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Three essays on human capital in China

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Three essays on human capital in China

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The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this dissertation. The Graduate College will ensure this dissertation is globally accessible and will not permit alterations after a degree is conferred.

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DEDICATION

To my family.

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ABSTRACT

This dissertation consists of three chapters on human capital in China.

Chapter 1 studies the relationship between prenatal exposure to air pollution and youth cognitive skill development in China. It finds that early exposure to air pollution in utero has a significant detrimental impact on youth cognitive skill development. The effect of prenatal health shock on human capital becomes more apparent as the child ages. The early health shock also has a more significant impact than late shocks on human capital outcomes since early shocks accumulate through time. Prenatal exposure to air pollution also adversely affects youth health, weight, and height in later childhood. The findings provide additional evidence supporting the "fetal origins" hypothesis, which predicts early shocks in utero affect outcomes later in life.

Chapter 2 focuses on the impact of the Cultural Revolution (1966 to 1976) on life-cycle earnings. The Cultural Revolution significantly lowered educational attainment, education quality and accumulated work experience for affected cohorts. Because of reduced education quantity and quality, the affected cohort earned a 12 percent less income than the youngest generation in 1995. Four percent of this twelve percent was caused by shortened education. The adverse effect on returns to human capital diminishes over time, but the losses due to smaller accumulations of human capital persist. The affected generations were further disadvantaged by being more likely to be laid off during the reform of state-owned enterprises in the late 1990s.

Chapter 3 examines the impact of three government policies on Chinese food production. Three events fundamentally changed modern Chinese economic history: the Great Leap Forward (1958~1961), the Cultural Revolution (1966~1976) and economic reform initiated in 1978. We apply the Caselli and Coleman (2006) framework to explore the dynamics of labor efficiency of grain production from 1952 to 2008. We apply non-linear least squares estimation allowing for imperfect substitution between low- and high-skill labor to approximate the production function for grains. This framework allows for endogenous choices of labor efficiency in response to a changing technological frontier. This study finds an enormous loss in technical frontier and labor efficiency after the Great Leap Forward. The technical frontier and labor efficiency only had a modest gain during the Cultural Revolution, and some provinces did not recover until the household-responsibility system was introduced after the rural economic reforms in 1978. There is a skill-biased technical change that favors skilled labor more than unskilled labor, but the skill-biased productivity gains were suppressed before the 1978 reforms.

CHAPTER 1. EARLY EXPOSURE TO AIR POLLUTION AND COGNITIVE DEVELOPMENT LATER IN LIFE: EVIDENCE FROM CHINA

1.1 Introduction

Air pollution is commonly associated with adverse health conditions. Epidemiological studies suggest that children are particularly vulnerable to ambient pollutants. High air pollution leads to more physical and mental problems for children (Evans, 2003; Gauderman et al., 2002; Romieu et al., 1996). However, few studies have measured the detrimental impact of air pollution on the cognitive ability and academic performance of youth. Since Chinese air quality is notoriously poor, a natural question is "what is the impact of air pollution on cognitive development of Chinese youth?". While air pollution is a consequence of the economic development of China, pollution could also hinder future growth if it lowers the cognitive potential of the next generation. The purpose of this paper is to explore the long-term effect of prenatal exposure to air pollution and the cognitive development of youth in China.

Early life shocks can have both immediate and persistent adverse impacts on life outcomes. Barker (1986, 1990) is the first to argue that adverse conditions as early as conception might lead to future diseases, and he proposed the "fetal origins" theory. Since then, many epidemiology studies have found that adverse shocks in utero hurt neonatal health[1]. In the study of economics, Currie and Hyson (1999) evaluated the effect of low birth weight on economic success in adulthood. Since then, air pollution in utero has been associated with various health consequences for children, including asthma (McConnell, et al 2002), infant mortality (Chay and Greenstone, 2003a, 2003b; Currie and Neidell, 2005; Tanaka, 2015) and low birth weight (Currie and Hyson, 1999; Currie and Walker; 2011; Currie and Schmieder; 2009; Bharadwaj et al.,

[1] See Barker (1995), Gluckman and Hanson (2009), Eriksson (2001), Hanson and Gluckman (2014).

2014). Almond and Currie (2011) summarized the development of the economic study of ‘fetal origins’ theory.

Health early in life has been associated with cognitive development and human capital outcomes (Case and Paxson, 2008, 2009; Currie et al., 2010 Figlio, 2014; Persico et al., 2019). Miguel and Kremer (2004) found that early treatment for intestinal worms improved children’s health and reduced absenteeism in schools. Baird et al. (2016) showed that adults who had received deworming treatments early in life worked more hours and earned 20% higher wages. Reyes (2011) evaluated the impact of early exposure to lead on cognitive development. She found that elevated levels of blood lead in early childhood are shown to adversely impact standardized test performance in Massachusetts. Maluccio et al. (2009) found that early childhood nutritional intervention improved reading and nonverbal cognitive ability and raised adult earnings for both women and men. Early exposure to high temperatures had a long-term impact on human capital accumulation and productivity later in life (Fishman et al., 2019).

Prenatal exposure to air pollution could also affect cognitive ability and impede human capital formation, especially academic performance. Sanders (2012) was the first to study the impact of prenatal exposure to air pollution on the cognitive development of youth. He found a significant detrimental effect of prenatal exposure to air pollution on the academic performance of youth in Texas during the 1980s. Bharadwaj et al. (2017) evaluated the impact of prenatal exposure to air pollution on cognitive ability using survey data of siblings. By exploiting the variation in prenatal exposure to air pollution between siblings, they found that prenatal exposure adversely affected academic performance in later childhood. Nevertheless, only a few studies have examined the long-term impact of air pollution on human capital formation, especially for developing countries that have huge populations and severe air pollution.

This study uses data on Chinese regional air pollution during 1981-2004, compiled by the World Bank, and information from a survey conducted in 2008 to show how total suspended particulates (TSPs) in utero affect later academic performance and cognitive skills for the children aged between 6 and 19. The Chinese Household Income Project (CHIP) 2008 contains the information of individual students from thirteen cities in eight provinces in China. It includes academic performance in mathematics and language for individual students. The air pollution is matched with the sample of CHIP 2008 based on the city codes. The analysis controls other possible confounding factors, including household characteristics, school features, economic demographics and weather conditions. Ordinary least squares (OLS) estimation and two-stage least squares (2SLS) estimation are used to test three hypotheses derived from a theoretical model built on Currie et al. (2010). This study finds that early exposure to air pollution in utero has a significant detrimental impact on youth cognitive skill development. The effect of prenatal health shock on human capital becomes more apparent as the child ages. Early health shocks also have a more significant impact than late shocks on human capital outcomes since early shocks accumulate over time. The OLS estimation shows that a one-standard-deviation increase of prenatal exposure to TSPs is associated with 27 percent of a standard deviation of math scores and 23 percent for language scores. The 2SLS estimation reflects that a one-standard-deviation increase in prenatal exposure to TSPs reduces math scores by 32 percent and 56 percent of a standard deviation of the math and language scores, respectively.

This research contributes to the language in three ways. First, it adds to the current language about the long-term adverse impact of air pollution on academic performance (Sanders, 2012; Bharadwaj et al., 2017). By using detailed survey data, this paper provides the micro-foundations supporting the “fetal origins” hypothesis, controlling for heterogeneity at the individual student level. This study finds that prenatal exposure to TSPs has a significantly negative effect on cognitive development.

Second, this is among the first studies examining the impact of air pollution on cognitive development in China. The only similar work is Zhang et al. (2018), which measures the transitory and accumulative impact of air pollution on cognitive development[2]. This study, however, examines the effect of prenatal exposure to air pollution. If damage to cognitive potential persists and accumulates over a person's lifetime, these external costs will lower potential individual welfare and future economic growth due to human capital loss.

Third, this study is the first to test the cognitive impact of early exposure in utero and after-birth exposure to air pollution simultaneously. By doing so, it compares the relative importance of the two. This study finds that prenatal exposure to air pollution dominates after-birth exposure.

This paper is organized as follows. Section 2 provides a background on Chinese air pollution and reviews previous studies on the detrimental impact of air pollution on brain functioning and cognitive skill development. Section 3 describes the data used in this study. Section 4 introduces the theoretical model and empirical specifications. Section 5 presents the empirical results. The discussion and concluding remarks are given in section 6.

1.2 Background

1.2.1 Chinese Air Pollution

China has a severe air pollution problem. The ambient concentration of total suspended particulates (TSPs) between 1981 and 2001 was five times the level in the United States before

[2] Zhang et al. (2018) conducted a panel study by linking the CFPS 2010 and CFPS 2014 with the air pollution indexes (APIs) provided by the Chinese Environment Department. Their research focuses on the impact of air pollution on the cognitive skill development across ages. They found a one-standard-deviation increase in the API within a week lowers test scores by 1.6%, and it lowers math scores by 0.6%.

the passage of the Clean Air Act in 1970. Hazardous pollutants have caused both economic and noneconomic damage. Zhang et al. (2008) estimated that the total economic cost in China caused by PM_{10}[3] was approximately $30 billion in 2004. He et al. (2018) found that air pollution significantly reduced worker's productivity in China. In addition, life expectancy has been shortened by three years due to air pollution in northern China (Chen et al., 2013). The air quality has improved since the 2008 Olympic Games, but air pollution levels are still high. The average concentration of PM 2.5[4] in Beijing was 155 $\mu g/m^3$ in the winter of 2016[5], approximately 16 times the WHO standard.

1.2.2 Air Pollution, Brain Functioning, and Cognitive Ability Development

Most research on the health consequences of air pollution came from epidemiology. Air pollution causes brain damage through the respiratory system, leading to more inflammation and depressing the neurons and white matter cells. (Calderon-Garciduenas et al., 2002; Costa et al., 2014; Fonken et al., 2011). Air pollution also affects genetic expression, which controls brain function (Risom et al., 2005; Calderon-Garciduenas et al., 2003).

Most economic research focuses on the contemporaneous impact of air pollution on the cognitive ability and academic performance of youth. For example, Zweig et al. (2009) found a negative short-term cognitive impact of air pollution caused by fuel combustion in California. Lavy et al. (2014) observed a detrimental impact of air pollutants (PM2.5 and CO) on the academic performance of students in Israel. Recent research (Liu and Salvo, 2018; Chen et al., 2018) analyzed the increase in student absences in schools when air pollution is severe in China. Zhang et al. (2018) utilized a rich sample and studied the transitory and cumulative impact of air

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[3] Airborne particulate with a diameter smaller than 10 micrometers. One micrometer = 10^{-6} meter.
[4] Airborne particulate with a diameter smaller than 2.5 micrometers.
[5] Data Source: Air quality data of U.S. embassy in Beijing, China. This data is available since 2008.

pollution on cognitive development in China. They found that cognitive skills are negatively correlated with the average air pollution level within three years.

Bharadwaj et al. (2017) found an adverse impact of exposure to air pollution in utero after controlling for the fixed effect among twins. Sanders (2012) studied the impact of prenatal exposure to TSPs on educational outcomes using county-level variations in air quality in Texas. From his cross-sectional analysis, he found that a standard deviation decrease in TSPs in utero is associated with two percent of a standard deviation increase in school test scores for OLS estimation and six percent for his IV estimation.

1.3 Data

1.3.1 Air Pollution Data

The World Bank's Development Economics Research Group (DECRG) collaborated with China National Environmental Monitoring Stations to provide Chinese air pollution data from 1981 to 1995. The China Environmental Yearbooks provide the same data from 1990 to 2004. I combine these two series for three measures of air pollution: total suspended particulates, sulfur dioxide, and nitrogen oxide. The air pollution data report these three air pollutants for the period 1981-2004. The suspended particulates are atmospheric particulate matter (PM) with a diameter of smaller than 100 micrometers and containing large particles such as pollen and finer matter produced by industry and fuel combustion. It is also called PM100 in the way that PM 10 and PM 2.5 are defined. Figure 1.1 illustrates the data availability of air pollution in China. Before 2004, TSPs, sulfur dioxide and nitrogen oxide were the only available measures of air pollution in China. The government has reported the air pollution index (API), which lists the amounts of various pollutants, including TSPs, sulfur dioxide and nitrogen oxide, since 2005. The U.S. embassies have reported the PM 2.5 levels of multiple cities since 2008. The currently used air quality index (AQI) was introduced in 2013, and PM 2.5 has also been available since then.

Figure 1.2 shows the geographic locations of all thirteen cities studied in this paper. Most cities are in southern China, away from Beijing. Figure 1.3 shows the time series data on total suspended particulates for multiple cities in the sample. TSPs level was particularly severe at the beginning of the 1980s. Air quality improved during the 1990s and has remained relatively constant at 100-250 $\mu g/m^3$ since 2000. As the statistical summary lists in Table 1.1, the average total suspended particulates at birth is approximately 256 $\mu g/m^3$, which is very high compared with the U.S. Environmental Protection Agency standard (45 $\mu g/m^3$ in 1971). Figure 1.4 illustrates the distribution of three different air pollutants in the sample. The prenatal exposure to TSPs ranged between 0.087 mg/m^3 (or 87 $\mu g/m^3$) and 0.815 mg/m^3 (or 815 $\mu g/m^3$).

Figure 1.5 illustrates the distributional pattern in the concentration of TSPs, sulfide dioxide, and nitrogen monoxide by different years in the period 1989-2002. The level of TSPs concentration has a decreasing trend and the variations between years and cities are sizeable. Figure 1.6 shows the correlation between every two types of air pollutants among TSPs, sulfide dioxide, and nitrogen monoxide. It shows that TSPs and SO_2 are correlated, and TSPs and NO_x are also correlated with each other while not as close as TSPs and SO_2.

Although Chinese government data on air pollution may be suspect, Chen, Ebenstein, Greenstone, and Li (2013), who used similar data with this study, reported that the data quality is not a critical issue. For the period of their study, government officials' evaluations were primarily based on economic growth rather than environmental indices. Moreover, the statistics were not widely available at that time, which reduced the incentive to publish inaccurate information. This study corrects for the potential bias from mismeasured pollution using an instrumental variable estimation and compares the empirical results to the ordinary least-squares estimate.

1.3.2 Test Scores and Household Demographics

Individual test scores were obtained from the 2008 Chinese Household Income Project (CHIP). The dataset provides detailed household demographics, including parents' information (e.g., income and education), children's characteristics (e.g., age, gender, birth order, and educational expenditure), and schools' features (e.g., school quality and type). The CHIP data contains the language and mathematics exam scores of students from thirteen cities in eight provinces. The study focuses on children aged 6 to 19 who are in primary and secondary schools. CHIP 2008 separates all observations into three subsamples: urban nonmovers, migrants, and rural nonmovers. Since almost all air pollution monitors are located in urban areas and to avoid misusing pollution exposure due to migration (Banzhaf and Walsh, 2008), this study first focuses on urban nonmovers and then tests a supplemental subsample of migrants in the same cities. The language and math test scores are converted into standard scores (i.e., z-value) based on school grades to make the scores comparable among students from different school grades. That is,

$$Z_{ij} = \frac{s_{ij} - \overline{S_j}}{\sigma(S_j)}.$$

The test score of an individual student *i* who is at school grade *j* (e.g., the 1st year of elementary school or the 2nd year of high school) has an exam score s_{ij} (a percentage value). $\overline{S_j}$ is the average test score for the students at school grade *j*, and $\sigma(S_j)$ is the standard deviation of the test scores of students at school grade *j*. Figure 1.7 shows the distribution of standardized math and language scores. The range of math test scores is (-7.744, 1.909), and the range of language test scores is (-5.626, 2.276). Figure 1.8 shows the distribution of math test scores and language test scores by birth years, and it also illustrates the correlation between prenatal exposure to TSPs and test scores. The top panel of Figure 1.8 shows a substantial variation in test scores of math and language. The bottom panel of Figure 1.8 implies an inverse correlation between prenatal exposure to TSPs and test scores.

Table 1.1 describes the data in this study. The information on the children includes their age, their gender, and their birth order. The education-related factors are school type, school quality, and educational expenditure. Other household characteristics include parents' education, annual income, and the number of children. CHIP also reports children's current height, weight, and health status, which measures children's health and physical maturity.

1.3.3 Other Factors

Weather can be a confounding factor because of the correlation between air pollution and atmospheric characteristics. To isolate the impact of air pollution, several weather indicators are included in the analysis. The climatic data come from the China Meteorological Data Service Center (CMDC). They provide annual information about mean temperature, the number of days with precipitation, sunshine hours, humidity, wind speed, and ground atmospheric pressure of different cities. I include the mean temperature, sunshine hours, number of days with precipitation more than one centimeter, and humidity as covariates in the estimation. Table 1.1 reports the atmospheric features of the cities in this study. This study also includes economic demographics such as GDP per capita at birth and the time when exams were taken to control for potential confounding factors that would bias the measured relationship between pollution and test performance. The data are from the yearbooks of each city between 1989 and 2008.
Table 1.1 contains a description of these factors. The GDP per capita at birth is 11636 CNY and 56520 CNY at test date after adjusting for inflation.

The other two atmospheric factors, wind speed, and ground atmospheric pressure serve as instrumental variables (IV) for air pollution. The current meteorology literature provides a correlation between air pollutants and weather conditions. Air pollutants tend to concentrate on a stable environment (Davis and Kalkstein, 1990). High air pollution concentrations are correlated with light wind speed (Niemeyer, 1960) and high air pressure (Chen et al, 2008; Cheng et al, 2007). High air pollutant concentrations usually occur in less windy and high ground pressure environments (Grundstrom et al, 2015). The underlying reason is that high ground pressure limits the dispersion of air pollutants and keeps air pollutants close to the ground. Environmental economic studies also use meteorological measurements as instrumental variables for air pollution. He, Liu and Salvo (2018) use weather measures including wind speed and ground temperature, as instruments for air pollutants and study the impact of air pollution on worker productivity.

This study also estimates the impacts of prenatal exposure to air pollution on the youth's current height, weight, and health status to examine whether air pollution also affects youth physical health. The current height and weight are normed with the national average of youths by different ages and genders. The national average height and weight are from the Yearbook of Health in China 2016, published by the National Health Commission of China.

After matching air pollution data with the household data, I have information about the children, their parents' and households' characteristics, the exposure to air pollution in utero and afterward, the school's features, and other weather conditions.

1.4 Conceptual Framework

Early shocks to fetal health have a potential impact on children's cognitive development trajectory (Cunha and Heckman, 2008; Conti et al., 2010; Currie et al., 2010). The initial human capital loss is compounded by the fact that current human capital is an input into subsequent human capital production. The model is built on Currie et al. (2010) to develop three hypotheses that can explain why initial shocks can have a larger impact later in life. Suppose that the outcome function is $S_t = aH_t^{\alpha}C_t^{\beta}$, where S_t represents the test scores at time t, H_t is the health condition at time t, and C_t is the student's cognitive skills at time t. For simplicity, the model assumes the cognitive skill at time t is jointly determined by cognitive skills and health condition of period t-1, and it has a Cobb-Douglas function form. In addition, the health condition at time t is a power function of the health condition in period t-1 with a disturbing shock on health. Using lower-case variables to designate logs, cognitive skill development follows: $c_t = b_0 + b_1 c_{t-1} + b_2 h_{t-1}$

The contemporaneous health condition follows: $h_t = \gamma h_{t-1} + u_t$, where $c_t = \ln(C_t)$, $h_t = ln(H_t)$, and u_t is the disturbing shock to health at time t, such as air pollution. Without loss of generality, I suppose an individual has lived three periods. Solving the model recursively to obtain (1):

$$ln(S_3) = \delta + \delta_1 c_0 + \delta_2 h_0 + \delta_3 u_3 + \delta_4 u_2 + \delta_5 u_1 \quad (1)$$

The parameters on the right side can be expressed as (2):

$$\begin{cases} \delta = ln(\alpha) + \beta b_0 + \beta b_0 b_1 + \beta b_1^2 b_0 \\ \delta_1 = \beta b_1^3 \\ \delta_2 = (\beta b_1^2 b_2 + [(\alpha\gamma + \beta b_2)\gamma + \beta b_1 b_2])\gamma \\ \delta_3 = \alpha \\ \delta_4 = \alpha\gamma + \beta b_2 \\ \delta_5 = \gamma\delta_4 + \beta b_1 b_2 \end{cases} \quad (2)$$

From this model, the first-period shock may persist to later outcomes under some conditions, for example, $b_2 > 0$ and $\gamma = 1$. In this model, the early shock accumulates over time ($|\delta_5| > |\delta_4| > |\delta_3|$). In particular, u_1 represents the exposure to air pollution in utero. u_2 and u_3 are the exposures to air pollution after the birth (i.e., in periods 2 and 3, respectively). c_0 and h_0 represent the cognitive ability and health condition at the beginning of conception. They are correlated with their parents' cognitive skills and health conditions. Here are the three hypotheses related to this model:

Hypothesis I: Early health shocks, e.g., air pollution, have an impact on later human capital formation, including cognitive skill and academic performance. This implies that $\delta_5 > 0$.

Hypothesis II: The impact of early health shocks on human capital becomes more apparent as the child ages. This implies $|\delta_5| > |\delta_4|$.

Hypothesis III: Early health shocks have a greater impact than late shocks on human capital outcomes since early shocks accumulate over time. This implies that $|\delta_5| > |\delta_3|$.

To test these three hypotheses embedded in (1), I control the exposure to air pollution in utero and afterward, c_0 and h_0. Because c_0 and h_0 are not directly observable, I use parents' education and income to control them. Therefore, the econometric specification is as follows:

$$S_{ibcl} = \delta_p P_{ib} + \beta X_i + \theta Z_s + \gamma Y_c + \lambda_c + \pi_b + \varepsilon_{ibcl} \quad (3)$$

where S_{ibcl} represents *S* in the theoretical model, and it is the score of subject *l* for individual *i* who was born in year *b* in city *c*. The exposure to air pollution in utero, which represents the early health shocks as u_1 in the model, is denoted by P_{ib}. X_i are the characteristics of the student and his/her household, including the student's age, gender, age entering primary school, number of siblings, and parents' education and income. Z_s is the characteristics of the kid's school, including school quality and school type (e.g., public schools, private schools, and boarding schools.) Y_c is the city characteristics including GDP per capita and weather factors. λ_c is the fixed effect of the birth city and π_b represent the fixed effect of his/her birth year. To allow heterogeneous correlation, the standard errors are double clustered by birth cities and birth years. δ_p represents the cognitive impact of prenatal exposure to TSPs.

The after-birth exposure to air pollution could mask the impact of prenatal exposure to air pollution, therefore I add a computed after-birth exposure to air pollution in (3). Suppose P_{iy} is the air pollution in age *y* after birth, $\sum_{y=1}^{a_i} P_{iy}$ represents the total cumulative exposure to air pollution after birth (a_i is the child's age). Because air pollution data of TSP are not available after 2004[6], the cumulative exposure can be computed as follows:

$$\sum_{y=1}^{a_i} P_{iy} = a_i * \frac{1}{2004-t_i^0} \sum_{T=t_i^0+1}^{2004} P_{iT} \qquad (4)$$

For student *i* who was born in the year t_i^0 , his/her accumulative exposure to this pollutant is equal to the product of age and average exposure after birth. a_i is the child's age. Since the test scores reported in CHIP were taken in 2008, it is obvious that $a_i = 2008 - t_i^0$. Figure 1.3 shows that air pollution is more severe in the early years, which implies a potential positive measurement error in the computed accumulative exposure. However, this potential bias would not change the conclusion about the adverse impact of prenatal air pollution exposure. If the accumulative exposure to air pollution is positively correlated with prenatal exposure and accumulative exposure also depresses cognitive development, and an overestimated accumulative exposure will absorb the impact of prenatal exposure. The magnitude and significance of prenatal exposure then decrease. The results of this study provide a lower bound of the adverse impact of prenatal exposure.

