horizontal axis represent coefficients and year, respectively. Panels A – D presents the results for GDP per capita, medical personnel per 10k people, health care facilities bed per 10k people, and health care facilities per 10k people, respectively. All models include province fixed effects and year fixed effects. Observations are at the province-year level. Robust standard errors are clustered at province level. Data Sources: China Statistical Yearbook 1987-1998.

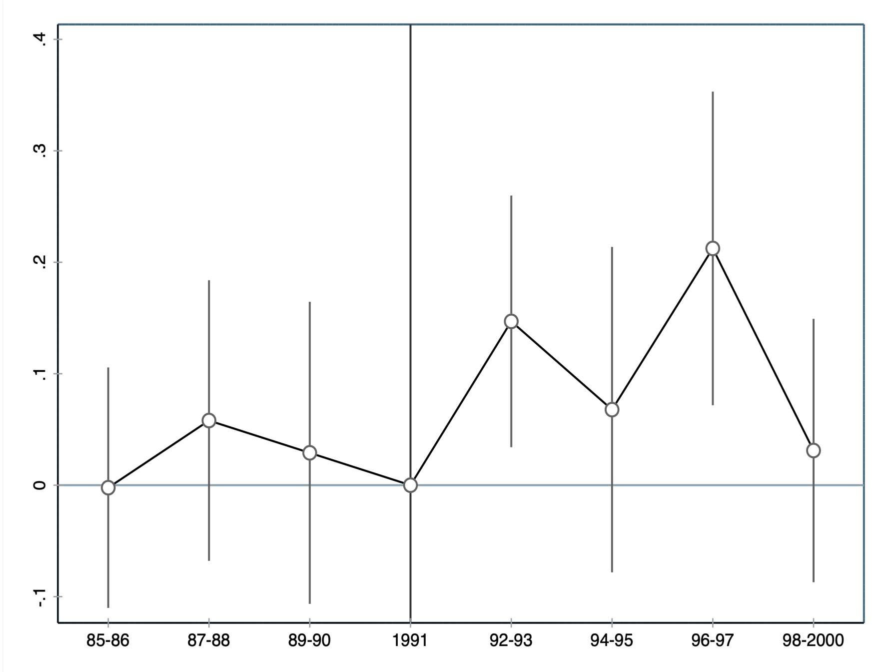
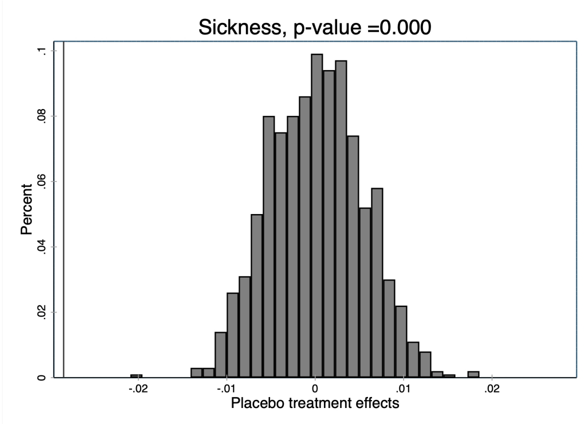


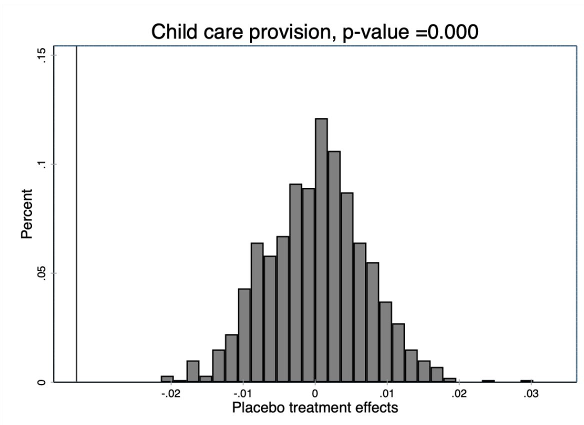
Figure A.2: Event study for high school attainment using the cohort sample

Notes: This figure presents the event study results for school attainment using cohort birth between 1985 to 2000. The vertical and horizontal axis represent coefficients and year, respectively. All models include birth province fixed effects, birth year fixed effects, age dummies, gender dummies, han ethnic group indicator, and interaction between birth year and 1990 provincial TB infection rate. Robust standard errors are clustered at province-year of birth level. Data Source: CHNS 2015.