Hypothesis I can be directly tested from the estimation of (3), and the sign of the coefficient of P_{ib} represents the impact of prenatal exposure to TSPs on test scores.

Hypothesis II indicates that the adverse impact of prenatal exposure becomes more prominent because the early shock accumulates over time. The best strategy of verifying

[6] For the availability of air pollution data, please see Figure 1.1.

hypothesis II is estimating the effect of prenatal exposure at different ages and checking the magnitude of the impact over time. But the test scores are only available from one cross-sectional survey (i.e., CHIP 2008). However, if the parameters in (2) are not fundamentally different among different cohorts[7], *Hypothesis II* can be tested in an alternative way. Under this assumption, an interaction term between prenatal exposure to TSPs and the birth year dummy variable is added in (3). From *Hypothesis II*, the magnitude of coefficient δ is expected to be greater among the older cohort.

Hypothesis III can be indirectly tested by comparing the magnitudes of the estimated coefficients of $\sum_{y=1}^{a_i} P_{iy}$ and P_{ib} , evaluated at the mean value. In addition, I add the exposures to TSPs after the birth in estimation (5) to verify *Hypothesis III* directly:

$$S_{ibcl} = \delta_p P_{ib} + \sum_{y=1}^{4} \delta_y P_{iy} + \beta X_i + \theta Z_s + \gamma Y_c + \lambda_c + \pi_b + \varepsilon_{ibcl} \quad (5)$$

The exposures to TSP between ages 1 and 4 are added in the estimation of (4), and *Hypothesis III* holds if the magnitude of δ_p is greater than δ_y, $\forall\, y \in (1,4)$.

1.5 Empirical Results

1.5.1 OLS and 2SLS Estimation Results

The following regressions control school quality, school type, parents' education and income, city economic demographics, and children's characteristics in all regressions. In all regressions, the error terms are double clustered by cities and birth years. When accumulative exposure to TSP is added, birth year fixed effects are not controlled to avoid the multicollinearity problem.

[7] It means δ_p in year t for cohort a is equal to δ_p in year t+j for cohort b, and the cohort a is j years older than cohort b.

This study first tests Hypothesis I, which states that early exposure to air pollution in utero has an adverse impact on the academic performance of students. Table 1.2 lists the empirical results of (3) using mathematics and language test scores as the dependent variables. I use prenatal exposure to TSPs at first. From the Column 1 and 2 of Table 1.2, a one-standard-deviation increase in prenatal exposure to TSPs (116 $\mu g/m^3$) lowers math scores by 0.27 (0.116*2.243/0.964=0.269) standard deviations and lowers language scores by 0.23 standard deviations. Both prenatal exposure and after-the-birth accumulative exposure to TSPs are added in Column 3 and 4. A one-standard-deviation increase in prenatal exposure to TSPs lowers math scores by 0.23 standard deviations and lowers language scores by 0.20 standard deviations. These results support Hypothesis I that prenatal exposure to air pollution has an adverse impact on academic performance and cognitive development in later life. At the same time, the results in Columns 3 and 4 provide indirect evidence supporting Hypothesis III that exposure to air pollution in utero has a more significant impact than later exposures after birth. The coefficient of accumulative exposure to TSPs is not substantial, while its sign is negative. A one-standard-deviation increase in accumulative exposure after the birth is associated with 23 percent of a standard deviation decrease in math scores, and 15 percent of that in language scores. The other two types of air pollutants, sulfur dioxide, and nitrogen oxide will be added into the estimation in forthcoming heterogeneous tests.

To verify the causality between prenatal exposure to air pollution and test scores and address the concern about measurement error in air pollution which causes an attenuation bias in the estimates, the two-stage least square approach is adopted in this study. Previous studies in environmental economic use weather variables to instrument air pollution (Arceo et al., 2016; He et al., 2018). The current meteorology literature provides a correlation between air pollutants and weather conditions. Air pollutants tend to concentrate on a stable environment where wind speed is low and air pressure is high (Chen et al, 2008; Cheng et al, 2007; Grundstrom et al, 2015). As such, two weather factors are used as instrumental variables for air pollution: the average wind speed and the ground atmospheric pressure of the birth year. Column 5 and 6 of Table 1.2 report the two-stage least squares estimation results. Math test scores and language test scores were adversely affected by prenatal exposure to TSPs, while the effect on math test scores is not statistically significant. A one-standard-deviation increase in prenatal exposure reduces math test scores by 0.24 standard deviations, and it reduces language test scores by 0.49 standard deviations. Because the attenuation bias from measure error is always toward zero, the magnitude of IV estimates is larger than that of OLS estimates. The first stage results are reported in Table A.1 in the appendix. Wind speed is negatively correlated with air pollution, while atmospheric pressure contributes to the concentration of air pollutants. Additionally, adding the accumulative exposure to TSPs after birth does not fundamentally change the conclusion, as the results are reported in Table A.2 in the appendix.

The estimation results are comparable to Sanders (2012) who studies the cognitive impact of prenatal exposure to TSPs in Texas. He found that a one-standard-deviation increase in TSPs (8-12 $\mu g/m^3$) in a student's birth year is associated with 0.02 standard deviations decrease in high school scores for OLS and 0.06 for IV estimation. Since the level of Chinese air pollution is ten times of that in Texas, my estimation is close to Sanders'.

As mentioned in the previous section, an interaction between prenatal exposure to TSPs and birth year dummy variables are added into the estimation of (3) to test Hypothesis II. If the second hypothesis holds, the adverse impact of early exposure to air pollution will be more prominent for the older cohort. Table 1.3 reports the empirical results for verifying Hypothesis

II. Column 1 and 2 of Table 1.3 report the OLS estimation results. The adverse effect of prenatal exposure to TSPs on test scores is more obvious for older cohorts. Cohorts born between 1989 and 1996 (i.e., aged between 12 and 19) were significantly affected by prenatal exposure to TSPs for both math and language test scores. The two-stage least squares estimation is also used, and Column 3 and 4 in Table 1.3 illustrate the results. Empirically, following Aghion et al. (2005), interactions of instrumental variables and birth year dummies are added into the 2SLS estimation. The empirical results of the 2SLS estimation show that adverse cognitive impacts caused by prenatal exposure to TSPs are more pronounced among older cohorts. Figure 1.9 illustrates the 95% confidence interval of the estimated effects of prenatal exposure to TSPs. The upper Panel A and B illustrate the estimated impacts from OLS, and Panel C and D report the estimated effects from 2SLS estimation. For math test scores, the OLS estimation (Panel A) shows that adverse cognitive impact is more obvious among older cohorts who were born between 1989 and 1996. The two-stage least squares estimation (Panel C) shows that the kids aged 18 and 19 were significantly affected by prenatal exposure to TSPs, while younger kids were not significantly affected. For language test scores, the adverse impact brought by prenatal exposure to TSPs is always more pronounced for older cohorts (especially for the kids born between 1989 and 1996), from the results of both OLS estimation (Panel B) and 2SLS estimation (Panel D). These results support our Hypothesis II that the impact of early health shocks on human capital becomes more apparent as the child ages.

To test Hypothesis III, children's exposures to air pollution after birth are added to the analysis using (5). The detrimental impact of prenatal exposure to air pollution is expected to be stronger than exposure to air pollution later in life, i.e., $|\delta_p| > |\delta_y|, \forall\ y \in (1,2,\dots,4)$.

Table 1.4 shows how air pollution exposures at different ages in life affect the test scores. The results show that exposure to air pollution in utero has a larger and more significant impact on test scores than exposures later in life. A one-standard-deviation increase in prenatal exposure to air pollution is associated with 0.53~0.64 standard deviations decrease in math scores and 0.30~0.36 standard deviations decrease in language scores. The exposures after birth, meanwhile, have a smaller detrimental impact on cognitive development. These results support Hypothesis III that the effects of exposure to air pollution after the birth are smaller than the effect of exposure to air pollution in utero, though air pollution exposures after birth also adversely affect academic performance. Therefore, prenatal exposure to air pollution has a greater detrimental impact on the cognitive development of youth than later exposures in life.

1.5.2 Heterogeneous Tests

Current research has found that air pollution has differential impacts in utero depending on fetal maturity (Currie and Schwandt, 2016). The effect is most significant for the first trimester of gestation. Since CHIP 2008 does not collect the length of the gestation period, the first trimester may occur in the year before the actual birth year. I add the average TSPs of the year before birth and test the impact of early exposures to TSPs. Table 1.5 illustrates how exposure to TSPs around birth affects children's cognitive ability later in life. A milligram (i.e., 1mg, or 1000 μg) increase is associated with 1.96-2.38 standard deviations decrease in math scores, and 1.73-2.14 standard deviations decrease in language scores.

In the theoretical model, early exposure to air pollution affects cognitive development because it adversely affects youth health. Case and Paxson (2008) regarded height as a measure of health and found that it correlated with future earnings and cognitive skills. The exposure to air pollution early in life may have an adverse effect on youth development other than the test scores in schools. Three measures of health are used in the following estimation: current height, weight, and self-reported health status compared with peers at the same age. Current weight and height are weighted with the national average by ages and genders. In the survey of CHIP 2008, respondents were asked to answer the question “how do you evaluate your current health compared with your peers at the same age”. Answers to this question are “Excellent”, “Good”, “Average”, “Poor”, and “Very Poor”. Since the answers of “Poor” and “Very Poor” are very few, I group the last three groups into one representing “poor health”. In general, the higher value of this variable indicates a worse health status. The OLS estimation is used for evaluating the impact on weight and height, and an ordered Probit model is used for evaluating the impact on health status. From the results of Table 1.6, prenatal exposure to TSPs negatively affects the child's current height, while the impact is not significant. Meanwhile, the accumulative exposure to TSPs adversely affects youth weight and height. Prenatal exposure to TSPs also negatively affect current health status, while the impact of accumulative exposure to TSPs is opposite and not significant. These results indicate that early air pollution exposure hurts youth maturity and health, which further affects the cognitive development of youth.

Table 1.7 includes two additional measures of air pollution, SO_2, and NO_x. These two measures have more missing values than do TSPs. These two types of air pollutants are added to the analysis using (3). The first four columns report the impact of each air pollutant on math and language test scores. There is no significant impact of prenatal exposure to SO_2 or NO_x on test scores. Columns 5 and 6 list the estimation results with all three measures of prenatal exposure to air pollution, and only the exposure to TSPs significantly adversely affects math and language scores. In the last two columns of Table 1.7, the cumulative exposure of three pollutants is added. Still, only prenatal exposure to TSPs will significantly affect the cognitive ability of youth later in life. These results indicate that the negative cognitive impact of prenatal exposure to air pollution is mostly from TSPs rather than SO_2 and NO_x. The estimations in the previous section, which focus only on TSPs, are not biased by excluding SO_2 and NO_x.

Migration is another concern because households may make their choices by feet when there is severe air pollution. First, if those who migrate because of air pollution are more sensitive to air pollution, then the current analysis solely focusing on urban nonmovers gives a lower bound of the adverse impact of air pollution. This means that the conclusions found so far are valid for the whole population. Otherwise, if those who migrate because of severe air pollution are less sensitive to air pollution, then the remaining individuals are more susceptible to air pollution. Thus, focusing on urban nonmovers may exaggerate the negative impact of air pollution. The second scenario mostly occurs when those migrants mainly come from wealthier households, and they are more likely to take avoidance behavior and therefore less exposed to air pollution by any means. To address the migration issue, the migrant's subsample of CHIP 2008 is included[8]. Table 1.8 lists the empirical results with the migrants in the cities. The migrant's sample of CHIP 2008 does not report the original place where these migrants come from. I assume the children who spend all year with their parents and study in the same city were born in the destination city. It is a strong but reasonable assumption. First, people are less likely to migrate when they have offspring. Moreover, it is very difficult and expensive for a Chinese child to attend a local school if he/she was not born in the same city. Table 1.8 reports the estimation results with migrant children. Table 1.8 shows that prenatal exposure to TSPs also adversely affects test scores of migrant children with OLS estimation or 2SLS estimation. From OLS estimation results in (1)-(4), a one-milligram increase in prenatal exposure to TSPs is associated with 3.98 standard deviations decrease in math scores and 3.97 standard deviations

[8] The data summary of migrant sample is included in Table A.3 in the appendix.

decrease in language scores, which are larger in magnitude compared with the impact on urban nonmovers. The adverse impact of prenatal exposure to TSPs is still there when adding accumulative exposure to TSPs after birth or instrumenting prenatal exposure to TSPs with wind speed and atmospheric pressure. These results suggest that the findings in the previous section do not fundamentally change with self-selected migration.

Table 1.9 focuses on the households differentiated by household wealth to address the concern of avoidance behavior. The households of each city are separated into three groups: wealthy households who are in the upper one-third, poor households who are in the bottom one-third, and other households whose income is between the wealthy and the poor. There is no significant difference in the impact of prenatal exposure to air pollution among different households.

In Table 1.10, dummy variables of the seasonality are included in the estimation. Since air quality is usually worse in the winter than in the summer, the kids whose mothers are pregnant in the winter are likely to be more susceptible to air pollution. There are four seasons in a year: season 1 (January-March), season 2 (April-June), season 3 (July-September), and season 4 (October-December). For the kid who was born in the fourth season, his mother was pregnant in the previous winter (i.e., December-February)[9]. Table 1.10 reports the estimation results, which show that the adverse impact of prenatal exposure to TSPs is more pronounced among the kids whose mother was pregnant between December and February.

Table A.4 in the appendix reports the effects of TSPs exposures around the birth year. The air pollutions before and after the birth year are added, and the prenatal exposure to TSPs still has a significant adverse effect on test scores later in childhood. The findings concluded

[9] The gestation period is assumed to be 40 weeks, that is about 10 months.

previously, that prenatal exposure to TSPs adversely affects cognitive development, do not fundamentally change in these heterogeneous tests.

1.6 Conclusion

This study finds a significant adverse impact of prenatal exposure to total suspended particulates on the cognitive development of youth in China. The OLS estimation shows that a one-standard-deviation increase of prenatal exposure to TSPs is associated with 0.27 standard deviations decrease in math scores and 0.23 standard deviations decrease in language scores. The 2SLS estimation shows that a one-standard-deviation increase in TSPs reduces math scores by 0.24 standard deviations and language scores by 0.49 standard deviations. The adverse impact of prenatal exposure to air pollution is more substantial in magnitude and more significant than exposures later in childhood. The negative effect of prenatal exposure becomes more prominent as the child ages. Moreover, air pollution has a profound impact on youth health and maturity. Youth health and maturity are negatively affected by prenatal exposure to air pollution. These results support the "fetal origins" theory that early shocks in utero have a great impact on outcomes in later life.

Although this study has explained some mechanisms by which early air pollution exposure may affect the later human capital outcome, the picture is not clear enough. Future work needs to include more information about children's health conditions throughout their childhood. For example, Currie et al. (2010) test how the health conditions in different ages of the same child affect young adult outcomes. In addition, it is interesting to test how severe air pollution affects the behavior and noncognitive development of the young.

Figures and Tables

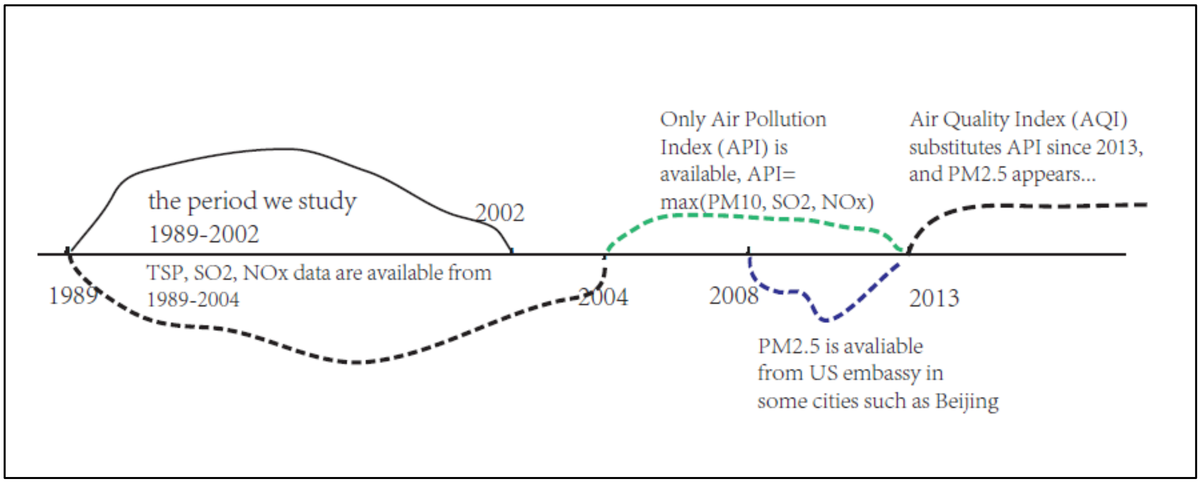

Figure 1.1 Data availability of air pollution in China

Figure 1.2 Cities in this study

NOTES. These cities are Shanghai, Hefei (Anhui Province), Nanjing and Wuxi (Jiangsu), Hangzhou and Ningbo (Zhejiang), Wuhan (Hubei), Guangzhou and Shenzhen (Guangdong), Zhengzhou, Anyang, and Luoyang (Henan), Chengdu (Sichuan).

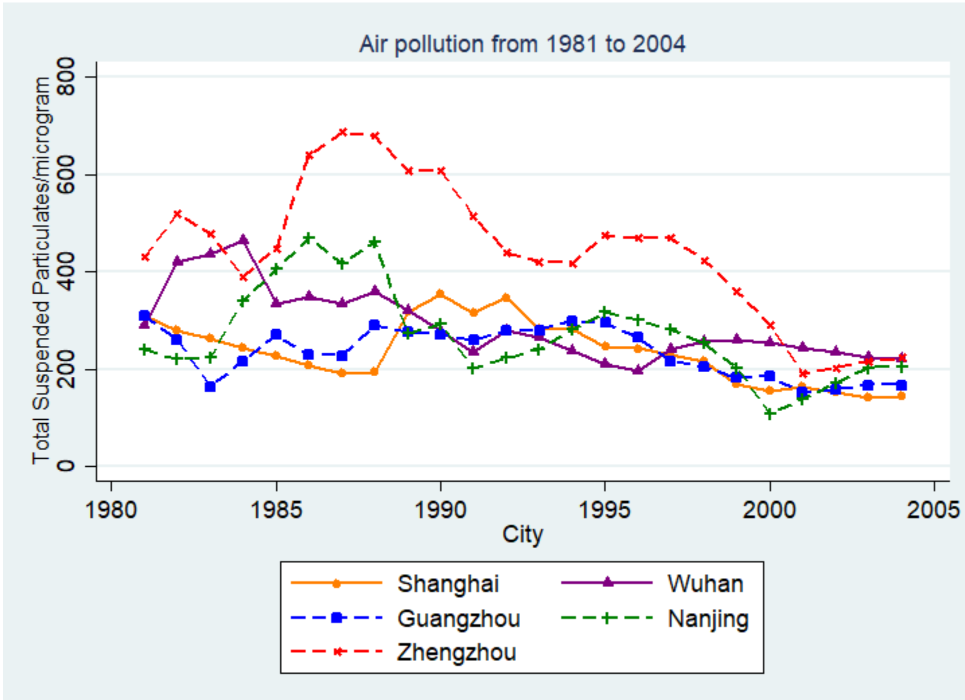

Figure 1.3 Annual daily average TSP

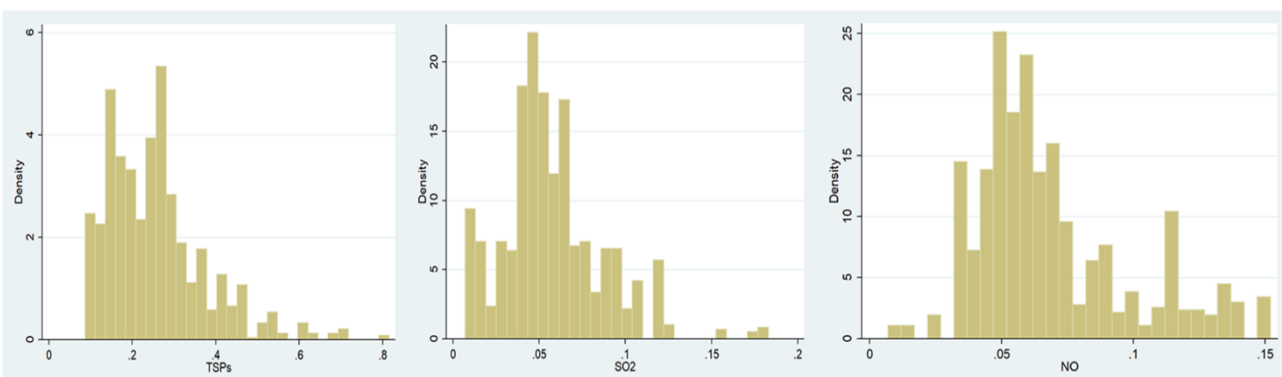

Figure 1.4 Distribution of various air pollutants (total suspended particulate, SO_2, and NO_x)

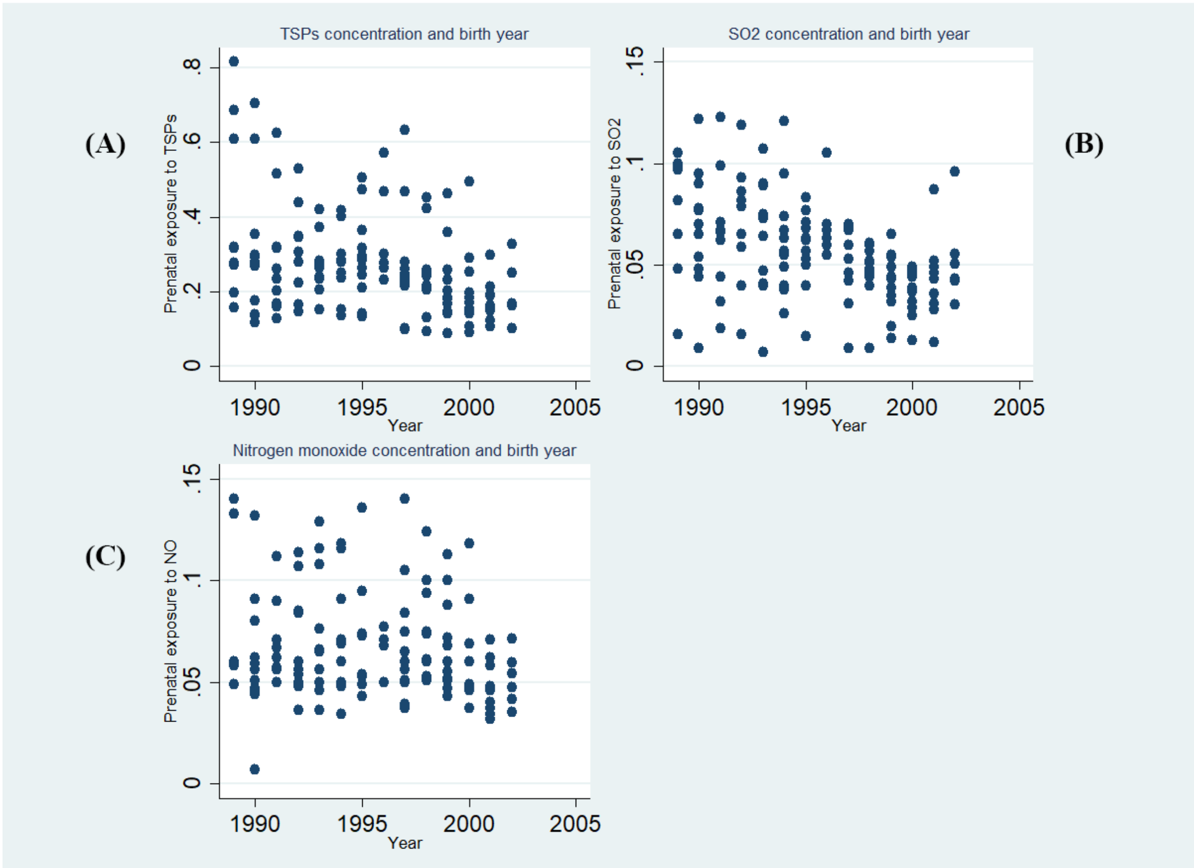

Figure 1.5 Prenatal exposure to TSPs, SO2, and NOx by birth years

NOTES. (A) Concentration of prenatal exposure to TSPs.

(B) Concentration of prenatal exposure to SO2.

(C) Concentrations of prenatal exposure to NOx.

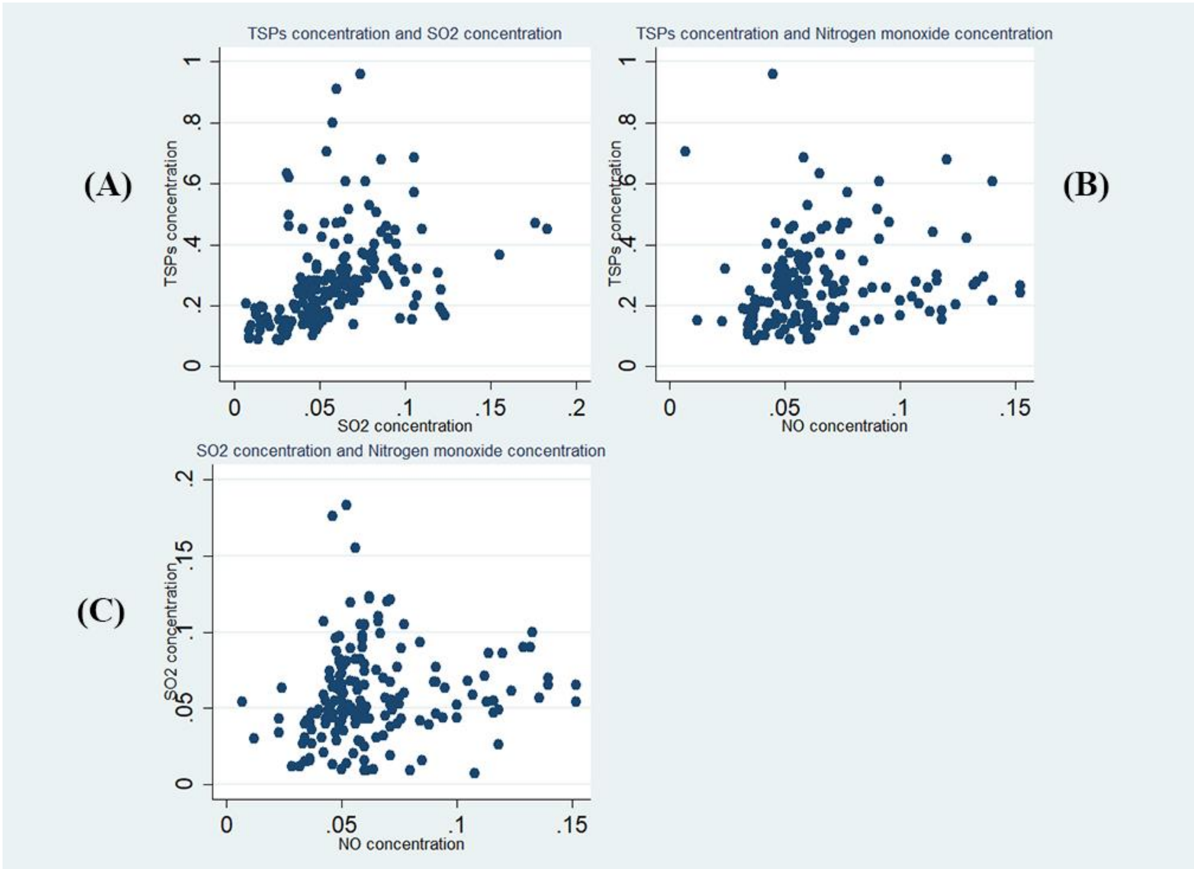

Figure 1.6 Correlation of different air pollutants including TSPs, SO2, and NOx.
NOTES. (A) Prenatal exposure to TSPs and SO2.
(B) Prenatal exposure to TSPs and NOx.
(C) Prenatal exposure to SO2 and NOx.

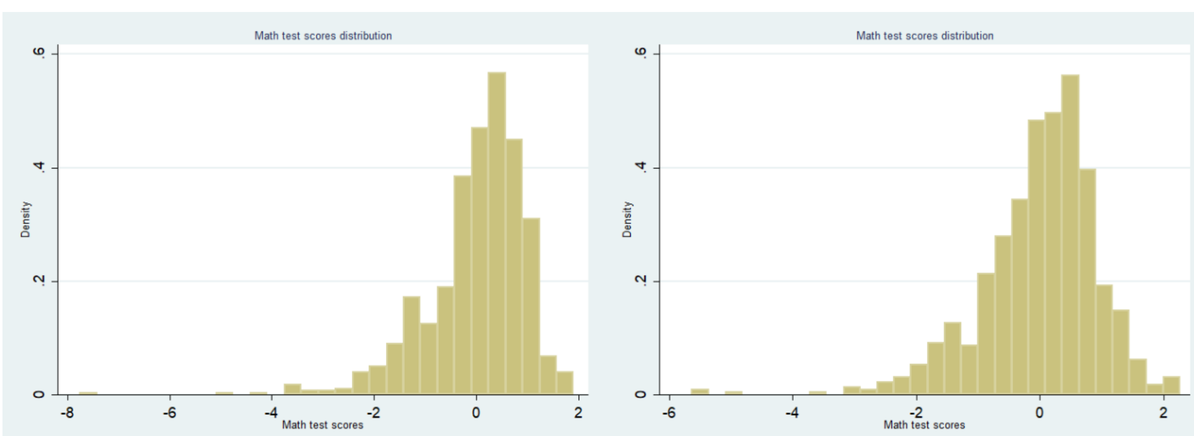

Figure 1.7 Distribution of standardized scores of math exam and language exam

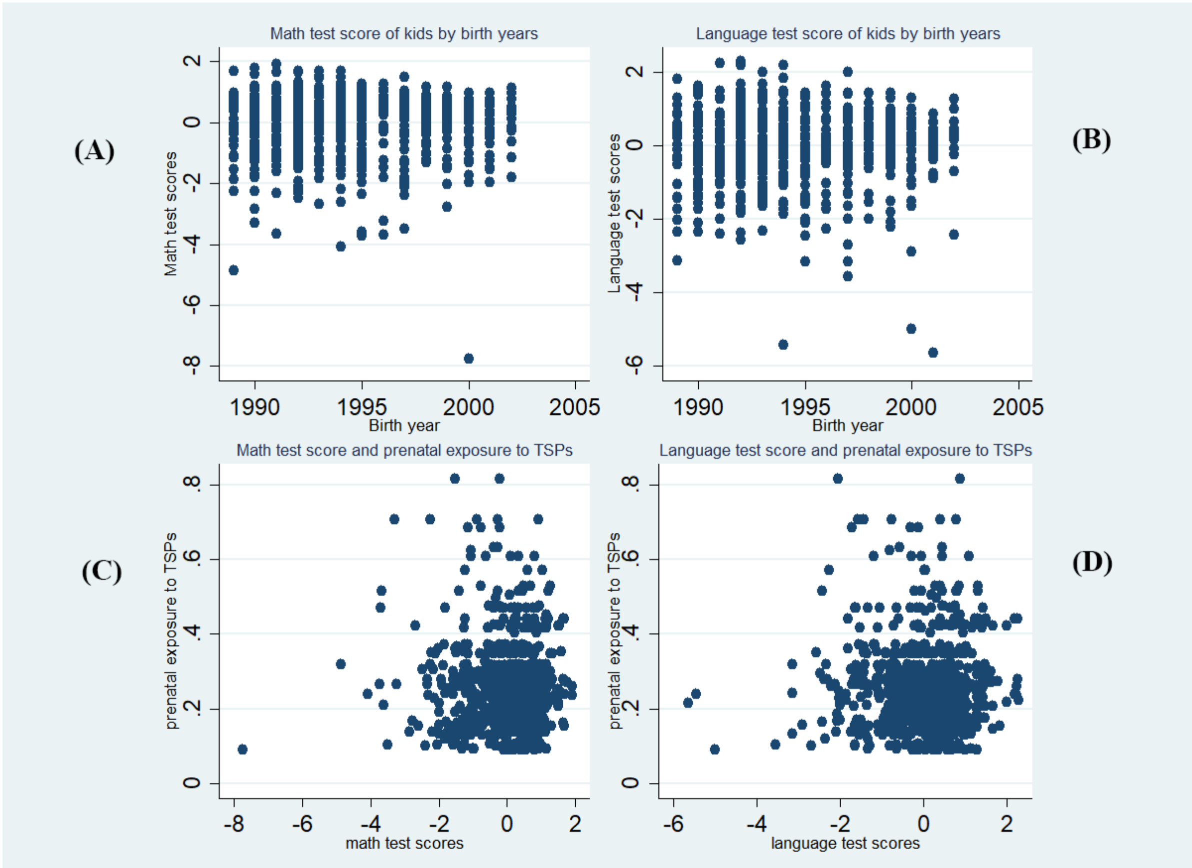

Figure 1.8 Distribution of test scores and test scores against prenatal exposure to TSPs

NOTES. (A) Math test scores of students by the birth year.
(B) Language test scores of students by the birth year.
(C) Prenatal exposure to TSPs and math test scores.
(D) Prenatal exposure to TSPs and language test scores.

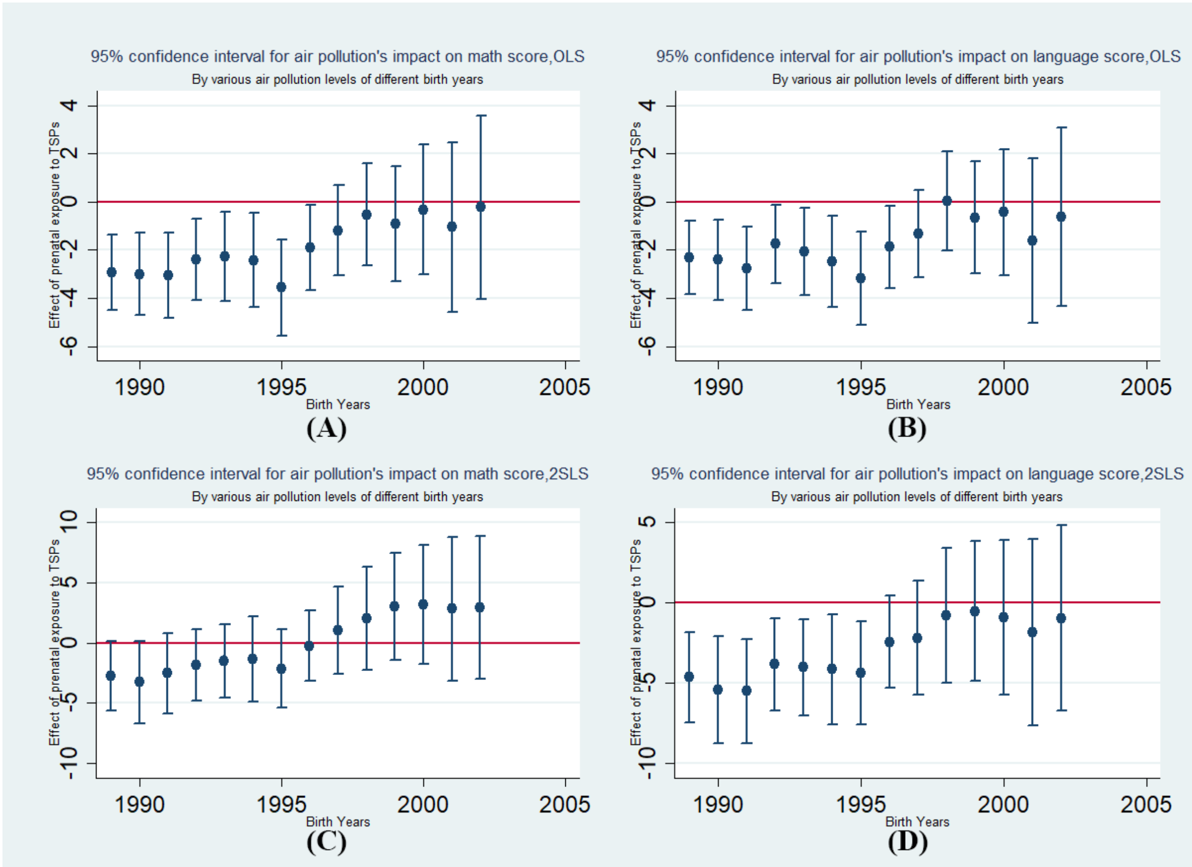

Figure 1.9 The 95% confidence interval of the estimated effect of prenatal exposure to TSPs on test scores
NOTES. (A) Cognitive effect of prenatal exposure to TSPs on math test scores, OLS.
(B) Cognitive effect of prenatal exposure to TSPs on language test scores, OLS.
(C) Cognitive effect of prenatal exposure to TSPs on math test scores, 2SLS.
(D) Cognitive effect of prenatal exposure to TSPs on language test scores, 2SLS.

Table 1.1 Data summary

	Observation	Mean	Standard Dev.	Min	Max
Z-score math	843	0.017	0.964	-7.744	1.909
Z-score language	843	0.011	0.939	-5.626	2.276
Prenatal exposure to TSPs (mg=1000 µg/m^3)	843	0.255	0.116	0.09	0.815
TSPs exposure in the year before birth year	837	0.269	0.128	0.09	0.96
SO_2 exposure in birth year	840	0.058	0.026	0.007	0.123
NO_x exposure in birth year	810	0.070	0.028	0.007	0.14
Accumulative exposure of TSPs after the birth	809	2.796	1.458	0.708	9.163
Accumulative exposure of SO_2after the birth	843	0.623	0.306	0.086	1.869
Accumulative exposure of NO_x after the birth	843	0.790	0.372	0.1645	2.094
$TSPs_{t+1}$ (TSPs of the year after birth year)	804	0.247	0.109	0.09	0.72
$TSPs_{t+2}$	742	0.243	0.103	0.09	0.633
$TSPs_{t+3}$	690	0.236	0.101	0.091	0.633
$TSPs_{t+4}$	623	0.232	0.098	0.09	0.571
GDP per capita birth year (in 2008 Yuan)	843	12174.580	8733.899	1111	34822
GDP per capita in 2008	843	57835.110	18307.170	19924	83431
Mean temperature in 2008	843	17.876	2.574	14.4	22.8
Ln (Father's annual income)	843	5.990	3.454	0	10.309
Ln (Mother's annual income)	843	4.849	3.622	0	9.798
Father's years of education	843	11.935	3.469	0	31
Mother's years of education	843	11.218	3.372	0	35

Source: China Household Income Project 2008, World Bank's Development Economics Research Group (DECRG), China Environmental Yearbooks, China Meteorological Data Service Center (CMDC), Yearbook of Health in China 2012, and GDP data comes from the city's yearbooks.

Table 1.1 Continued
Data summary

	N	Mean	Standard Dev.	Min	Max
Gender (Girls=1)	843	0.485	0.500	0	1
Number of siblings	843	0.355	0.658	0	6
Birth order	843	1.068	0.269	1	3
Attending average school	843	0.345	0.476	0	1
Attending better than average school	843	0.498	0.500	0	1
Attending worse than average school	843	0.011	0.103	0	1
Attending best school	843	0.146	0.353	0	1
Attending public School	843	0.932	0.251	0	1
Attending private School	843	0.063	0.243	0	1
Attending boarding school	843	0.147	0.354	0	1
Expenditure on tutoring classes	843	1251.451	2417.642	0	36100
Current Height (cm)	821	0.019	0.059	-0.336	0.249
Current Weight (kg)	819	0.039	0.205	-0.505	0.994
Your current state of health, Excellent	843	0.199	0.400	0	1
Your current state of health, Good	843	0.664	0.473	0	1
Your current state of health, Average or lower	843	0.136	0.343	0	1
Number of days with precipitation > 0.1cm	843	123.068	26.269	48	172
Average temperature (C°)	843	17.592	2.848	13.9	23.8
Humidity (%)	843	75.243	4.422	61	86
Annual sunshine hours	843	1768.193	297.745	818.6	2372.2
Wind Speed (m/s)	843	2.237	0.682	1	3.4
Atmospheric pressure (hPa)	843	1030.453	16.383	972.6	1045.7
Birth year	843	1995.281	3.626	1989	2002

Source: China Household Income Project 2008, World Bank's Development Economics Research Group (DECRG), China Environmental Yearbooks, China Meteorological Data Service Center (CMDC), Yearbook of Health in China 2012, and GDP data comes from the city's yearbooks.

Table 1.2 Prenatal exposure to TSPs and test scores

	(1) OLS Math	(2) OLS Language	(3) OLS Math	(4) OLS Language	(5) 2SLS Math	(6) 2SLS Language
Prenatal exposure to TSPs (mg/m^3)	-2.243***	-1.856***	-1.917**	-1.644**	-1.965	-3.991**
	(0.716)	(0.558)	(0.807)	(0.767)	(2.228)	(1.974)
Accumulative exposure of TSP after the birth			-0.156*	-0.099		
			(0.081)	(0.069)		
Gender (Girls=1)	-0.046	0.155**	-0.067	0.156**	-0.073	0.144**
	(0.064)	(0.067)	(0.067)	(0.068)	(0.063)	(0.066)
Ln (Father's income)	-0.005	0.002	-0.008	0.005	-0.008	0.000
	(0.011)	(0.011)	(0.012)	(0.011)	(0.011)	(0.010)
Ln (Mother's income)	0.002	0.008	-0.003	0.001	-0.003	0.004
	(0.009)	(0.011)	(0.009)	(0.010)	(0.009)	(0.010)
Father's education years	0.019*	-0.007	0.019	-0.009	0.018	-0.005
	(0.011)	(0.013)	(0.012)	(0.014)	(0.012)	(0.014)
Mother's education years	0.017	0.023	0.019	0.023	0.019	0.022
	(0.014)	(0.014)	(0.015)	(0.015)	(0.014)	(0.014)
Better than average school *versus* Best schools	-0.213**	-0.166*	-0.231**	-0.184**	-0.250***	-0.209**
	(0.088)	(0.092)	(0.089)	(0.093)	(0.081)	(0.085)
Average school vs Best school	-0.395***	-0.384***	-0.431***	-0.386***	-0.441***	-0.446***
	(0.100)	(0.103)	(0.102)	(0.099)	(0.093)	(0.097)
Worse than average vs Best school	-0.745	-1.358**	-0.654	-1.507**	-0.791	-1.423***
	(0.564)	(0.573)	(0.593)	(0.628)	(0.528)	(0.552)
Private vs Public school	-0.269	-0.068	-0.246	-0.030	-0.236	-0.031
	(0.219)	(0.173)	(0.225)	(0.183)	(0.208)	(0.169)
Non-board vs board school	0.006	0.073	0.057	0.129	0.086	0.151
	(0.117)	(0.105)	(0.118)	(0.110)	(0.115)	(0.106)
Expenditure on tutoring class	-0.000	0.000	-0.000	0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Table 1.2 Continued
Air pollutant and test scores

	(1) Z-score Math	(2) Z-score Language	(3) Z-score Math	(4) Z-score Language	(5) Z-score Math	(6) Z-score Language
Number of days with precipitation > 0.1cm	-0.000	-0.006	-0.000	-0.007	-0.002	-0.008*
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Average temperature (C°)	0.043	-0.104	0.082	0.038	0.127	0.038
	(0.198)	(0.186)	(0.087)	(0.075)	(0.088)	(0.080)
Humidity (%)	0.024	0.017	0.020	0.031	0.003	0.034
	(0.042)	(0.036)	(0.029)	(0.030)	(0.030)	(0.030)
Annual sunshine hours	0.001*	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Birth Year Fixed Effect	Y	Y	N	N	Y	Y
Birth City Fixed Effect	Y	Y	Y	Y	Y	Y
N	843	843	809	809	843	843
R^2	0.111	0.112	0.084	0.096	0.088	0.088

NOTES. All estimations above control school grade fixed effects, the number of siblings, birth orders, cities' GDP per capita in the birth year and test year (2008), and the average temperature in 2008. Error terms are double clustered by birth cities and birth years. Standard errors are reported in parentheses. *** indicates significance at the 1% level., ** indicates significance at the 5% level, and * indicates significance at the 10% level. The first stage of 2SLS estimation is reported in the appendix.