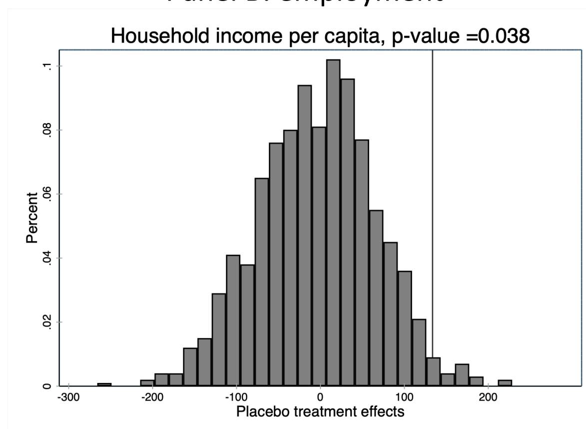


Panel A: Sickness

Panel B: employment



Panel C: Child care provision



Panel D: Household income per capita

Figure A.3: Permutation tests using child-bearing age adults sample

Notes: We randomly assign provinces as DOTS provinces. The histogram displays the distribution of the placebo estimates from 999 random assignments. The vertical line is the estimated coefficient. The p-value of the permutation test is the proportion of placebo estimates greater than or equal to in absolute value the estimated effect of the actual reform from the baseline analysis. Data Source: CHNS 1989 – 2000.

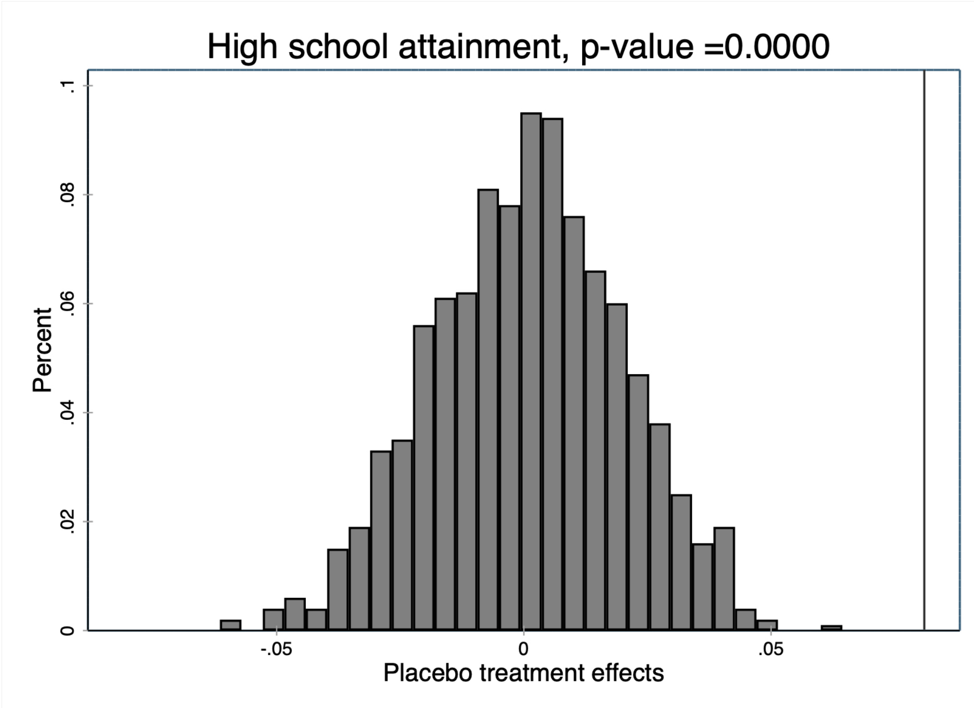


Figure A.4: Permutation tests using cohort sample

Notes: We randomly assign provinces as DOTS provinces. The histogram displays the distribution of the placebo estimates from 999 random assignments. The vertical line is the estimated coefficient. The p-value of the permutation test is the proportion of placebo estimates greater than or equal to in absolute value the estimated effect of the actual reform from the baseline analysis. Data Source: CHNS 2015.