Table 1.3 Prenatal exposure to TSPs and test scores by birth years

	(1) OLS Math	(2) OLS Language	(3) 2SLS Math	(4) 2SLS Language
Prenatal Exposure to TSPs × I_{1989}	-2.933***	-2.309***	-2.714*	-4.632***
	(0.794)	(0.772)	(1.469)	(1.433)
Prenatal Exposure to TSPs × I_{1990}	-3.005***	-2.410***	-3.268*	-5.402***
	(0.869)	(0.845)	(1.743)	(1.700)
Prenatal Exposure to TSPs × I_{1991}	-3.042***	-2.761***	-2.527	-5.507***
	(0.902)	(0.878)	(1.691)	(1.649)
Prenatal Exposure to TSPs × I_{1992}	-2.388***	-1.753**	-1.835	-3.840***
	(0.859)	(0.836)	(1.503)	(1.466)
Prenatal Exposure to TSPs × I_{1993}	-2.258**	-2.054**	-1.516	-4.012***
	(0.945)	(0.919)	(1.566)	(1.528)
Prenatal Exposure to TSPs × I_{1994}	-2.429**	-2.486**	-1.319	-4.134**
	(0.996)	(0.969)	(1.797)	(1.753)
Prenatal Exposure to TSPs × I_{1995}	-3.563***	-3.177***	-2.138	-4.366***
	(1.014)	(0.986)	(1.664)	(1.623)
Prenatal Exposure to TSPs × I_{1996}	-1.903**	-1.869**	-0.228	-2.429*
	(0.897)	(0.872)	(1.503)	(1.466)
Prenatal Exposure to TSPs × I_{1997}	-1.186	-1.326	1.042	-2.201
	(0.957)	(0.931)	(1.852)	(1.807)
Prenatal Exposure to TSPs × I_{1998}	-0.533	0.030	2.015	-0.783
	(1.083)	(1.053)	(2.183)	(2.129)
Prenatal Exposure to TSPs × I_{1999}	-0.926	-0.660	3.014	-0.517
	(1.221)	(1.188)	(2.270)	(2.215)
Prenatal Exposure to TSPs × I_{2000}	-0.326	-0.430	3.187	-0.910
	(1.371)	(1.333)	(2.505)	(2.444)
Prenatal Exposure to TSPs × I_{2001}	-1.053	-1.603	2.824	-1.823
	(1.788)	(1.739)	(3.030)	(2.955)
Prenatal Exposure to TSPs × I_{2002}	-0.226	-0.619	2.921	-0.957
	(1.945)	(1.892)	(3.017)	(2.943)
Birth Year Fixed Effect	Y	Y	Y	Y
Birth City Fixed Effect	Y	Y	Y	Y
N	843	843	843	843
R^2	0.163	0.143	0.165	0.14

NOTES. All estimations above control school quality and type, school grade fixed effects, expenditure on tutoring classes, family characteristics including parent's education, income, and children's gender, the number of siblings and birth order. I also control cities' GDP per capita in the birth year and test year (2008), and the weather in the birth year and test year. Error terms are double clustered by the birth city and birth year. Standard errors are reported in parentheses. *** indicates significance at the 1% level., ** indicates significance at the 5% level, and * indicates significance at the 10% level.

Table 1.4 Test scores and prenatal exposure to TSPs: air pollution of multiple years

	(1) OLS Math	(1) OLS Math	(2) OLS Math	(3) OLS Math	(4) OLS Language	(4) OLS Language	(5) OLS Language	(6) OLS Language
Prenatal Exposure to TSPs(mg/m^3)	-4.397***	-4.714***	-5.186***	-5.360***	-2.460**	-2.385**	-2.906**	-2.922**
	(1.162)	(1.159)	(1.272)	(1.332)	(1.012)	(1.060)	(1.217)	(1.280)
$TSPs_{t+1}$	0.637	1.459	1.613	1.465	-1.997	-2.194	-2.024	-2.037
	(1.392)	(1.484)	(1.468)	(1.428)	(1.271)	(1.377)	(1.377)	(1.365)
$TSPs_{t+2}$		-1.420	-0.836	-0.929		0.340	0.986	0.978
		(1.167)	(1.301)	(1.348)		(1.091)	(1.312)	(1.300)
$TSPs_{t+3}$			-1.236	-0.520			-1.368	-1.304
			(1.675)	(1.681)			(1.729)	(1.683)
$TSPs_{t+4}$				-1.099				-0.099
				(1.514)				(1.329)
$\sum TSP_s$	-3.760***	-4.674***	-5.645***	-6.443**	-4.458***	-4.239***	-5.312***	-5.384**
	(1.197)	(1.430)	(2.006)	(2.504)	(1.078)	(1.373)	(1.884)	(2.292)
Birth Year Fixed Effect	Y	Y	Y	Y	Y	Y	Y	Y
Birth City Fixed Effect	Y	Y	Y	Y	Y	Y	Y	Y
N	604	604	604	604	604	604	604	604
R^2	0.127	0.127	0.126	0.126	0.120	0.119	0.118	0.117

NOTES. All estimations above control school quality and type, school grade fixed effects, expenditure on tutoring classes, family characteristics including parent's education, income, and children's gender, number of siblings and birth order. I also control cities' GDP per capita in the birth year and test year (2008), and the weather in the birth year and test year. Error terms are double clustered by the birth city and birth year. Standard errors are reported in parentheses. *** indicates significance at the 1% level., ** indicates significance at the 5% level, and * indicates significance at the 10% level.

Table 1.5 Effect of exposure to TSPs before birth and prenatal exposure to TSPs on test scores

	(1) OLS Math	(2) OLS Language	(3) OLS Math	(4) OLS Language
TSPs exposure in birth year ($TSPs_t$, mg/m^3)	-2.403**	-1.598*	-1.965*	-1.127
	(1.039)	(0.880)	(1.077)	(0.943)
TSPs level before the birth year ($TSPs_{t-1}$, mg/m^3)	0.111	-0.298	-0.049	-0.500
	(0.862)	(0.903)	(0.936)	(0.826)
Accumulative exposure of TSPs after the birth (mg/m^3)			-0.161**	-0.117*
			(0.081)	(0.069)
A standard deviation increases in $TSPs_t$ and $TSPs_{t-1}$	-2.292***	-1.887***	-2.014**	-1.627*
	(0.712)	(0.602)	(0.827)	(0.858)
Birth Year FE	Y	Y	N	N
Birth City FE	Y	Y	Y	Y
N	837	837	803	803
R^2	0.112	0.105	0.086	0.085

NOTES. All estimations above control school quality and type, school grade fixed effects, expenditure on tutoring classes, family characteristics including parent's education, income, and children's gender, the number of siblings and birth order. I also control cities' GDP per capita in the birth year and test year (2008), and the weather in the birth year and test year. Error terms are double clustered by the birth city and birth year. *** indicates significance at the 1% level., ** indicates significance at the 5% level, and * indicates significance at the 10% level.

Table 1.6 Prenatal exposure to TSPs and current height, weight, and health status

	(1) OLS Current Height	(2) OLS Current Weight	(3) Ordered Probit "Poor" Health
Prenatal Exposure to TSPs (mg/m^3)	-0.010	0.201	1.654**
	(0.038)	(0.135)	(0.774)
Accumulative exposure after the birth (mg/m^3)	-0.011**	-0.034*	-0.076
	(0.005)	(0.017)	(0.101)
Birth City FE	Y	Y	Y
N	1176	1176	1176
R^2	0.069	0.091	0.067

NOTES. Heath status is self-evaluated by a question: "What is your current health status compared with your peers at the same age?" The answer has five categories: "1. Excellent", "2. Good", "3. Average", "4. Poor", and "5. Very Poor". There are very few responses for "Poor" and "Very Poor", so I group the last three into one group representing "Poor health". Current weight and height are weighted by the national average height by age and gender. I control the number of siblings and birth order in these estimations. Error terms are double clustered by the birth city and birth year. Standard errors are reported in parentheses. *** indicates significance at the 1% level., ** indicates significance at the 5% level, and * indicates significance at the 10% level.

Table 1.7 Multiple measures of air pollution and test scores

	(1) OLS Math	(2) OLS Language	(3) OLS Math	(4) OLS Language	(5) OLS Math	(6) OLS Language	(7) OLS Math	(8) OLS Language
Prenatal exposure to SO_2 (mg/m^3)	2.078	1.107			-0.150	0.168	3.081	0.638
	(2.939)	(2.621)			(3.231)	(2.914)	(3.385)	(3.205)
Prenatal exposure to NO_x (mg/m^3)			3.424	1.780	4.554*	2.485	3.997	2.052
			(2.323)	(2.279)	(2.432)	(2.423)	(2.492)	(2.518)
Prenatal exposure to TSPs (mg/m^3)					-2.092**	-1.672**	-2.175**	-1.945**
					(0.843)	(0.670)	(0.870)	(0.923)
Accumulative exposure to SO_2 after birth (mg/m^3)							-0.881	-0.226
							(0.606)	(0.671)
Accumulative exposure to NO_x after birth (mg/m^3)							0.001	0.027
							(0.115)	(0.125)
Accumulative exposure to TSPs after birth (mg/m^3)							0.218	-0.215
							(0.296)	(0.326)
Birth Year FE	Y	Y	Y	Y	Y	Y	Y	Y
Birth City FE	Y	Y	Y	Y	Y	Y	Y	Y
N	874	874	838	838	810	810	776	776
R^2	0.104	0.102	0.104	0.105	0.101	0.107	0.075	0.090

NOTES. All estimations above control school quality and type, school grade fixed effects, expenditure on tutoring classes, family characteristics including parent's education, income, and children's gender, the number of siblings and birth order. I also control cities' GDP per capita in the birth year and test year (2008), and the weather in the birth year and test year. Error terms are double clustered by the birth city and birth year. Standard errors are reported in parentheses. *** indicates significance at the 1% level., ** indicates significance at the 5% level, and * indicates significance at the 10% level.

Table 1.8 Air pollution and test scores, migrants and urban non-movers

	(1)	(2)	(3)	(4)
	OLS	OLS	OLS	OLS
	Math	Language	Math	Language
	Migrants	Migrants	Migrants & non-movers	Migrants & non-movers
Prenatal Exposure to TSPs (mg/m^3)	-3.838***	-3.635*	-2.410***	-1.871***
	(1.306)	(2.005)	(0.560)	(0.588)
Birth Year FE	Y	Y	Y	Y
City FE	Y	Y	Y	Y
N	172	172	1015	1015
R^2	0.175	0.237	0.077	0.095
	(5)	(6)	(7)	(8)
	Math	Language	Math	Language
	Migrants	Migrants	Migrants & non-movers	Migrants & non-movers
Prenatal Exposure to TSPs	-3.730***	-2.740*	-1.660**	-1.620**
	(1.336)	(1.509)	(0.669)	(0.635)
Accumulative exposure to TSPs after the birth	0.181	0.037	-0.056	-0.019
	(0.152)	(0.141)	(0.062)	(0.060)
Birth Year FE	N	N	N	N
City FE	Y	Y	Y	Y
N	161	161	970	970
R^2	0.113	0.201	0.061	0.093

NOTES. All estimations above control school quality and type, school grade fixed effects, expenditure on tutoring classes, family characteristics including parent's education, income, and children's gender, siblings, and birth order. I also control cities' GDP per capita in the birth year and test year (2008), and the weather in the birth year and test year. Error terms are double clustered by the birth city and birth year. Standard errors are reported in parentheses. *** indicates significance at the 1% level., ** indicates significance at the 5% level, and * indicates significance at the 10% level. The first stage used for calculating inverse mills ration is reported in the appendix.

Table 1.8 Continued
Air pollution and test scores, migrants and urban non-movers

	(9) 2SLS Math	(10) 2SLS Language	(11) 2SLS Math	(12) 2SLS Language
	Migrants	Migrants	Migrants & non-movers	Migrants & non-movers
Prenatal Exposure to TSPs	-0.903	-5.612*	-1.481	-4.906**
	(2.973)	(3.299)	(2.041)	(2.234)
Weak IV Test (Cragg-Donald Wald F statistic)	19.116	19.116	57.960	57.960
Birth Year FE	Y	Y	Y	Y
City FE	Y	Y	Y	Y
N	172	172	1015	1015
R^2	0.096	0.228	0.074	0.076

NOTES. A dummy variable indicating the migration status (or if the kid's parents are migrants) is added in pooled regressions. All estimations above control school quality and type, school grade fixed effects, expenditure on tutoring classes, family characteristics including parent's education, income, and children's gender, siblings, and birth order. I also control cities' GDP per capita in the birth year and test year (2008), and the weather in the birth year and test year. Error terms are double clustered by the birth city and birth year. Standard errors are reported in parentheses. *** indicates significance at the 1% level., ** indicates significance at the 5% level, and * indicates significance at the 10% level. The first stage used for calculating inverse mills ration is reported in the appendix.

Table 1.9 Prenatal exposure to TSPs and cognitive development: households with different income levels

	(1) OLS Math	(2) OLS Language
Prenatal exposure to TSPs (mg/m^3)	-2.468**	-1.844**
	(0.972)	(0.900)
Prenatal exposure to TSPs × (middle 1/3 households)	0.831	0.539
	(0.980)	(1.103)
Prenatal exposure to TSPs × (top 1/3 households)	0.842	0.041
	(0.890)	(1.092)
Accumulative exposure after the birth (mg/m^3)	-0.104	-0.087
	(0.090)	(0.082)
Accumulative exposure after the birth×(top 1/3 households)	-0.079	-0.040
	(0.092)	(0.095)
Accumulative exposure after the birth×(middle 1/3 households)	-0.091	0.003
	(0.080)	(0.093)
Birth City FE	Y	Y
N	809	809
R^2	0.081	0.091

NOTES. All estimations above control school quality and type, school grade fixed effects, expenditure on tutoring classes, family characteristics including parent's education, income, and children's gender, siblings and birth order. I also control cities' GDP per capita in the birth year and test year (2008), and the weather in the birth year and test year. Error terms are double clustered by the birth city and birth year. Standard errors are reported in parentheses. *** indicates significance at the 1% level., ** indicates significance at the 5% level, and * indicates significance at the 10% level.

Table 1.10 Prenatal exposure to TSPs and test scores, by the season of birth

	(1) OLS Math	(2) OLS Language
Prenatal Exposure to TSPs (mg/m^3)	-2.348***	-2.178**
	(0.878)	(0.855)
Prenatal Exposure to TSPs×Season 2	-1.302	-0.022
	(1.036)	(1.105)
Prenatal Exposure to TSPs×Season 3	0.516	1.130
	(1.003)	(0.933)
Prenatal Exposure to TSPs×Season 4	-1.252*	-1.332*
	(0.718)	(0.758)
Birth Year FE	Y	Y
Birth City FE	Y	Y
Birth Season FE	Y	Y
N	843	843
R^2	0.094	0.106

NOTES. The whole twelve months are categorized into four seasons: season 1 (JAN-MAR), season 2 (APR-JUN), season 3 (JUL-SEP), and season 4 (OCT-DEC). For those kids who were born in the fourth season (i.e., Oct-Dec), the mother's pregnancy starts between December and February in the previous year, or the last winter period. All estimations above control school quality and type, school grade fixed effects, expenditure on tutoring classes, family characteristics including parent's education, income, and children's gender, siblings, birth order and gender. I also control cities' GDP per capita in the birth year and test year (2008), and the weather in the birth year and test year. Error terms are double clustered by the birth city and birth year. Standard errors are reported in parentheses. *** indicates significance at the 1% level., ** indicates significance at the 5% level, and * indicates significance at the 10% level.

CHAPTER 2. THE IMPACT OF THE CULTURAL REVOLUTION ON LIFETIME EARNINGS OF DIFFERENT GENERATIONS

2.1 Introduction

The Cultural Revolution, which occurred from 1966 to 1976, interrupted the education and occupation plans for millions of Chinese citizens. Urban high school graduates were sent to rural areas for menial agricultural work. Previous literature found the Cultural Revolution brought interruptions on later education attainment, especially when the interruption occurred at the high school level (Meng and Gregory, 2002). This study focusses on the evolution of human capital stock and education return for the generations who experienced the Cultural Revolution. It compares the wage-age profiles of cohorts exposed to the Cultural Revolution with cohorts that attended school before or after the Cultural Revolution. The results allow me to measure how the differences in education quantity and quality contributed to differences across cohorts in wage levels and growth over their lifetimes.

The Cultural Revolution caused a large and persistent interruption to expected educational opportunity, affecting tens of millions of youth over a decade. Very little is known about the human capital loss caused by this political decision or its impact on the lifetime earnings. Moreover, the adverse impact on educational attainment and quality may dissipate or accumulate over time. It is worthy to test the dynamics of the impact of the Cultural Revolution on youth’s human capital in China.

Our empirical results show that generations of people whose education was affected by the Cultural Revolution earn less than other cohorts because their lack of formal education and low educational quality. Because of the reduced education quantity and quality, the wage loss of the birth cohort 1955-1958 was ranged from 9.3 to 36.9 million CNY accounting for 10-40 percent of their incomes. Compared to the birth cohort of 1971-1973, the birth cohort of 1955-

1958 whose education was interrupted at all educational levels from primary education to college education, earn an 8 percent less income because of a reduced education return in 1995. And they earn a 4 percent less income because they had fewer years of education. However, the negative impact brought by low educational quality evanesces over time. In 2013, the education return of the birth cohort 1971-1973 is lower than that of the birth cohort 1955-1958. Additionally, this paper estimates how the Cultural Revolution cohort would earn when their education could be fully appreciated, no wage discrimination existed, and their skills' portfolio were parallel with other cohorts. We depict these counterfactual wages and calculate the human capital loss during the Cultural Revolution.

This paper proceeds as follows. Section 2 provides backgrounds of the Cultural Revolution and Chinese educational system at that time. We also introduce the decomposition method established by Oaxaca, which is the method we adopt in this study. Section 3 describes the data used in this research. In section 4, we discuss the conceptual framework and empirical methodology in this paper. Section 5 presents the empirical results. We discuss and give concluding remarks in section 6.

2.2 Background

2.2.1 The Cultural Revolution and Education System

After assessing that the planned economy was not succeeding in China, Mao Zedong determined that the failure was due to remaining capitalist sympathies in the society. The Cultural Revolution was aimed at removing these sympathies. The movement had two periods. The first, the active phase, lasted from 1966 to the death of Mao's successor, Vice chairman Lin, in 1971. During that period, all universities and colleges were closed and enrollment or teaching took place. Those who had entered universities before the Cultural Revolution were allowed to stay but were not allowed to pursue study of their curricula. They were given jobs in factories or the government if they graduated. At the same time, the youth in the urban were sent to rural areas for "reeducation". The second inactive phase lasted from 1971 to Mao's death in 1976. After 1971, the colleges began to recruit new students based on their family backgrounds and political attitudes rather than academic merits. These new students were mainly drawn from populations of peasants, workers or soldiers. The low quality of incoming students and the lack of qualified professors meant that the quality of college education was quite low between 1971 and 1977. Moreover, the "Down to the countryside movement" stopped in 1978. In December 1977, the government reopened the college entrance exam and universities began to enroll new students based on academic merits.

The whole education system was also altered during the Cultural Revolution. The Chinese education system had included 6 years of primary school, 3 years of junior middle school, 3 year of high middle school, and 4 years of college or university study. The age thresholds for youth to enter primary schools, middle schools, high schools, and colleges are 6, 12, 15, and 18, respectively. The graduates from each level are required to take an entrance exam in order to progress to the next level. At the start of the CR period in 1966-68, all schools except primary levels were closed, and colleges and universities were closed until 1972 (Bernstein, 1977). The entrance exams also stopped at each level, and were not resumed at the secondary level until the 1970s. The college entrance exam resumed in 1977 after the end of Cultural Revolution. Even during the inactive phase, the education system experienced extreme upheaval (Deng and Triman, 1997). First, the schools had to enroll more students whose education was delayed during the active phase. Second, almost all educational institutions lacked qualified teachers. Therefore, the education quality was adversely affected during the Cultural Revolution.

Previous literature has studied the impact of Cultural Revolution on education and education return. Meng and Gregory (2002) found that the interrupted education plans during the Cultural Revolution had a substantial impact on educational attainment, and the largest negative impact was experienced by children with parents of lower educational achievement and lower occupational status. Zhang, Liu and Yung (2007) utilized a set of Chinese twin's data, and they found that Cultural Revolution had no significant impact on education return. Liu (1998) asserts the low wage of skilled workers is caused by the wage rigidity under central planning economy. Li (2003) and Fleisher and Wang (2005) found that the relative wages of educated workers were low before the economic reform in the late 1990s. Afterwards, the growth of the private sector contributed to widening wage difference between skilled and unskilled workers in China. Our contribution is to examine wage levels and wage growth after the implementation of the Chinese economic reform in 1978, which allows us to measure the long-term consequences of the Cultural Revolution on educational attainment and quality.

Based on the age of starting each level of education, the whole population is separated into several cohorts to evaluate the impact of interruption in education during the Cultural Revolution[10]. As shown in Table B.1, there are nine cohorts for those who were born between 1946 and 1973. The oldest cohorts born in 1946-1948 would be affected only if they were in colleges when the Cultural Revolution occurred in 1966. The second oldest cohort born between 1949 and 1951 experienced an interruption in both high school and college education. The 1952-

[10] Some places adopted a "5+4+3" system: 5 years of primary school, 4 years of middle school, and 3 years of high school. They also used a "6+2+2" system in very rare situations. However, we assume a "6+3+3" system in this study for three reasons. First, the "6+3+3" plan is most popular plan in China. Second, the local educational scheme changed frequently before the economic reform, which makes it very difficult to track the changes. The fact that the CHIP data does not tell us where the worker got his education makes it more difficult to find out which system an individual studied with. Third, the whole population were grouped into nine cohorts because the education of each cohort was differently affected by the Cultural Revolution. And it is still true even though there were changes in educational schemes.

1954 generation was affected by the Cultural Revolution in middle school, high school and college education. The generation born between 1955 and 1958 was affected at every stage of education, primary through college. The other cohorts born in the periods 1959-1961, 1962-1964, 1965-1967, 1968-1970, and 1971-1973 serve as comparisons. This study will analyze wage gaps between the base and comparison cohorts.

2.2.2 Wage Difference Decomposition

Oaxaca (1973) provides a method for measuring the outcome difference between two groups. This method divides the difference of interested outcome into two parts: (1) the difference caused by the observed characteristics' differentials and (2) the difference due to the different estimated coefficients. This method is used to test the wage gap across genders, different cohorts and distinct population groups. Blau and Kahn (1994) used this method to analyze the gender wage gap in U.S. Their results indicated that American women's status in the labor market was improved in the face of rising inequality. Orazem and Vodopivec (2000) studied the wage gap across genders in the transitional period of Slovenia and Estonia in early 1990s. They found the women's status in the labor market has been improved in the transitional period because of the higher human capital return and increased labor demand in both countries. Juhn et al. (1993) studied the trend of wage gap between skilled workers and unskilled workers, and they estimated the contribution of wage-related characteristics and wage structure factors. They found the widen inequality in male's earnings is due to the skill factors embedded in human capital rather than the length of education years. Reimers (1983) decomposed the wage differential between white and non-white males in United States, and she found a discrimination toward Hispanic and Black males in the labor market. Using NLSY, Antecol and Bedard (2004) revisited the wage differential between ethnic groups. They found the wage gap explained by potential work experience is quite different with the part explained by actual experience. Leping and Toomet (2008) followed the similar method and studied ethnic wage differentials during the transitional period in Estonia. They found the economic and political transition favored Estonian-speaking males. The unobserved human capital played a role in this situation. Blackaby et al. (1998) study a similar topic in Britain, and they found the job discrimination towards the non-white minorities, especially for unemployment.

2.3 Data

This study uses the urban sample of the 1995, 2002, 2007 and 2013 waves of the Chinese Household Income Program (CHIP) to study the impact of the Cultural Revolution on human capital. The survey was conducted by the China Institute of Income Distribution. All the surveys are cross-sectional household data collected by the National Bureau of Statistics. Though this survey starts in 1988, that survey does not report the actual years of work experience in the current job. Our analysis relies on actual work experience because work histories may be disrupted by the Cultural Revolution, and so potential experience (as measured by age minus education minus 6) would be subject to important measurement errors correlated with birth cohorts. The other CHIP surveys include actual years of work.

In addition to actual work experience, the CHIP surveys contain the worker's gender, age, years of education, and whether the employer is a state-owned enterprise or private firm. The survey covers 16 provinces and more than 26,000 individual workers. Table 2.1 provides data descriptions. Different birth cohorts were affected unequally by the Cultural Revolution. The Cultural Revolution affected all four stages of education for the cohort of 1955-1958, which is the base cohort in our analysis. There are eight comparison cohorts who were born in the period 1946-1954 and 1959-1971. The youngest cohort's education was not affected by the Cultural Revolution since their primary school started later than 1976. At the same time, the other two youngest generations experienced the shocks only in their primary education. We can evaluate the impact of educational interruption at different stages by comparing the wage and wage growth between different generations whose education was unequally affected by the Cultural Revolution. For example, by comparing the wage and wage growth between the generations of 1966-1958 and 1946-1948, we can figure out how the deterioration in school quality and quantity for primary and secondary education affected wages and wage growths.

Table 2.1 reports the statistical summary of the data in this study. The base birth cohort 1955-1958 had more education than the cohort 1952-1954, in accordance with the fact that the Cultural Revolution was much more active at the beginning. Figure 2.1 also shows the original wage-age profiles for different cohorts. Each birth cohort experienced a rapid wage growth in the periods of 1995-2002 and 2002-2007, when the reform was launched in state owned enterprises and China entered WTO[11], respectively. Since then, the wage growth is modest. Some birth cohort, such as those who were born between 1955 and 1958, had a decline in earnings in 2013. The wage growth of the cohort whose education is mostly interrupted by the Cultural Revolution also has a smaller wage growth.

In the analysis, we adjust the annual income for the inflation. The price adjustment factors are from World Bank. The wage rates are adjusted to the currency in 1995 based on consumption inflation rate through time.

2.4 Conceptual Framework

Oaxaca (1973) provides a basic method to decompose the wage differential into two parts: one part attributed to observable characteristics and another part correlated with the estimated coefficients. The leftover is unobservable features which are correlated with discrimination. For example, at time t, the wage equations of cohort i and cohort j are:

[11] China entered WTO in 2001.

$W_i = \beta_i E_i + \gamma_i X_i + \varepsilon_i$

$W_j = \beta_j E_j + \gamma_j X_j + \varepsilon_j$

Where E_i and E_j are years of education for cohort i and j. X_i and X_j are years of work experience on the job. Considering workers of each birth cohort have almost same work experience, the return to work experience can be regarded as constant and do not decline with age. Therefore, the square of work experience is not included in the wage equation in this study. Calculating the wage difference between of cohort m and cohort n

$$W_i - W_j = (\beta_i - \beta_j)E_i + \beta_j(E_i - E_j) + (\gamma_i - \gamma_j)X_i + \gamma_j(X_i - X_j) + (\varepsilon_i - \varepsilon_j) \quad (1)$$

$(\beta_i - \beta_j)E_i$ and $(\gamma_i - \gamma_j)X_i$ are the wage differentials attributed to the different returns of human capital, while $\beta_j(E_i - E_j)$ and $\gamma_j(X_i - X_j)$ are the wage differentials attributed to the human capital differences between two cohorts. The remained wage gap $(\varepsilon_i - \varepsilon_j)$ is unexplained.

When we study the trend of the wage gap between these two cohorts, we can extend equation (1) to another time period t', that is:

$$W_i' - W_j' = (\beta_i' - \beta_j')E_i' + \beta_j'(E_i' - E_j') + (\gamma_i' - \gamma_j')X_i' + \gamma_j'(X_i' - X_j') + (\varepsilon_i' - \varepsilon_j') \quad (2)$$

With equations (1) and (2), we have:

$$(W_i' - W_i) - (W_j' - W_j) = [(E_i' - E_i) - (E_j' - E_j)]\beta_i' + E_i[(\beta_i' - \beta_i) - (\beta_j' - \beta_j)] + [(\beta_i' - \beta_j')(E_i' - E_i)] + [(\beta_j' - \beta_j)(E_i - E_j)] + [(X_i' - X_i) - (X_j' - X_j)]\gamma_i' + X_i[(\gamma_i' - \gamma_i) - (\gamma_j' - \gamma_j)] + [(\gamma_i' - \gamma_j')(X_i' - X_i)] + [(\gamma_j' - \gamma_j)(X_i - X_j)] + (\varepsilon_i' - \varepsilon_i) - (\varepsilon_j' - \varepsilon_j) \quad (3)$$

We assume the workers do not acquire any additional education between the two years, and so $[(E_i' - E_i) - (E_j' - E_j)] = 0$ and $E_i' - E_i = 0$. Equation (3) can be simplified as:

$$(W_i' - W_i) - (W_j' - W_j) = E_i[(\beta_i' - \beta_i) - (\beta_j' - \beta_j)] + [(\beta_j' - \beta_j)(E_i - E_j)] + [(X_i' - X_i) - (X_j' - X_j)]\gamma_i' + X_i[(\gamma_i' - \gamma_i) - (\gamma_j' - \gamma_j)] + [(\gamma_i' - \gamma_j')(X_j' - X_j)] + [(\gamma_j' - \gamma_j)(X_i - X_j)] + (\varepsilon_i' - \varepsilon_i) - (\varepsilon_j' - \varepsilon_j) \quad (3')$$

$E_i[(\beta_i' - \beta_i) - (\beta_j' - \beta_j)]$ and $X_i[(\gamma_i' - \gamma_i) - (\gamma_j' - \gamma_j)]$ capture how the between-cohorts earnings differential changed in response to changes in the between-cohorts gap in returns to human capital. $[(X_i' - X_i) - (X_j' - X_j)]\gamma_i'$ measures the earnings differential attributed to the difference in the growth of work experience between cohorts. $[(\beta_j' - \beta_j)(E_i - E_j)]$ and $[(\gamma_j' - \gamma_j)(X_i - X_j)]$ measure how changes in the returns to human capital affected the wage gap. $[(\gamma_i' - \gamma_j')(X_j' - X_j)]$ captures the wage gap differential related to the difference in work experience . When these equations are evaluated at the mean, the last term in (3') disappears by the assumption that $E(\varepsilon_i|E,X) = E(\varepsilon_j|E,X) = 0$. In the empirical analysis, we decompose the wage differentials in three ways:

The **wage growth** of each cohort is:

$$E(W_i') - E(W_i) = (\beta_i' - \beta_i)\bar{E}_i' + (\gamma_i' - \gamma_i)\bar{X}_i' + \gamma_i(\bar{X}_i' - \bar{X}_i) \quad (4)$$

The **wage differential** between the base cohort and comparison cohort:

$$E(W_i) - E(W_j) = (\beta_i - \beta_j)\bar{E}_i + \beta_j(\bar{E}_i - \bar{E}_j) + (\gamma_i - \gamma_j)\bar{X}_i + \gamma_j(\bar{X}_i - \bar{X}_j) \quad (5)$$

The **differential in wage growth** between the base cohort and comparison cohort

$$\left(E(W_i') - E(W_i)\right) - \left(E(W_j') - E(W_j)\right) = \bar{E}_i[(\beta_i' - \beta_i) - (\beta_j' - \beta_j)] + [(\beta_j' - \beta_j)(\bar{E}_i - \bar{E}_j)] + [(\bar{X}_i' - \bar{X}_i) - (\bar{X}_j' - \bar{X}_j)]\gamma_i' + \bar{X}_i[(\gamma_i' - \gamma_i) - (\gamma_j' - \gamma_j)] + [(\gamma_i' - \gamma_j')(\bar{X}_j' - \bar{X}_j)] + [(\gamma_j' - \gamma_j)(\bar{X}_i - \bar{X}_j)] \quad (6)$$

In the next section, we provide measures of these three equations, and show how they change over time.

2.5 Empirical Results

2.5.1 Wage Determination of Different Cohorts

In this section, we discuss the empirical results about the wage differentials between cohorts. In all the following analyses, we control the labor characteristics including the education, work experience, gender, ethnicity and working locations. Table 2.2 lists the Mincer equations' result for various cohorts in different years. The results in Table 2.2 tells us the generation of 1955-1958 earns the lowest education return compared with other cohorts in 1995. Specifically, one more year of formal education improves their earnings by 4 percent for the base cohort of 1955-1958, while one additional year of education will increase annual income by 4.8~6.6 percent for the younger cohorts in 1995. The difference in the return of education shrinks between 1995 and 2002. The base cohort of 1955-1958 still has a lower education return to education than their older counterparts in 2007, but a higher education return than the younger generations. These results indicate that there is a convergence in the return to education across generations, although the education quality largely depreciated during the Cultural Revolution.

The results in Table 2.3 provide a better way to see the difference in the returns to education across generations. In this table, a pooled OLS regression shows that the base cohort earns a lower return to education than other cohorts in 1995 and 2002. However, the gap gets smaller after 2002. Similarly, the return to work experience is also significantly lower for the workers who were born between 1955 and 1958. For an additional year of work, the earnings of younger cohorts who were born after 1958 outpaced the base cohort by 0.8-7.1 percent in 1995. There also exist a convergence in the return to work experience. All generations enjoyed a 2-percentage point increase in annual income with an additional year of work experience on the job in 2007 and 2012.

2.5.2 Wage Growths of Different Cohorts

Oaxaca (1973) first decomposed the wage differential between genders into two dimensions: (1) the quantity effect referring to the labor characteristic differentials, (2) the price effect which refers to the difference in the returns to human capital. Similarly, we first test how the overall earning changes with time after the economic reform during the 1990s in China, using the method of equation (4). We take the earnings for different cohorts in 1995 as the baseline wage, and then compare it with the average wage in 2002, 2007 and 2013.

Table 2.4 shows the decomposition of wage changes for different generations. All four cohorts in our study experienced significant wage growth during the period 1995-2013. Generally, the younger cohorts have greater wage growth than the old ones. For example, the cohort of 1971-1973 enjoyed a 166% increase in earnings while the cohort of 1955-1958 had a 91% increase. Two features are especially remarkable about the return to formal education. First, each cohort has a growing return of education over time, except the oldest cohort. The birth cohort 1959-1961 had the smallest earning growth from the increase in education return, that is 12.5% increase in annual income from 1995 to 2013. The birth cohort 1952-1954 experienced a 62.5% increase in their earnings due to a much higher return to education in 2013. The cohort whose education is most affected by the Cultural Revolution, those who were born in 1952-1954, experienced the largest increase in the education return. The cohort 1955-1958 also experienced a substantial increase in the return to education. An additional year of education was associated with 4 percent increase in earnings in 1995, and it increases to 7.5 percent in 2013. Their earnings increased by 37.6 percent from an increasing education return from 1995 to 2013.

In addition, most workers also had a higher return to work experience in 2013 than that in 1995. For those who were born before 1965, their earnings increased by 6.3-55 percent from 1995 to 2013 due to a higher return to work experience. On the contrary, younger workers had a loss in annual income because of a decline in the return to work experience. At the same time, workers who were born after 1959 had a significant growth in their earnings because of accumulating more work experience from 1995 to 2013. But this did not happen to those older workers. It indicates that the older workers accumulated less work experience compared with young workers[12].

2.5.3 Wage Gaps Between Different Cohorts

Wage gaps between these cohorts also varied over the period 1995-2013. Table 2.5 reports the decomposition of wage gaps between the base cohort and comparison cohorts. Three patterns are noteworthy from this table. First, the younger generations caught up with older colleagues over time. For example, the base cohort 1955-1958 gradually earned more than their older counterparts while they lost a margin over younger cohorts. Second, the between-cohort differences in the return to education and work experience did not lead to a significant divergence in earnings.

Third, cohorts are very different from one another in their levels of education and work experience. These differences significantly affected wage gaps. The base cohort had more education than most of the older cohorts, and they had less education than younger cohorts. For the base cohort, this led to a positive margin over the older cohorts and a negative one over the younger cohorts. For example, the base cohort earned 3.5-7 percent more than the 1952-1954 cohort, who experienced the worst interruption in education. At the same time, the base cohort earned 3.9-23 percent less than the cohort 1971-1973, whose education was not interrupted by the Cultural Revolution at all.

[12] One concern is whether workers will retire early or informally at old ages, which makes them accumulate less work experience than others. However, the CHIP 2002 tells us only two percent of workers tend to retire early or informally. Involuntary retirement is not the reason of a smaller accumulation of work experience.

As one would expect, the base cohort had more work experience than younger workers. But the gap in work experience shrank with time. For example, compared with the youngest cohort who were born between 1971 and 1973, the base cohort earned 69.3 percent more because of more work experience in 1995. However, they only earned 10.2 percent more from the difference in work experience. Therefore, the base cohort accumulated less work experience than younger workers in the period 1995-2013. This shrinking advantage of accumulated work experience becomes one of the persistent losses attributable to the Cultural Revolution.

2.5.4 Different Wage Growth Among Various Cohorts

The various cohorts have distinct exposure to the Cultural Revolution, and presumably it affects the earnings of those cohorts unequally. We examine the wage growth of different cohorts using equation (6). Table 2.6 lists the results for six birth cohorts, with those born in 1955-1958 as the base group. From 1995 to 2013, the base cohort had significantly slower wage growth than younger cohorts, and they had faster wage growth than older workers. There are two obvious patterns from Table 2.6. First, there is no significant difference in the change of return to education and work experience across different cohorts. Although the base cohort had a greater increase in the return to education and work experience than other generations, it did not make a significant contribution to the overall difference in wage growth. Second, the difference in the growth of work experience is almost in accordance with the overall difference in the wage growth. In specific, the base cohort has a greater increase in the work experience than the older workers, while they accumulated less work experience than younger workers. It means the base cohort are more likely to keep their jobs than the older workers, and they are more likely to lose jobs than younger workers. Why are older workers more likely to lose their jobs than are younger workers, especially when the older workers are of prime working ages?

2.5.5 Reforms of SOE in China

A major reform of state-owned enterprises happened in China during 1990s. The purpose of this movement is to make these firms more competent compared with private sectors and meet the requirements of entry to WTO. Many drastic measures were taken in this reform including many workers in SOE were laid-off based on their ability, tenure, and other characteristics. We found the older workers accumulated less work experience over time. In this section, we will discuss whether it is correlated to the reform in SOE.

Table 2.7 reports the marginal effects from a probit model identifying the generational differences in the probability of working in a SOE. Compared with the base cohort, the older workers are more likely to work in a SOE, while younger workers are less likely to work in a SOE. It is not surprising since positions in private sector were very limited before the economic reform in 1978, and so older workers had to work in SOEs. In CHIP 2002, the survey collects detailed information about employment history of individual workers. Therefore, the second column reports the probability of being laid off in 2002. The base cohort is the most likely to be laid off compared with younger cohorts, and this cohort is less likely to be laid off compared with older cohorts. These results explained why the base cohort accumulated less work experience than the younger cohorts. Moreover, the results in column 3 and 4 explained why the older cohorts accumulated even less work experience. Column 4 tells us the older generations were more reluctant to try to find a job after leaving the previous one. Column 5 tells us that the older cohorts were less likely to find a new job even when they tried to find one.

In conclusion, the reason why the base cohort accumulated less work experience than the younger is that the base cohort was more likely to work in a SOE and be laid off during the reform in the late 1990s[13]. They are better than the older workers because they were more active in finding a new job and they were more likely to find a new job.

2.5.6 How Affected Generations Would Earn Without The Cultural Revolution

We have discussed the quantity and quality impact of human capital on wage differentials between multiple cohorts, and the analyses above show us how disadvantaged the affected generation is in the labor market. A natural question then arises as to how much this cohort of workers could earn if the Cultural Revolution never happened? In this study, we compute the potential wage-age profiles for the affected generation based on the estimated human capital return and remained determinants (i.e, the unexplained part) from the wage equations of other generations. That is to say, we assume the base cohort has the same education quality and quantity with a comparison cohort.

Figure 2.2 shows the counterfactual wage-age profile the base cohort would have had if it had the same education and education returns as younger cohorts born after 1965, whose education was barely affected by the Cultural Revolution. The counterfactual wage is $W_{ij}^c = \beta_j E_j + \gamma_i X_i' + \varepsilon_i$, where $X_i' = X_i - (E_j - E_i)$.

W_{ij}^c is the counterfactual earning of birth cohort i (i.e., the cohort of 1955-1958) if they had same education quality and quantity with younger cohorts j. Their work experience was adjusted by the change in amount of education.

[13] We also test whether the workers in a SOE were differently affected than the workers in a private firm with respect to the accumulation of work experience. Table B.2 analyzes the wage differentials across cohorts in state-owned enterprises. They accumulated less work experience than the youngest two cohorts, but the magnitude of the interruption of work experience is smaller than what we found in Table 2.5. The base cohort even accumulated more work experience than the cohort of 1965-1967. The intuition is, for those who survived in the SOE, their work experience was not severely interrupted. It can be interpreted from another perspective. For the workers in the private firms in 1995, they were not affected by the SOE reforms. However, some workers in SOE were laid-off and had to find a job in the private sector, and this interruption lowered the average work experience of the base cohort in the private sector in 2002.

Figure 2.2 shows the corresponding counterfactual wage-age profile for the base cohort if its quality and quantity of education were same as the younger cohorts born after 1965. The base cohort could earn more if they had never experienced the Cultural Revolution. Table 2.8 reports the actual and counterfactual quantity and quality of education and work experience for calculating actual and counterfactual wages. The education return of the base cohort is 2-9 percent lower than comparison cohorts. Their education was 1-1.7 years fewer because of the Cultural Revolution. Table 2.9 reports the loss of income for the base birth cohort, and the loss is in present value in 2013. The wage loss of the birth cohort was ranged from 9.3 to 36.9 million CNY accounting for 10-40 percent of their incomes.

We also consider the impact of the Cultural Revolution on work experience. Assuming the base cohort i's work experience had the same dynamic with younger cohorts j, we can calculate the counterfactual wage $\widetilde{W}_{ij}^{c} = \beta_j E_j + \gamma_j X_j' + \varepsilon_i$.

And $X_j' = X_j - (A_j - A_i)$, where the work experience is adjusted by $A_j - A_i$, the age difference between the base cohort and birth cohort j. Therefore, we can compute the counterfactual wage by

$$\widetilde{W}_{ij}^{c} = \beta_j E_j + \gamma_j [X_j - (A_j - A_i)] + \varepsilon_i$$

Figure 2.3 shows the corresponding counterfactual wage-age profile for the base cohort if its quality and quantity of education and work experience were same as the younger cohorts born after 1965. The base cohort could earn more if they had never experienced the Cultural Revolution. Table 2.10 reports the actual and counterfactual quantity and quality of education and work experience for calculating actual and counterfactual wages. The education return of the base cohort is 10-31 percent lower than comparison cohorts. Their education was 4.2-6.3 years fewer because of the Cultural Revolution. Table 2.11 reports the loss of income for the base birth cohort, and the loss is in present value in 2013. The wage loss of the birth cohort was ranged from 49 to 306.6 million CNY accounting for 53-331 percent of their incomes.

Table B.3 and B.4 reports the estimated earning loss of other birth cohorts whose education was interrupted by the Cultural Revolution. Table B.3 shows that birth cohort 1959-1961 had a 10-37 million CNY of earning loss accounting for 11-40 percent of the earnings. Table B.4 shows that birth cohort 1962-1964 had an 8-34 million CNY loss of earning, accounting for 9-37 percent of the earnings. The cohorts whose primary education and middle education were affected were disadvantaged in the earnings.

2.6 Conclusion

In this paper, we test the loss of human capital quantity and quality during one of the most famous political turmoil in modern history, the Cultural Revolution occurring in 1966-1976 in China. We compare different generations who have distinct exposure to this event and find out the loss earnings due to the reduced and depreciated education and work experience in the period 1995-2013. We extend the Oaxaca decomposition method and test the difference in the wage growth caused by the shock in human capital. This study also estimates the potential wage-age profile of the affected cohorts and illustrate the wage loss caused by depressed education.

This study found that the cohort of 1955-1958, who experienced the largest interruption in education during the Cultural Revolution, has the lowest return to human capital including education and work experience in 1995. Because of reduced education quantity and quality, the affect cohort earned a 12 percent less income than the youngest generation (i.e., the cohort whose education was not affected by the Cultural Revolution) in 1995. Four percent of this twelve percent was caused by shortened education. Because of the reduced education quantity and quality, the wage loss of the birth cohort 1955-1958 was ranged from 9.3 to 36.9 million CNY accounting for 10-40 percent of their incomes. The gaps in the return to education and work experience between birth cohorts mitigated over the period 1995-2013. The affected cohorts had less education and more work experience than younger cohorts, and it makes a significant wage difference between generations. Last but not least, the affected cohorts accumulated less work experience than younger workers because they were more likely to enter a state-owned enterprise and lost the jobs during the reform in the late 1990s, which led to a difference in the wage growth and changed their wage-age profiles.