Table A.1. Contemporaneous effects of the TB program on people from all age groups and urban areas

	Sickness	Employment	Child care provision	Household income per capita	School enrollment
	(1)	(2)	(3)	(4)	(5)
Panel A: Childbearing age					
Dots*post	-0.0072	-0.0094	-0.0319	21.0878	
	(0.0191)	(0.0277)	(0.0300)	(312.0647)	
Observations	6,708	6,744	7,471	7,825	
Panel B: Older age					
Dots*post	0.0007	-0.0603	0.0193	-341.7812	
	(0.0411)	(0.0422)	(0.0239)	(420.9433)	
Observations	5,451	5,477	5,508	5,641	
Panel C: School age					
Dots*post	0.0109				-0.0139
	(0.0327)				(0.0389)
Observations	2,894				2,534

Notes: All models include individual fixed effects, province fixed effects, survey year fixed effects, age dummies, and interaction between survey year and 1990 provincial TB infection rate. Robust standard errors are clustered at province-survey year level. *** p<0.01, ** p<0.05, * p<0.1. Data Source: CHNS 1989 – 2000.

Table A.2. Summary statistics of outcome and control variables of the cohort sample constructed from the 2015 1% Census.

	Overall		Treated Group		Control Group		Men				Women			
							Treated Group		Control Group		Treated Group		Control Group	
	Obs	Mean	Obs	Mean	Obs	Mean	Obs	Mean	Obs	Mean	Obs	Mean	Obs	Mean
Panel A: Cohort sample														
High School	94724	0.3831	42642	0.3857	52082	0.3806	22486	0.3829	27714	0.3861	20156	0.3889	24368	0.3743
Age	94724	23.2309	42642	23.2806	52082	23.1840	22486	23.2314	27714	23.0733	20156	23.3345	24368	23.3112
Han	94724	0.8821	42642	0.8884	52082	0.8761	22486	0.8891	27714	0.8750	20156	0.8876	24368	0.8772

Data Sources: 2015 1% Census.

Table A.3. Investigation of the 93 program induced potential bias

	High school
	(1)
Dots*post	0.1252**
	(0.0583)
Observations	3,206

Notes: Using cohort sample birth between 1985 and 2000. The model includes the 93 program interaction term, birth province fixed effects, birth year fixed effects, age dummies, gender dummies, han ethnic group indicator, and interaction between birth year and 1990 provincial TB infection rate. Robust standard errors are clustered at province-year of birth level. *** p<0.01, ** p<0.05, * p<0.1. Data Source: CHNS 2015.

Table A.4. Robustness checks using cohort sample

	High school (1)
Panel A: placebo test	
Dots*cohort	0.0856**
	(0.0367)
Observations	3206
Panel B: Schistosomiasis	
Dots*cohort	0.0925***
	(0.0309)
Observations	3206
Panel C: Region-time trend	
Dots* cohort	0.0585*
	(0.0327)
Observations	3206
Panel D: Wild-cluster bootstrap	
Original p-value	0.0059
Wild-cluster bootstrap p-value	0.0120
Observations	3206

Notes: All models include birth province fixed effects, birth year fixed effects, age dummies, gender dummies, han ethnic group indicator, and interaction between birth year and 1990 provincial TB infection rate. Robust standard errors are clustered at province-year of birth level. *** p<0.01, ** p<0.05, * p<0.1. Data Source: CHNS 2015.