Figures and Tables

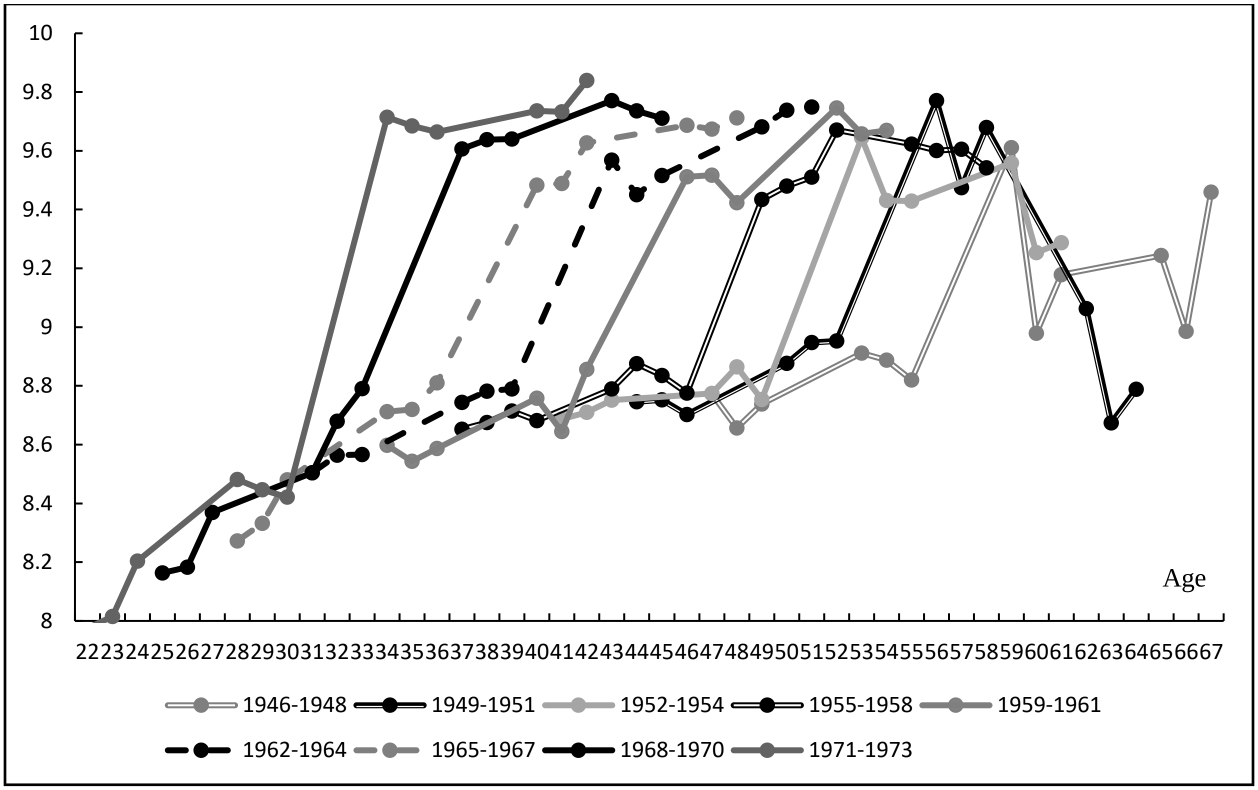

Figure 2.1 Wage-Age profiles for different cohorts

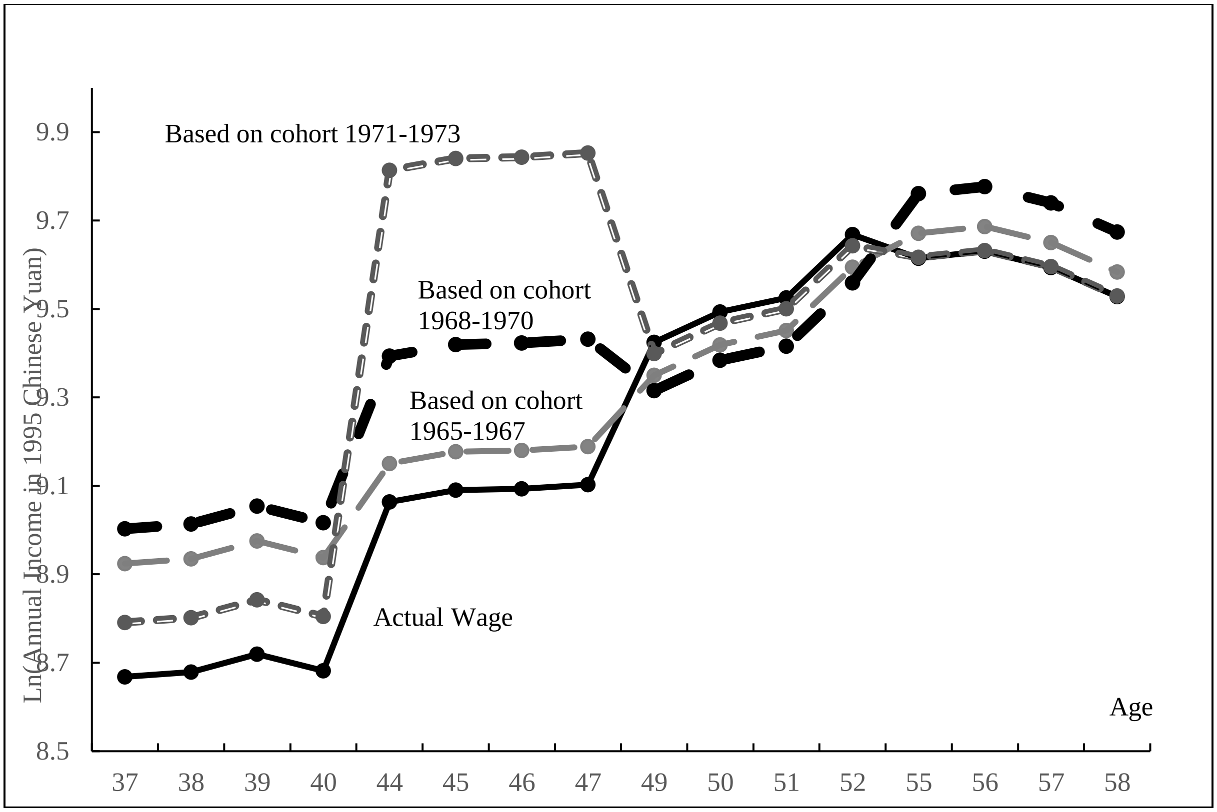

Figure 2.2 Fitted earnings if the cohort of 1955-1958 has the same education and education's return with younger cohorts born after 1965

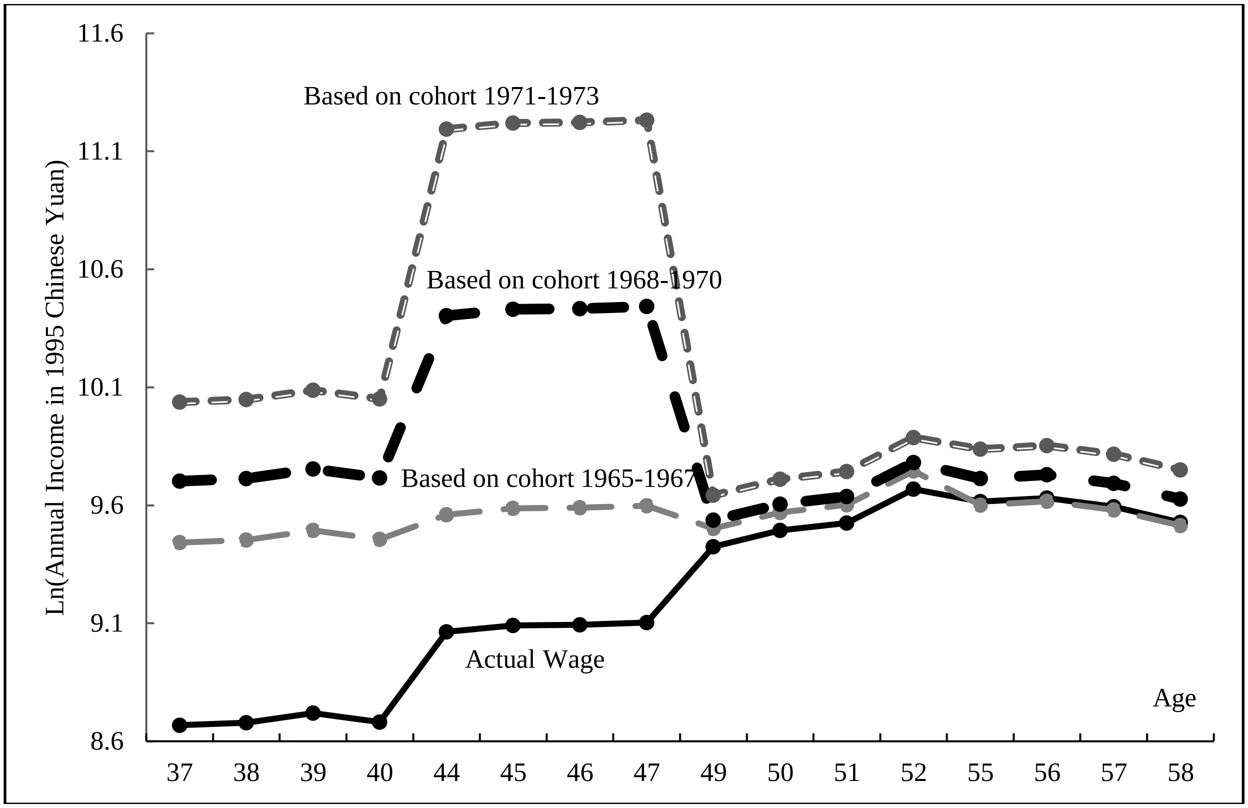

Figure 2.3 Fitted earnings if the cohort of 1955-1958 has the same quantity and return of education and work experience with younger cohorts born after 1965

Table 2.1 Data Summary

	Ln (Annual Income)	Education Years	Work Experience	Gender(m=1)
Birth cohort 1946-1948				
Mean 1995	8.743	10.415	20.325	0.534
Standard Dev.	0.600	3.227	8.787	0.499
N	945	945	945	945
Mean 2002	9.269	11.141	23.324	0.798
Standard Dev.	0.789	3.230	11.860	0.402
N	410	410	410	410
Mean 2007	9.478	10.733	18.567	0.850
Standard Dev.	0.861	3.502	16.325	0.360
N	60	60	60	60
Mean 2013	9.251	7.615	10.846	0.846
Standard Dev.	0.770	4.021	15.322	0.368
N	26	26	26	26
Birth cohort 1949-1951				
Mean 1995	8.749	9.929	19.234	0.497
Standard Dev.	0.534	2.854	7.646	0.500
N	1259	1259	1259	1259
Mean 2002	9.256	10.510	20.763	0.726
Standard Dev.	0.856	2.919	11.573	0.446
N	653	653	653	653
Mean 2007	9.646	10.707	22.250	0.894
Standard Dev.	0.743	3.105	15.196	0.308
N	208	208	208	208
Mean 2013	8.870	7.982	9.464	0.804
Standard Dev.	0.995	3.920	14.043	0.401
N	56	56	56	56
Birth cohort 1952-1954				
Mean 1995	8.726	9.851	17.940	0.475
Standard Dev.	0.594	2.696	7.007	0.500
N	1479	1479	1479	1479
Mean 2002	9.168	10.493	19.489	0.625
Standard Dev.	0.839	2.957	10.494	0.484
N	1010	1010	1010	1010
Mean 2007	9.523	10.201	20.184	0.757
Standard Dev.	0.904	2.946	13.884	0.429
N	354	354	354	354
Mean 2013	9.454	9.265	17.556	0.795
Standard Dev.	0.945	3.622	16.597	0.405
N	151	151	151	151

Table 2.1 Continued
Data Summary

	Ln (Annual Income)	Education Years	Work Experience	Gender(m=1)
Birth cohort 1955-1958				
Mean 1995	8.688	10.522	15.342	0.486
Standard Dev.	0.574	2.748	6.007	0.500
N	1868	1868	1868	1868
Mean 2002	9.089	10.905	17.634	0.537
Standard Dev.	0.944	2.703	8.796	0.499
N	1479	1479	1479	1479
Mean 2007	9.521	10.786	18.429	0.698
Standard Dev.	0.771	2.813	13.016	0.460
N	645	645	645	645
Mean 2013	9.595	9.869	18.895	0.783
Standard Dev.	0.897	3.346	14.569	0.412
N	466	466	466	466
Birth cohort 1959-1961				
Mean 1995	8.581	10.745	12.987	0.481
Standard Dev.	0.646	2.450	5.098	0.500
N	977	977	977	977
Mean 2002	9.033	11.241	15.254	0.513
Standard Dev.	1.086	2.811	8.234	0.500
N	946	946	946	946
Mean 2007	9.493	11.092	16.387	0.558
Standard Dev.	0.785	2.505	11.382	0.497
N	489	489	489	489
Mean 2013	9.702	10.520	18.461	0.709
Standard Dev.	0.795	2.959	12.979	0.455
N	375	375	375	375
Birth cohort 1962-1964				
Mean 1995	8.552	11.394	11.311	0.488
Standard Dev.	0.567	2.719	4.411	0.500
N	1169	1169	1169	1169
Mean 2002	9.053	11.781	14.135	0.508
Standard Dev.	1.018	2.751	7.160	0.500
N	1285	1285	1285	1285
Mean 2007	9.512	11.512	15.079	0.533
Standard Dev.	0.677	3.398	10.113	0.499
N	806	806	806	806
Mean 2013	9.722	10.759	16.939	0.615
Standard Dev.	0.763	3.006	12.041	0.487
N	849	849	849	849

Table 2.1 Continued
Data Summary

	Ln (Annual Income)	Education Years	Work Experience	Gender(m=1)
Birth cohort 1965-1967				
Mean 1995	8.385	11.508	8.688	0.457
Standard Dev.	0.793	2.639	3.587	0.498
N	794	794	794	794
Mean 2002	9.039	12.143	11.601	0.514
Standard Dev.	0.940	3.114	5.922	0.500
N	837	837	837	837
Mean 2007	9.538	11.699	13.316	0.538
Standard Dev.	0.883	3.309	8.546	0.499
N	541	541	541	541
Mean 2013	9.688	10.802	15.548	0.568
Standard Dev.	0.791	3.170	10.754	0.496
N	787	787	787	787
Birth Cohort 1968-1970				
Mean 1995	8.269	11.476	6.538	0.491
Standard Dev.	0.839	2.635	3.386	0.500
N	666	666	666	666
Mean 2002	8.937	12.277	9.523	0.483
Standard Dev.	1.114	2.899	4.921	0.500
N	853	853	853	853
Mean 2007	9.635	12.228	12.261	0.517
Standard Dev.	0.859	3.240	7.276	0.500
N	690	690	690	690
Mean 2013	9.746	11.357	14.414	0.536
Standard Dev.	0.744	3.000	9.298	0.499
N	998	998	998	998
Birth Cohort 1971-1973				
Mean 1995	8.109	11.368	4.046	0.497
Standard Dev.	0.952	2.581	2.262	0.500
N	652	652	652	652
Mean 2002	8.861	12.612	7.322	0.479
Standard Dev.	1.302	2.821	3.998	0.500
N	547	547	547	547
Mean 2007	9.693	12.961	9.772	0.528
Standard Dev.	0.822	3.330	5.970	0.500
N	589	589	589	589
Mean 2013	9.773	11.875	12.552	0.522
Standard Dev.	0.750	3.068	7.763	0.500
N	936	936	936	936

Table 2.2 Mincer equations of various cohort for different years

	Ln (Earning)								
	1946-1948	1949-1951	1952-1954	1955-1958	1959-1961	1962-1964	1965-1967	1968-1970	1971-1973
	1995								
Education	0.057***	0.040***	0.053***	0.040***	0.053***	0.048***	0.059***	0.066***	0.048***
	(0.006)	(0.005)	(0.005)	(0.005)	(0.008)	(0.006)	(0.011)	(0.012)	(0.015)
Work experience	0.002	-0.001	0.003	0.002	0.013***	0.008**	0.030***	0.038***	0.065***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.004)	(0.004)	(0.008)	(0.010)	(0.017)
N	945	1259	1479	1868	977	1169	794	666	652
	2002								
Education	0.086***	0.071***	0.088***	0.085***	0.085***	0.086***	0.085***	0.104***	0.135***
	(0.011)	(0.011)	(0.008)	(0.009)	(0.012)	(0.010)	(0.010)	(0.012)	(0.019)
Work experience	0.009***	0.011***	0.008***	0.015***	0.026***	0.024***	0.031***	0.057***	0.071***
	(0.003)	(0.003)	(0.002)	(0.003)	(0.004)	(0.004)	(0.005)	(0.007)	(0.013)
N	410	653	1010	1479	946	1285	837	853	547
	2007								
Education	0.098***	0.079***	0.099***	0.076***	0.054***	0.047***	0.065***	0.060***	0.064***
	(0.031)	(0.015)	(0.014)	(0.010)	(0.013)	(0.006)	(0.011)	(0.009)	(0.009)
Work experience	0.020***	0.009***	0.022***	0.016***	0.016***	0.018***	0.019***	0.020***	0.020***
	(0.006)	(0.003)	(0.003)	(0.002)	(0.003)	(0.002)	(0.004)	(0.004)	(0.005)
N	60	208	354	645	489	806	541	690	589
	2013								
Education	-0.007	0.062*	0.116***	0.075***	0.064***	0.086***	0.075***	0.080***	0.065***
	(0.047)	(0.032)	(0.019)	(0.012)	(0.013)	(0.008)	(0.008)	(0.008)	(0.008)
Work experience	0.029**	0.018*	0.011**	0.015***	0.018***	0.011***	0.008***	0.008***	0.017***
	(0.013)	(0.009)	(0.004)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.003)
N	26	56	151	466	375	849	787	998	936

NOTES. t-statistics in parentheses*** p<0.01, ** p<0.05, * p<0.1

Table 2.3 Mincer equations for multiple cohorts in different years

	1995	2002	2007	2013
	Ln(Earning)			
Years of education	0.039***	0.074***	0.077***	0.065***
	(0.005)	(0.009)	(0.010)	(0.010)
Work experience	0.002	0.016***	0.016***	0.015***
	(0.002)	(0.003)	(0.002)	(0.002)
Male	0.158***	0.183***	0.303***	0.309***
	(0.012)	(0.021)	(0.022)	(0.023)
Education*1946-1948 (#1)	0.024***	0.010	0.006	0.005
	(0.008)	(0.017)	(0.028)	(0.035)
Education*1949-1951 (#2)	0.002	-0.014	0.006	-0.025
	(0.008)	(0.015)	(0.019)	(0.025)
Education*1952-1954 (#3)	0.010	0.006	0.024	0.040**
	(0.008)	(0.013)	(0.016)	(0.020)
Education*1959-1961 (#5)	0.007	0.011	-0.011	-0.009
	(0.009)	(0.014)	(0.016)	(0.016)
Education*1962-1964 (#6)	0.010	0.009	-0.024*	0.015
	(0.008)	(0.013)	(0.012)	(0.013)
Education*1965-1967 (#7)	0.020**	0.012	-0.009	0.004
	(0.009)	(0.013)	(0.014)	(0.013)
Education*1968-1970 (#8)	0.026**	0.027*	-0.014	0.010
	(0.010)	(0.014)	(0.013)	(0.013)
Education*1971-1973 (#9)	0.005	0.055***	-0.015	-0.003
	(0.011)	(0.016)	(0.013)	(0.013)
Experience*#1	0.002	-0.008	0.003	-0.007
	(0.003)	(0.005)	(0.006)	(0.009)
Experience*#2	-0.000	-0.006	-0.006*	0.011
	(0.003)	(0.004)	(0.004)	(0.007)
Experience*#3	0.004	-0.008**	0.004	-0.002
	(0.003)	(0.004)	(0.003)	(0.004)
Experience*#5	0.013***	0.011**	0.000	0.004
	(0.004)	(0.004)	(0.004)	(0.004)
Experience*#6	0.008*	0.008*	0.001	-0.003
	(0.005)	(0.004)	(0.003)	(0.003)
Experience*#7	0.034***	0.016***	0.003	-0.006*
	(0.006)	(0.006)	(0.004)	(0.003)
Experience*#8	0.041***	0.040***	0.003	-0.006*
	(0.007)	(0.007)	(0.004)	(0.003)
Experience*#9	0.071***	0.059***	0.005	0.002
	(0.011)	(0.010)	(0.005)	(0.004)
N	9809	8020	4382	4644
R2	0.242	0.173	0.256	0.286

NOTES. t-statistics in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 2.4 The decomposition of wage growth for each cohort

	$ln(w_1)$	$ln(w_0)$	Difference	Return to Education	Return to Experience	Experience	N
Birth cohort 1: 1946-1948							
2002 vs 1995	9.269	8.743	0.526***	0.298**	0.156**	0.005	1355
			(0.044)	(0.132)	(0.076)	(0.006)	
2007 vs 1995	9.478	8.743	0.735***	0.421	0.377***	-0.003	1005
			(0.119)	(0.331)	(0.135)	(0.005)	
2013 vs 1995	9.251	8.743	0.508***	-0.667	0.550**	-0.014	971
			(0.174)	(0.494)	(0.263)	(0.019)	
Birth cohort 2: 1949-1951							
2002 vs 1995	9.256	8.749	0.507***	0.312***	0.217***	-0.001	1912
			(0.037)	(0.119)	(0.065)	(0.003)	
2007 vs 1995	9.646	8.749	0.897***	0.389**	0.180**	-0.002	1467
			(0.055)	(0.153)	(0.070)	(0.006)	
2013 vs 1995	8.870	8.749	0.121	0.222	0.352*	0.006	1315
			(0.143)	(0.325)	(0.182)	(0.018)	
Birth cohort 3: 1952-1954							
2002 vs 1995	9.168	8.726	0.442***	0.353***	0.098*	0.005	2489
			(0.031)	(0.098)	(0.057)	(0.003)	
2007 vs 1995	9.523	8.726	0.797***	0.462***	0.345***	0.007	1833
			(0.051)	(0.151)	(0.068)	(0.005)	
2013 vs 1995	9.454	8.726	0.728***	0.625***	0.139	-0.001	1630
			(0.080)	(0.192)	(0.084)	(0.004)	
Birth cohort 4: 1955-1958							
2002 vs 1995	9.089	8.688	0.401***	0.481***	0.206***	0.005	3347
			(0.028)	(0.103)	(0.052)	(0.005)	
2007 vs 1995	9.521	8.688	0.833***	0.386***	0.213***	0.006	2513
			(0.033)	(0.114)	(0.047)	(0.007)	
2013 vs 1995	9.595	8.688	0.907***	0.376***	0.194***	0.007	2334
			(0.044)	(0.132)	(0.052)	(0.008)	

Table 2.4 Continued
The decomposition of wage growth for each cohort

	$ln(w_1)$	$ln(w_0)$	Difference	Return to Education	Return to Experience	Experience	N
Birth cohort 5: 1959-1961							
2002 vs 1995	9.033	8.581	0.453***	0.352**	0.165**	0.030***	1923
			(0.041)	(0.154)	(0.073)	(0.010)	
2007 vs 1995	9.493	8.581	0.912***	0.013	0.032	0.044***	1466
			(0.041)	(0.166)	(0.064)	(0.015)	
2013 vs 1995	9.702	8.581	1.121***	0.125	0.063	0.071***	1352
			(0.046)	(0.168)	(0.065)	(0.023)	
Birth cohort 6: 1962-1964							
2002 vs 1995	9.053	8.552	0.501***	0.435***	0.370***	0.024**	2454
			(0.033)	(0.131)	(0.058)	(0.010)	
2007 vs 1995	9.512	8.552	0.960***	-0.012	0.299***	0.032**	1975
			(0.029)	(0.095)	(0.046)	(0.014)	
2013 vs 1995	9.722	8.552	1.170***	0.438***	0.222***	0.048**	2018
			(0.031)	(0.114)	(0.046)	(0.020)	
Birth cohort 7: 1965-1967							
2002 vs 1995	9.039	8.385	0.653***	0.296*	0.005	0.088***	1631
			(0.043)	(0.165)	(0.080)	(0.024)	
2007 vs 1995	9.538	8.385	1.152***	0.070	-0.094	0.139***	1335
			(0.048)	(0.174)	(0.077)	(0.038)	
2013 vs 1995	9.688	8.385	1.302***	0.187	-0.196***	0.206***	1581
Birth cohort 8: 1968-1970							
2002 vs 1995	8.937	8.269	0.667***	0.436**	0.125	0.112***	1519
			(0.050)	(0.201)	(0.078)	(0.030)	
2007 vs 1995	9.635	8.269	1.366***	-0.067	-0.116*	0.215***	1356
			(0.046)	(0.177)	(0.068)	(0.056)	
2013 vs 1995	9.746	8.269	1.477***	0.162	-0.192***	0.295***	1664
			(0.040)	(0.166)	(0.064)	(0.076)	

Table 2.4 Continued
The decomposition of wage growth for each cohort

	$ln(w_1)$	$ln(w_0)$	Difference	Return to Education	Return to Experience	Experience	N
Birth cohort 9: 1971-1973							
2002 vs 1995	8.861	8.109	0.753***	0.989***	0.025	0.211***	1199
			(0.068)	(0.273)	(0.088)	(0.058)	
2007 vs 1995	9.693	8.109	1.584***	0.189	-0.180**	0.370***	1241
			(0.051)	(0.200)	(0.073)	(0.101)	
2013 vs 1995	9.773	8.109	1.664***	0.200	-0.193***	0.549***	1588
			(0.045)	(0.190)	(0.071)	(0.148)	

NOTES. t-statistics in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 2.5 The decomposition of wage differentials between cohorts by years

	$ln(w_1)$	$ln(w_0)$	Difference	Return to Education	Return to Experience	Education	Experience	N
1955-1958 vs 1946-1948								
1995	8.688	8.743	-0.055**	-0.182**	0.011	0.006	-0.007	2813
			(0.024)	(0.075)	(0.059)	(0.007)	(0.010)	
2002	9.089	9.269	-0.180***	-0.004	0.147	-0.020	-0.052***	1889
			(0.046)	(0.159)	(0.097)	(0.015)	(0.019)	
2007	9.521	9.478	0.043	-0.228	-0.077	0.005	-0.003	705
			(0.121)	(0.353)	(0.124)	(0.045)	(0.044)	
2013	9.595	9.251	0.343*	0.626	-0.151	-0.016	0.230*	492
			(0.178)	(0.375)	(0.147)	(0.106)	(0.135)	
1955-58 vs 1949-1951								
1995	8.688	8.749	-0.061***	-0.004	0.052	0.024***	0.003	3127
			(0.020)	(0.067)	(0.054)	(0.005)	(0.007)	
2002	9.089	9.256	-0.167***	0.146	0.100	0.028***	-0.033***	2132
			(0.042)	(0.146)	(0.081)	(0.011)	(0.010)	
2007	9.521	9.646	-0.126**	-0.032	0.160*	0.006	-0.033**	853
			(0.061)	(0.188)	(0.085)	(0.019)	(0.016)	
2013	9.595	8.870	0.724***	0.103	-0.028	0.118*	0.166*	522
			(0.148)	(0.275)	(0.091)	(0.070)	(0.094)	
1955-58 vs 1952-1954								
1995	8.688	8.726	-0.038*	-0.129*	-0.017	0.035***	-0.008	3347
			(0.020)	(0.070)	(0.053)	(0.006)	(0.005)	
2002	9.089	9.168	-0.079**	-0.033	0.137*	0.036***	-0.016***	2489
			(0.036)	(0.126)	(0.070)	(0.011)	(0.006)	
2007	9.521	9.523	-0.002	-0.237	-0.127	0.058***	-0.039*	999
			(0.057)	(0.177)	(0.077)	(0.021)	(0.021)	
2013	9.595	9.454	0.141	-0.378*	0.070	0.070*	0.014	617
			(0.089)	(0.205)	(0.088)	(0.040)	(0.017)	

Table 2.5 Continued

The decomposition of wage differentials between cohorts by years

	$ln(w_1)$	$ln(w_0)$	Difference	Return to Education	Return to Experience	Education	Experience	N
1955-58 vs 1959-1961								
1995	8.688	8.581	0.107***	-0.139	-0.143**	-0.012**	0.031***	2845
			(0.025)	(0.101)	(0.058)	(0.006)	(0.010)	
2002	9.089	9.033	0.056	0.001	-0.157**	-0.029***	0.061***	2425
			(0.043)	(0.163)	(0.073)	(0.011)	(0.013)	
2007	9.521	9.493	0.028	0.250	0.006	-0.016*	0.032**	1134
			(0.047)	(0.181)	(0.060)	(0.009)	(0.013)	
2013	9.595	9.702	-0.107*	0.117	-0.060	-0.042**	0.008	841
			(0.059)	(0.186)	(0.075)	(0.016)	(0.017)	
1955-58 vs 1962-1964								
1995	8.688	8.552	0.136***	-0.095	0.119**	-0.042***	0.034**	3037
			(0.021)	(0.085)	(0.046)	(0.007)	(0.014)	
2002	9.089	9.053	0.036	-0.010	-0.123*	-0.075***	0.085***	2764
			(0.038)	(0.154)	(0.065)	(0.012)	(0.015)	
2007	9.521	9.512	0.009	0.339**	-0.030	-0.034***	0.060***	1451
			(0.039)	(0.132)	(0.045)	(0.009)	(0.013)	
2013	9.595	9.722	-0.127**	-0.119	0.059	-0.077***	0.022**	1315
			(0.050)	(0.153)	(0.057)	(0.018)	(0.010)	
1955-58 vs 1965-1967								
1995	8.688	8.385	0.303***	-0.222*	-0.222***	-0.058***	0.184***	2662
			(0.031)	(0.133)	(0.070)	(0.012)	(0.052)	
2002	9.089	9.039	0.050	0.007	-0.177***	-0.105***	0.185***	2316
			(0.041)	(0.158)	(0.067)	(0.016)	(0.032)	
2007	9.521	9.538	-0.017	0.130	-0.045	-0.059***	0.099***	1186
			(0.049)	(0.171)	(0.064)	(0.015)	(0.025)	
2013	9.595	9.688	-0.093*	-0.001	0.112**	-0.070***	0.025**	1253
			(0.051)	(0.155)	(0.057)	(0.016)	(0.010)	

Table 2.5 Continued

The decomposition of wage differentials between cohorts by years

	$ln(w_1)$	$ln(w_0)$	Difference	Return to Education	Return to Experience	Education	Experience	N
1955-1958 vs 1968-1970								
1995	8.688	8.269	0.419***	-0.280*	-0.212***	-0.061***	0.303***	2534
			(0.035)	(0.151)	(0.065)	(0.014)	(0.085)	
2002	9.089	8.937	0.152***	-0.221	-0.378***	-0.142***	0.447***	2332
			(0.046)	(0.185)	(0.075)	(0.021)	(0.061)	
2007	9.521	9.635	-0.114**	0.196	-0.045	-0.087***	0.121***	1335
			(0.045)	(0.166)	(0.059)	(0.017)	(0.029)	
2013	9.595	9.746	-0.152***	-0.044	0.090*	-0.118***	0.038***	1464
			(0.048)	(0.158)	(0.052)	(0.018)	(0.013)	
1955-1958 vs 1971-1973								
1995	8.688	8.109	0.579***	-0.079	-0.240***	-0.039***	0.693***	2520
			(0.040)	(0.178)	(0.072)	(0.014)	(0.200)	
2002	9.089	8.861	0.228***	-0.624**	-0.401***	-0.230***	0.724***	2026
			(0.061)	(0.262)	(0.101)	(0.037)	(0.140)	
2007	9.521	9.693	-0.172***	0.167	-0.049	-0.138***	0.181***	1234
			(0.046)	(0.176)	(0.056)	(0.023)	(0.047)	
2013	9.595	9.773	-0.178***	0.105	-0.018	-0.133***	0.102***	1402
			(0.049)	(0.165)	(0.051)	(0.020)	(0.022)	

NOTES. t-statistics in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 2.6 The decomposition of wage growth differentials between cohorts by different years

	1995-2002					
	4 vs 1	4 vs 2	4 vs 3	4 vs 5	4 vs 6	4 vs 9
$(W_2' - W_2) - (W_1' - W_1)$	-0.018	-0.048	0.060	-0.039	-0.091***	-0.237***
SE	(0.052)	(0.046)	(0.041)	(0.050)	(0.043)	(0.073)
Education						
$\bar{E}_i[(\beta_i' - \beta_i) - (\beta_j' - \beta_j)]$	0.180	0.151	0.104	0.137	0.079	-0.435
SE	(0.168)	(0.163)	(0.147)	(0.182)	(0.158)	(0.273)
$[(\beta_j' - \beta_j)(\bar{E}_i - \bar{E}_j)]$	0.003	0.019***	0.024***	-0.007	-0.033***	-0.074***
SE	(0.004)	(0.008)	(0.007)	(0.005)	(0.011)	(0.023)
Experience						
$\bar{X}_i[(\gamma_i' - \gamma_i) - (\gamma_j' - \gamma_j)]$	0.089	0.033	0.122*	0.011	-0.295***	0.019
SE	(0.078)	(0.074)	(0.071)	(0.101)	(0.095)	(0.338)
$[(\gamma_j' - \gamma_j)(\bar{X}_i - \bar{X}_j)]$	-0.038**	-0.044***	0.022***	0.030**	0.132***	0.069
SE	(0.019)	(0.013)	(0.008)	(0.013)	(0.022)	(0.246)
$[(\bar{X}_i' - \bar{X}_i) - (\bar{X}_j' - \bar{X}_j)]\gamma_i'$	-0.011***	0.012***	0.011***	0.000	-0.008***	-0.015***
SE	(0.004)	(0.003)	(0.003)	(0.002)	(0.003)	(0.004)
$[(\gamma_i' - \gamma_j')(\bar{X}_j' - \bar{X}_j)]$	0.019	0.007	0.011*	-0.023**	-0.025*	-0.181***
SE	(0.013)	(0.006)	(0.006)	(0.011)	(0.013)	(0.045)
EXPLAINED BY EDU AND EXP	0.241	0.177	0.294	0.148	-0.151	-0.616
UNEXPLAINED	-0.259	-0.225	-0.235	-0.186	0.060	0.379
	1995-2007					
$(W_2' - W_2) - (W_1' - W_1)$	0.090	-0.071	0.030	-0.074	-0.127***	-0.783***
SE	(0.118)	(0.063)	(0.060)	(0.053)	(0.044)	(0.060)
Education						
$\bar{E}_i[(\beta_i' - \beta_i) - (\beta_j' - \beta_j)]$	-0.040	-0.027	-0.107	0.373*	0.397***	0.211
SE	(0.354)	(0.198)	(0.197)	(0.199)	(0.144)	(0.217)
$[(\beta_j' - \beta_j)(\bar{E}_i - \bar{E}_j)]$	0.004	0.023**	0.031***	0.000	0.001	-0.014
SE	(0.006)	(0.010)	(0.011)	(0.003)	(0.007)	(0.015)
Experience						
$\bar{X}_i[(\gamma_i' - \gamma_i) - (\gamma_j' - \gamma_j)]$	-0.072	0.069	-0.082	0.175**	-0.192**	0.895***
SE	(0.112)	(0.073)	(0.074)	(0.089)	(0.078)	(0.282)
$[(\gamma_j' - \gamma_j)(\bar{X}_i - \bar{X}_j)]$	-0.092***	-0.036**	0.077***	0.006	0.106***	-0.502**
SE	(0.034)	(0.014)	(0.011)	(0.012)	(0.017)	(0.205)
$[(\bar{X}_i' - \bar{X}_i) - (\bar{X}_j' - \bar{X}_j)]\gamma_i'$	0.077***	0.001	0.013***	-0.005	-0.011***	-0.042***
SE	(0.013)	(0.004)	(0.004)	(0.003)	(0.003)	(0.007)
$[(\gamma_i' - \gamma_j')(\bar{X}_j' - \bar{X}_j)]$	0.007	0.022	-0.014	0.001	-0.008	-0.024
SE	(0.015)	(0.014)	(0.011)	(0.012)	(0.011)	(0.032)
EXPLAINED BY EDU AND EXP	-0.116	0.052	-0.081	0.550	0.294	0.523
UNEXPLAINED	0.206	-0.122	0.111	-0.624	-0.420	-1.306

Table 2.6 Continued
The decomposition of wage growth differentials between cohorts by different years

	1995-2013					
	4 vs 1	4 vs 2	4 vs 3	4 vs 5	4 vs 6	4 vs 9
$(W_2' - W_2) - (W_1' - W_1)$	0.425***	0.802***	0.231**	-0.200***	-0.264***	-0.783***
SE	(0.158)	(0.141)	(0.090)	(0.063)	(0.054)	(0.062)
Education						
$\bar{E}_i[(\beta_i' - \beta_i) - (\beta_j' - \beta_j)]$	1.049**	0.141	-0.292	0.253	-0.029	0.191
SE	(0.516)	(0.369)	(0.244)	(0.211)	(0.169)	(0.220)
$[(\beta_j' - \beta_j)(\bar{E}_i - \bar{E}_j)]$	-0.007	0.013	-0.055***	-0.003	-0.034***	-0.015
SE	(0.009)	(0.020)	(0.014)	(0.004)	(0.010)	(0.014)
Experience						
$\bar{X}_i[(\gamma_i' - \gamma_i) - (\gamma_j' - \gamma_j)]$	-0.221	-0.087	0.075	0.119	-0.108	0.926***
SE	(0.205)	(0.154)	(0.089)	(0.092)	(0.081)	(0.275)
$[(\gamma_j' - \gamma_j)(\bar{X}_i - \bar{X}_j)]$	-0.135**	-0.071*	0.031***	0.011	0.079***	-0.539***
SE	(0.065)	(0.037)	(0.012)	(0.012)	(0.017)	(0.199)
$[(\bar{X}_i' - \bar{X}_i) - (\bar{X}_j' - \bar{X}_j)]\gamma_i'$	0.191***	0.195***	0.058***	-0.028***	-0.030***	-0.073***
SE	(0.037)	(0.036)	(0.012)	(0.006)	(0.006)	(0.014)
$[(\gamma_i' - \gamma_j')(\bar{X}_j' - \bar{X}_j)]$	0.132	0.029	-0.002	-0.018	0.020	-0.018
SE	(0.130)	(0.094)	(0.009)	(0.023)	(0.020)	(0.034)
EXPLAINED BY EDU AND EXP	1.009	0.220	-0.185	0.335	-0.102	0.472
UNEXPLAINED	-0.584	0.582	0.416	-0.535	-0.162	-1.255

NOTES. t-statistics in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 2.7 Marginal effects of maximum likelihood estimations (Probit Model)

	(1) SOE	(2) Laid-off	(3) Try to find a job	(4) Find a new job
Base: 1955-1958 (#4)				
1946-1948 (#1)	0.013***	0.027***	-0.215***	-0.129**
	(0.002)	(0.004)	(0.067)	(0.061)
1949-1951 (#2)	0.018***	0.006**	-0.243***	-0.145***
	(0.001)	(0.003)	(0.056)	(0.053)
1952-1954 (#3)	0.040***	0.013***	-0.089*	-0.052
	(0.001)	(0.001)	(0.048)	(0.052)
1959-1961 (#5)	-0.015***	-0.022***	0.076	0.089
	(0.001)	(0.001)	(0.055)	(0.069)
1962-1964 (#6)	-0.011***	-0.038***	0.091*	0.085
	(0.002)	(0.001)	(0.053)	(0.066)
1965-1967 (#7)	-0.037***	-0.035***	0.086	0.106
	(0.002)	(0.001)	(0.061)	(0.078)
1968-1970 (#8)	-0.046***	-0.026***	0.126**	0.154**
	(0.003)	(0.002)	(0.058)	(0.077)
1971-1973 (#9)	-0.079***	-0.004	0.217***	0.367***
	(0.004)	(0.003)	(0.062)	(0.085)
Male	0.051***	-0.070***	0.179***	0.204***
	(0.009)	(0.009)	(0.032)	(0.035)
Years of education	0.033***	-0.020***	-0.003	-0.007
	(0.001)	(0.002)	(0.006)	(0.007)
N	24400	9074	1054	673

NOTES. t-statistics in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 2.8 The actual and counterfactual quantity and quality of human capital

Base cohort of 1955-1958	Actual Wage of base cohort	Counterfactual Wage by 1965-1967	Counterfactual Wage by 1968-1970	Counterfactual Wage by 1971-1973
Return to education, β	0.069	0.071	0.078	0.078
Return to experience, γ	0.012	0.012	0.012	0.012
Education, E	10.521	11.538	11.835	12.204
Experience, X	17.575	16.558	16.262	15.892

Table 2.9 Income loss from reduced education quality and quantity caused by the Cultural Revolution

Year	Income Loss (/CNY in 2013)	Ratio of Income	Income Loss	Ratio of Income	Income Loss	Ratio of Income
	Same with 1965-1967		Same with 1968-1970		Same with 1971-1973	
1995	6977328	29.195	9499360	39.748	3130949	13.101
2002	2775079	9.053	11955395	39.003	34247416	111.729
2007	-1471504	-7.125	-2135356	-10.339	-510607.3	-2.472
2013	1006761	5.758	2749994	15.728	28171.5	0.161
Total	9287663	10.020	22069392	23.810	36895928	39.806

Table 2.10 The actual and counterfactual quantity and quality of human capital

Base cohort of 1955-1958	Actual Wage of base cohort	Counterfactual Wage by 1965-1967	Counterfactual Wage by 1968-1970	Counterfactual Wage by 1971-1973
Return to education, β	0.069	0.071	0.078	0.078
Return to experience, γ	0.012	0.022	0.031	0.043
Education, E	10.521	11.538	11.835	12.204
Experience, X	17.575	21.734	23.146	23.862

Table 2.11 Income loss from reduced education quality and quantity caused by the Cultural Revolution

Year	Income Loss (/CNY in 2013)	Ratio of Income	Income Loss	Ratio of Income	Income Loss	Ratio of Income
	Same with 1965-1967		Same with 1968-1970		Same with 1971-1973	
1995	27903316	116.755	43364396	181.448	70025608	293.005
2002	19687564	64.229	86407536	281.896	227211501	741.256
2007	1654417	8.010	2457008	11.896	5035283	24.380
2013	-247910	-1.418	1815787	10.385	4353296	24.898
Total	48997388	52.862	134044725	144.617	306625690	330.810

CHAPTER 3. GOVERNMENT POLICY AND TECHNICAL INEFFICIENCY IN CHINESE FOOD PRODUCTION, 1952-2008

3.1 Introduction

Three events fundamentally changed modern Chinese economic history: the Great Leap Forward (1958~1961), the Cultural Revolution (1966~1976) and the economic reforms initiated in 1978.Food security is a critical objective in the world's most populous developing country. These government policies have had dramatic effects on the national food supply. However, few studies have examined the relative impacts of these policies. Using a consistent framework, this study compares the technical efficiencies of the labor allocations in these three policies and shows their implications for historical Chinese food production.

This study contributes to current literature in three ways. First, this study adapts the Caselli and Coleman (2006) framework to measure how labor efficiency and the related technological frontier were affected by these government policies over the 56-year period between 1952-2008. We apply non-linear least squares estimation allowing for imperfect substitution between low- and high-skill labor to approximate the production function for grains. This framework also allows for the endogenous choice of labor efficiency in response to a changing technological frontier.

Second, this paper employs several datasets that have not been previously exploited: an imbalanced panel of provincial agricultural production spanning the period 1952-2008 for as many as 25 Chinese provinces. We introduce a novel econometric model which enables us to estimate labor efficiency by skill and recover the technological frontier for Chinese food production.

Third, this paper explores the role of human capital in Chinese agricultural production. The empirical analysis shows that agricultural production was characterized by skill-biased technical progress over time, but that these gains were not exploited during the Great Leap Forward and the Cultural Revolution. We can show the lost production due to misallocations of the labor force over time. Our paper finds an enormous loss in technological frontier and labor efficiency after the Great Leap Forward. The output loss associated with reduced labor efficiency ranged from 6.9 to 35.2 percent compared with grain output in 1958. The technological frontier and labor efficiency only had a modest gain during the Cultural Revolution and some provinces did not recover until the household-responsibility system was introduced after the rural economic reforms in 1978. Grain output increased by 10.4 percent because of improved labor efficiency after the reform, accounting for 44 percent of the total increase in grain output. There was skill-biased technological change favoring skilled labor more than unskilled labor, but the skill-biased productivity grains were suppressed before the 1978 reforms.

Compared with the economic reform in the 1980s, the compulsory collectivization after the Great Leap Forward caused a greater disruption in food production. The best available technology, represented by the highest technological frontier among the 25 provinces, deteriorated in the early 1970s. This led finally to the abandonment of the communal system in food production in 1978.

The paper is organized as follows. Section II provides an overview of three policy changes in China. In section III, we discuss the model specification which enables us to calculate the labor efficiency of skilled and unskilled labor. Built on Caselli and Coleman (2006), we also introduce a technological frontier function that determines labor efficiency endogenously. Section IV discusses the data used for our analysis. Section V reports the estimation results. We use these results to evaluate the impacts of changes in government policy on the technical efficiency of food production. In section VI, sensitivity tests are launched to examine the robustness of the results and findings in the previous section. Section VII gives concluding remarks and discussion.

3.2 Review of Government Policy and Chinese Agriculture Production

3.2.1 The Great Leap Forward and The Cultural Revolution

When the communist party came to power in China in 1949, they inherited a largely rural economy dominated by peasant farming. Agriculture represented 46% of the economy and 88.2% of the population lived in rural areas. Agricultural production was characterized by small and highly fragmented farms using traditional methods, even more as land was confiscated from landlords and redistributed to tenants during the 1950s. In 1953, the central government adopted a Soviet-style economy and enacted its first five-year plan aimed at transiting from traditional farming to collective agriculture.

There were three significant forms of cooperatives in the process of collectivization, “mutual-aid teams” and “primary cooperatives” as lower stage cooperatives, and “advanced cooperatives” as higher stage cooperatives. The lower stage teams and primary cooperatives had voluntary participation. Individual farmers pooled labor, tools, and animals together temporarily or permanently. These cooperatives usually included a small number of neighboring households. Participants retained their property rights over their contributed land and tools. Revenue was distributed to the participants in proportion to their contribution of labor and capital.

The “advanced cooperatives” included hundreds of voluntary households. Revenue was distributed according to member labor contribution to collective production. Families were allowed to keep some livestock and engaged in sideline production such as handicrafts and knitting, but these products were not allowed to trade freely such as selling them to urban residents. By the end of 1957, around 90 percent of households participated in some form of cooperative, but they still enjoyed the right to exit.

The initial success of this transition encouraged the central government to take a bolder policy in the fall of 1958: the Great Leap Forward. The "advanced cooperatives" were scaled up to "People's Communes" each of which grouped thousands of households. Participation was mandatory. Each household was obligated to work for the commune. Agricultural inputs were collected and owned by the collective. Remuneration was based on nutritional needs and only partially based on the contribution of the individual farmer. During the Great Leap Forward, local markets closed and free trade was prohibited. Farmers were not allowed to keep private plots. Food production declined dramatically between 1959 and 1961. As Figure 3.1 shows, grain output fell 14.2 percent in 1959, fell 15.3 percent more in 1960, then fell an additional 5 percent in 1961. By 1961, agricultural output was two-thirds of the 1958 level.

Following the Great Leap Forward, total factor productivity in agriculture stayed at a low level for the entire collectivization period 1958-78 (Tang, 1984; Wen, 1995). Lin (1990) and Lin and Yang (1998) argued that the main cause of the failure of collective farming was the lack of a right to exit the collective. The success of a collective farm depends on a self-enforcing contract in a repeated game in which each participant promises to discipline himself to avoid punishment from other participants. However, this self-enforcing contract cannot be sustained under a one-time game when exit is not allowed. Li and Yang (2000) argued that too much food was diverted from the agricultural sector to support industrial development, leading to insufficient nutrition for labor in the agricultural sector. Dong and Dow (1993) argued that inefficiency was caused by imperfect monitoring in collective teams. Members devoted 10-20% of total labor time monitoring one another to prevent free-rider problems.

After the failure of the Great Leap Forward, the central government made several policy changes in attempts to recover food production. Rural trade markets reopened in the fall of 1959, and private plots were restored in the summer of 1960 (Perkins, 1966). However, collectivization was not fully eliminated. The “People’s Commune” disappeared, but mandatory participation in “cooperative teams” continued through 1978. Not all in the government agreed with the relaxation of the collectivist movement. In 1966, the Cultural Revolution was imposed to purge remaining remnants of capitalist thought in order to insure Maoist thought would be the dominant ideology. The biggest disruptions were in urban areas. Industrial output fell by 15 percent in 1967, and it fell by another 10 percent in 1968. However, rural areas were taxed with absorbing millions of urban youth who were sent to the countryside for menial agricultural work.

Food production rose during this period. However, total factor productivity stayed low (Tang, 1984; Wen, 1995; Wiens, 1982), reflecting the stagnating technical progress in food production during the Cultural Revolution.

3.2.2 Rural Economic Reform and Household Responsibility System

By the end of 1978, continuing slow growth of food production led to the abandonment of the mandatory cooperative teams (McMillan et al.,1989). Production switched from a collective system to a household-based one called the “production responsibility system.” Each household signed a contract with the government setting a delivery quota payable to the state. The household was allowed to keep any output above the quota and sell it on the market. Most restrictions on the household’s private land plots were removed. Families were allowed to specialize in planting crops more suitable to their land and environmental features and to control agricultural input allocations.

At the same time, a market system was introduced that set grain prices according to demand and supply. By the end of 1984, more than 97 percent of farm families operated under this system. As shown in Figure 3.1, grain production rose significantly after 1978. Lin (1988) argued that the institutional changes in Chinses agriculture were equivalent to a labor augmenting innovation. Because families could keep more of their production after the reform, they had a greater incentive and used the inputs more efficiently. McMillan et al. (1989) found that three-quarters of the measured productivity increase was attributable to the household-based system. Lin (1992) found the introduction of the new system caused a 49 percent growth in crop production. Zhang and Carter (1997) estimated the growth due to the reforms at 38 percent between 1980-1985.

3.2.3 Role of Labor Quality in Chinese Food Production

Labor quality is critical to the agricultural production, both because more educated workers are more productive, but also because more educated workers make better decisions in the production process (Shultz, 1975; Huffman, 2001). Khaldi (1975) found that the level of education was positively correlated with the allocative efficiency of the inputs including machinery, labor, and fertilizer. The measure of scale economy also improved with more education. Yang (1997) was the first to study the role of labor quality in Chinese agriculture. He developed a household production model that contained multiple education measures to approximate labor quality and managerial skills. He found that the household member with the highest schooling contributes the most to productive efficiency. Liu and Zhuang (2000) applied a stochastic production frontier function to farm-level data in two Chinese provinces to show that the education of the household head is positively correlated with agricultural output. Wang et al. (1996) found the household's education level improved production efficiency. Fan and Pardey (1997) used Chinese provincial-level data to find that research expenditures significantly contribute to agricultural output over the period 1965-1993. In this study, we will propose a consistent framework to evaluate production efficiency in Chinese agriculture from 1952 to 2008.

3.3 Model Specification

3.3.1 Grain Production Function

We extend the Caselli and Coleman (2006) model to the case of Chinese agricultural production. While Caselli-Coleman analyzed aggregate production with capital and labor across many countries at one point in time, we focus on agricultural production in a single country with many inputs across many time periods. Similar to Caselli-Coleman, we begin by assuming that imperfect substitute inputs including skilled and unskilled labor and other inputs enter a CES production function:

$$Y_{it} = A_{it} D_{it}^{\alpha_{1t}} M_{it}^{\alpha_{2t}} F_{it}^{\alpha_{3t}} [(A_{it}^{s} L_{it}^{s})^{\sigma} + (A_{it}^{u} L_{it}^{u})^{\sigma}]^{\alpha_{4t}/\sigma} \quad (1)$$

where Y_{it} is the grain output of province i in year t; $D_{it}, M_{it},$ and F_{it} are land, machinery, and fertilizer used in grain production; L_{it}^{s} and L_{it}^{u} represent skilled labor and unskilled labor; A_{it} is a Hicks neutral index of total factor productivity of province i at year t; A_{it}^{s} and A_{it}^{u} are the labor efficiency unit of skilled and unskilled labor; α_{1t}, α_{2t}, α_{3t}, and α_{4t} are the output elasticities for land, machinery, fertilizer, and effective labor. Effective labor is the nonlinear combination of the two types of labor with the elasticity of substitution between skilled and unskilled labor equal to $1/(1-\sigma)$. Skilled and unskilled labor are imperfect substitutes when $\sigma < 1$. A_{it}^{s} and A_{it}^{u} convert raw quantities of skilled and unskilled labor into efficiency units. All parameters except σ are time-varying but fixed across provinces. Technical change is captured in the evolving values of A_{it}^{s} and A_{it}^{u}. If the ratio A_{it}^{s}/A_{it}^{u} is constant over time, technical change is defined as skill neutral. Rising values of A_{it}^{s}/A_{it}^{u} indicate skill biased technical change while falling values imply technical changes favoring less skilled labor.

We identify the total factor productivity A_{it} and elasticity parameters α_{1t}, α_{2t}, α_{3t}, and α_{4t} from an estimation of equation (1). Following Fan (1991) and Zhang and Fan (2001), we assume that α_{1t}, α_{2t}, α_{3t}, and α_{4t} change at a constant rate over time, respectively. Therefore, $\alpha_{nt} = \alpha_n^0 + \beta_n \times t, \forall \text{ n} = 1,2,3,4.$

3.3.2 Relationship Between Labor Efficiencies

From equation (1), we can solve for the marginal rate of substitution between skilled and unskilled labor, which is also equal to the skill premium between skilled labor's wage (w_{it}^s) and unskilled labor's wage (w_{it}^u).

$$MRP_{it}^{L^s} \Big/ MRP_{it}^{L^u} = \left(\frac{A_{it}^s}{A_{it}^u}\right)^{\sigma} \left(\frac{L_{it}^s}{L_{it}^u}\right)^{\sigma-1} = \frac{w_{it}^s}{w_{it}^u} \tag{2}$$

After a simple algebraic transformation, we can define

$$\delta_{it} \equiv \frac{(A_{it}^s L_{it}^s)^{\sigma}}{(A_{it}^u L_{it}^u)^{\sigma}} = \frac{w_{it}^s L_{it}^s}{w_{it}^u L_{it}^u} \tag{3}$$

Therefore, we can combine equation (1) and (3) to rewrite the production function as

$$Y_{it} = A_{it} D_{it}^{\alpha_{1t}} M_{it}^{\alpha_{2t}} F_{it}^{\alpha_{3t}} [(1 + \delta_{it})(A_{it}^u L_{it}^u)^{\sigma}]^{\alpha_{4t}/\sigma} \tag{4}$$

A_{it} is affected by prices of output, cost of inputs, and percentage of land used for grain production. It can be expressed as $A_{it} = e^{\theta_0 + \theta_1 t + \rho \times p_t + \phi \times c_t + \mu \times r_{it} + \xi_i}$. p_t and c_t represent grain price and cost of agricultural inputs of year t, r_{it} is the percentage of land for planting grains. ξ_i is the provincial fixed effect. Same as Lin(1992), we assume that changes in input and output prices will affect the relative use of skilled and unskilled labor, but they will also affect time allocated to work and leisure. It is because technology choice is influenced by price changes (Hayami and Ruttan, 1971). The mix of crops also responds to soil, temperature, rainfall, and other region-specific characteristics are a major growth in agriculture (Lin, 1992). After a logarithmic transformation, (4) is expressed as:

$$y_{it} = ln(A_{it}) + \alpha_{1t}d_{it} + \alpha_{2t}m_{it} + \alpha_{3t}f_{it} + \frac{\alpha_{4t}}{\sigma}ln[(1+\delta_{it})(L_{it}^{u})^{\sigma}] + \alpha_{4t}ln(A_{it}^{u})$$

$$= \theta_0 + \theta_1 t + (a_1^0 + \beta_1 t)d_{it} + (a_2^0 + \beta_2 t)m_{it} + (a_3^0 + \beta_3 t)f_{it}$$

$$+ \frac{1}{\sigma}(a_4^0 + \beta_4 t)ln[(1+\delta_{it})(L_{it}^{u})^{\sigma}] + \rho \times p_t + \phi \times c_t + \mu r_{it} + \delta_i + \alpha_{4t}ln(A_{it}^{u}) \quad (5)$$

Where $y_{it}, d_{it}, m_{it}, f_{it}$ are logarithms of Y_{it}, D_{it}, M_{it}, and F_{it}. Nonlinear least square estimation is used to estimate (5) after controlling for the provincial fixed effect. We can recover A_{it}^{u} from the error term in the estimation of (5) and then get A_{it}^{s} from (2). There are five levels in education attainment: illiteracy, elementary school (six years), junior high school (three years), senior high school (three years), and college (four years). In this study, we define "skilled" labor as those who have completed at least the elementary schooling. Therefore, unskilled labor refers to illiterate farmers.

We define unskilled and skilled labor in this way for two reasons. First, illiterate farmers are qualitatively different from those who complete primary schooling. The workers who never get formal education would face more difficulties in handling the tasks requiring reading and mathematics (e.g., use fertilizers and operate tractors). They would also have difficulties in managing accounts, sales, and resource allocation. Second, the average farmer in China has minimal education. Figure 3.1 shows that the average education level for rural labor in China was still less than seven years in 2008. The sensitivity test included in section 6 define skilled labor in an alternative way, and the result shows that our findings are robust and do not fundamentally change with the definition of skilled labor.

We choose the subgroup with the least education as the base and then weight the remaining subgroups by their wages relative to the wage of workers in the base group. Let $L_{s,0}$ be the number of farmers who finish elementary school; and $L_{s,1}, L_{s,2}$, and $L_{s,3}$ are, respectively, farmers who completed junior high school, high school, and college education. $w_{s,i}; i = 1,2,3$, is the wage ratio between farmers of school level *i* and the wage of farmers who complete primary schools. Then, skilled labor L_s is constructed as $L_{s,0} + L_{s,1}w_{s,1} + L_{s,2}w_{s,2} + L_{s,3}w_{s,3}$. L_s measures skilled labor in "elementary schooling equivalents." As mentioned above, L_u is the number in the labor force who have not finished elementary school.

To get the wage ratio between education attainment subgroups, we use the Mincerian coefficient and the duration in years of the various education levels. The wage equation has the form of $ln(w_i) = \pi \cdot edu_i + \psi_1 \cdot exp_i + \psi_2 exp_i^2 + \varsigma$, where π is the percentage change in wage earnings with an additional year of education.

Since elementary education takes six years of schooling, the difference in schooling years between skilled workers and unskilled workers is six years. Since the Mincerian coefficient (π) reflects percentage income gain associated with an additional year's schooling, the wage ratio between skilled labor and unskilled labor is $\exp(6\pi)$.

3.3.3 Technological Frontier

We now provide a simple economic explanation for the determination of the efficiency pair (A_{it}^s, A_{it}^u). Suppose an individual farm has a production function of the form (1):

$$Y_{it} = A_{it} D_{it}^{\alpha_{1t}} M_{it}^{\alpha_{2t}} F_{it}^{\alpha_{3t}} [(A_{it}^s L_{it}^s)^\sigma + (A_{it}^u L_{it}^u)^\sigma]^{\alpha_{4t}/\sigma}$$

The farm not only optimally chooses its factor inputs, but it also optimally chooses how efficiently to use labor. The farm will pick the pair of labor's efficiencies, (A_{it}^s, A_{it}^u), to achieve the highest grain output. The menu of feasible technology choices is given by:

$$(A_{it}^s)^\omega + \gamma_{it} (A_{it}^u)^\omega \leq B_{it} \qquad (6)$$

where ω, γ_{it}, and B_{it} are all positive, exogenously determined parameters. On the technological frontier of a form like (6), the farmer faces a trade-off between the efficiency of skilled labor and the efficiency of unskilled labor. Parameters ω and γ describes the trade-off.

Figure 3.2 illustrates a technological frontier from (6). The area under the frontier illustrates the feasible choices of (A_{it}^s, A_{it}^u). The area under the technological frontier expands with a higher ω, because a larger ω indicates the boundary is further away from the origin. The parameter *B* represents the "height" of the technological frontier. Larger values of *B* imply more possible pairs (A_{it}^s, A_{it}^u) are available to the farm. The technological frontier function (6) is very flexible. Caselli and Coleman assume that there is a technological menu representing the best combinations of (A_{it}^s, A_{it}^u) that producer can choose among all countries at one time. They also assume that every country can achieve the best frontier if there is no cost of transferring the technology. In our study, we assume each province can achieve its own technological menu's frontier of yesterday since it can always produce with the old technology. Moreover, the technological menu does not change much in a short period unless there were exogenous shocks such as policy changes.

The farm maximizes its grain production by optimally choosing L^s, L^u, A^s and A^u subject to (1) and (6). Caselli and Coleman (2006) prove that a unique equilibrium exists if $\omega > \sigma/(1-\sigma)$ [14]. If $\omega < \sigma/(1-\sigma)$, some farms will choose $A^u = 0$ and employ only skilled labor, while other farms will choose $A^s = 0$ and employ only unskilled labor. When σ is small, the skilled labor and unskilled labor are poor substitutes, the farmers will use both types of labor. When σ is large, the two kinds of labor become better substitutes, and it leads some farmers to use either skilled labor or unskilled labor.

Combining (1) and (6), the first-order condition implies:

$$\left(\frac{A_{it}^s}{A_{it}^u}\right)^{\omega-\sigma} = \gamma \left(\frac{L_{it}^s}{L_{it}^u}\right)^{\sigma} \qquad (7)$$

[14] The proof is in the appendix.

$$\begin{cases} A_{it}^{s} = \left(\frac{B_{it}}{1+\gamma_{it}^{\sigma/(\sigma-\omega)}(L_{it}^{s}/L_{it}^{u})^{\omega\sigma/(\sigma-\omega)}}\right)^{1/\omega} \\ A_{it}^{u} = \left(\frac{B_{it}/\gamma_{it}}{1+\gamma_{it}^{\sigma/(\omega-\sigma)}(L_{it}^{s}/L_{it}^{u})^{\omega\sigma/(\omega-\sigma)}}\right)^{1/\omega} \end{cases} \quad (8)$$

Since $\omega > \frac{\sigma}{(1-\sigma)} > \sigma$, (8) implies A_s increases with B and L_s/L_u, while A_u increases with B and L_u/L_s. The farmer will choose higher efficiency A_i $(i = s, u)$ when L_i is relatively more abundant.

The logarithm form of (8) gives us a way to back out ω and γ. That is:

$$\log\left(\frac{A_{it}^{s}}{A_{it}^{u}}\right) = \frac{\sigma}{\omega-\sigma}\log\left(\frac{L_{it}^{s}}{L_{it}^{u}}\right) + \frac{1}{\omega-\sigma}\log(\gamma_{it}) \quad (9)$$

Since γ_{it} is assumed exogenous and not correlated with $\frac{L_{it}^{s}}{L_{it}^{u}}$, we can back out ω from the coefficient of $\log\left(\frac{L_{it}^{s}}{L_{it}^{u}}\right)$. Then we can back out γ from (8). In the empirical analysis, we found the "back-out" ω satisfies the condition "$\omega > \sigma/(1-\sigma)$".

3.4 Data

Our analysis is based on information on grain output and four inputs: land, machinery, fertilizer, and labor. Our data set covers twenty-five provinces over the period 1978-2008 (24 provinces since 1970, except Hebei province), and it has related information of some provinces before 1978. Among these provinces, Fujian, Hunan, Jiangxi, Shandong, and Shanxi have available information about agricultural production for the period of 1957-1976 when the Great Leap Forward and Cultural Revolution occurred. Following previous studies on this topic (Zhang and Fan,2000; Lin,1992), our study excludes Shanghai, Beijing, Tianjin, and Tibet since they represent relatively small shares of agricultural production. We also exclude Chongqing and

Hainan from this study since these two provinces were separated from Sichuan and Guangdong in 1988 and 1997, respectively.

3.4.1 Output

Grain production was obtained from the China Compendium of Statistics compiled by the National Bureau of Statistics of China (1949-2008). It provides grain production on the provincial level as early as 1949. This dataset reconciles the statistics for Sichuan and Guangdong for the whole period, even before Chongqing and Hainan separated in 1988 and 1997, respectively.

3.4.2 Land

The land data is the total sown area for grain production from the China Compendium Statistics (1949-2008). Moreover, China Compendium of Statistics also provides the total sown acreage for cropping. In the end, we have provincial-level land information since 1952.

3.4.3 Machinery

Agricultural capital is measured by the aggregated horsepower of agrarian machinery and draft animals from the China Compendium Statistics (1949-2008) and The Agricultural Statistics of the People's Republic of China reproduced by the USDA,1949-1990. The machinery refers to large and medium tractors, small and hand tractors, combine harvesters, irrigation and drainage equipment, trucks and draft animals. The horsepower used on grain production is weighted as follows.

$$M_{it,grain} = M_{it} \times \frac{Value_{it,grain}}{Value_{it,agriculture}} \times \frac{D_{i,t}^{g}}{D_{i,t}^{c}}$$

Where $HorsePower_{grain,p,t}$ represents the horsepower used in grain production in province *i* of year *t*. $HorsePower_{p,t}$ is total horsepower used in agricultural production in province *i* of year *t*.

Chinese agricultural production has four divisions: cropping, forestry, animal husbandry, and fishery. To get the horsepower used in grain production, we assign several weights to the total horsepower. In the first step, the total horsepower usage is weighted by the ratio of crop's value over total agricultural output's value. $Value_{c,i,t}$ is the monetary value of crops in province *i* at year *t*. $Value_{ag,i,t}$ is the total monetary value of agriculture products in province *i* at year *t*. In the second step, we weight the result from the first phrase by the ratio between the sown area for grain production and the total sown area for cropping. $SA^{g}_{i,t}$ is the sown area for grain production, and $SA^{c}_{i,t}$ is the sown area for cropping. This method follows Lin (1992).

However, the total usage of horsepower ($HorsePower_{p,t}$) of some provinces is not directly available before 1979. We estimate it based on the national horsepower and provincial weights. First, we use the 1980's horsepower for all provinces including the provinces excluded from our analysis (e.g., Shanghai, Beijing, etc.), to calculate the allocation weights for fertilizer. Note that the individual province's weight changes over time because we have a different number of missing values in each year. For example, Yunnan lacks the horsepower data only for 1970, while Heilongjiang lacks the horsepower data from 1970 to 1977. The weight is calculated by:

$Weight_{it} = \frac{M_{i,1980}}{\sum_{i=1}^{n_t} M_{i,1980}}$, where n_t is the number of provinces that lack the information at year t. $Weight_{i,t}$ represents the weight of the subject province *i* of year t. With the allocation weight of each province of each year, we can estimate the horsepower usage by timing the weights with the sum of horsepower for these n_t provinces, which is equal to the national horsepower usage differencing all other provinces.

$$M_{it} = Weight_{it} \times \left(\widehat{National}\ M_t - \sum_{J=1}^{31-n_t} M_{Jt}\right)$$

Where $M_{j,t}$ is the horsepower usage of the provinces *j* at time *t*. 31 is the number of provinces including 25 provinces for our analysis and 6 provinces that have limited agricultural production. With this method, we estimate 55 values for the missing value of horsepower in these 25 provinces for the period of 1970-2008.

3.4.4 Fertilizer

Chemical fertilizer is measured in an effective amount. The effective amount measures the actual nutrient content such as ammonium sulfate, superphosphate, and potassium sulfate. The fertilizer used on grain production is weighted by the ratio of sown land in grain production and the total sown area.

$$F_{it,grain} = F_{it} \times \frac{D_{it}^{g}}{D_{it}^{c}}$$

The fertilizer usage of some provinces is not available before 1979. We estimate it based on national fertilizer usage and provincial weights for the period of 1970-1979. We use a similar method above to deal with missing data. In the end, we estimate 69 values of fertilizer for those 25 provinces for the period of 1970-2008.

3.4.5 Labor

Labor force used in grain production is estimated from the data of total labor force in cropping, animal husbandry, forestry, and fishery. The data is obtained from the China Compendium Statistics of Agriculture. We first derive the labor used in the cropping sector by weighting the total labor by the ratio between the crop output's value and the overall agricultural product's value. Then we get an estimated labor force in grain production based on sown land used in grain production and total sown area. That is,

$$Labor_{it,grain} = Labor_{it,agriculture} \times \frac{Value_{c}}{Value_{ag}} \times \frac{D_{it}^{g}}{D_{it}^{c}}$$

Since the data of the total labor force in agricultural production is not available before 1978, we use the labor in the primary sector to estimate the labor force in agricultural production. The statistical definition of the primary sector in China corresponds closely to agricultural labor as it includes farming, forestry, animal husbandry, fishing and services for farming, forestry, animal husbandry, and fishing, and it excludes mining. We estimate the labor force in agricultural production using:

$$\widehat{Labor}_{it,agriculture} = \vartheta Labor_{it,prime} + \varepsilon_{i,t}$$

Where $Labor_{prime,i,t}$ is the labor force in the primary sector of the economy of province i of year t.

3.4.6 Labor Education

The labor education data is obtained from the China Center of Human Capital and Labor Market Research. They provide the population by educational levels for each province of China since 1982. The share of labor by education group is reported for the population above age 25 by which time most would have completed their education and entered the labor market. For the years before 1982, we project backward by reversely aging the population. Those aged 35-65 in 1970 would be 25-55 in 1960 for example. Table C.1 of the appendix shows the educational distribution among the labor in grain production.

Here we assume the quality of labor in food production is not different from other sectors employing rural workers. It is possible that the average education of labor in food production is less than other sectors such as manufacturing, but the mismeasurement will not fundamentally change the conclusions. Because an over-measurement of skilled labor will lead to an overestimate of A^s[15], and it means that the actual A^s/A^u is even lower than our estimate. The estimated cost of misuse of skilled labor gives the lower bound of actual cost.

Another concern about the mismeasurements of L^s and L^u comes from the rural-urban migration. The migrants move to cities mainly because of two reasons, either for study or for work. For those who migrate for study, they graduate from the college and register as urban residents[16]. Therefore, the migrants for study will not cause the mismeasurement of skilled labor.

The mismeasurement caused by other migrants, those who are registered in the rural and move to cities for work, will not cause a big problem. First, these workers usually are more educated than their peers at the same age, and again it will cause an overestimate of A^s/A^u. Second, most of them work as gig workers and they will come back home to help the family in agricultural work during the plant and harvest seasons.

3.4.7 Education Return

The Mincerian coefficient, which captures the education return, is also obtained from the China Center of Human Capital and Labor Market Research. This data set provides Mincerian coefficients (i.e., return rate to education) for each province by the rural and urban residence since 1985 in the China Human Capital Report (2019). Provincial data used for estimation comes from Urban Household Survey (UHS), China Household Income Project (CHIP), China Health and Nutrition Survey (CHNS), China Household Finance Survey (CHFS), China Family Panel Studies (CFPS) and China Labor-force Dynamics Survey (CLDS). When all data sets are available for a sample year, they drop CHNS and use other data sets due to the relatively low

[15] This can be seen from (2), $\left(\frac{A_{it}^s}{A_{it}^u}\right)^{\sigma}\left(\frac{L_{it}^s}{L_{it}^u}\right)^{\sigma-1}=\frac{w_{it}^s}{w_{it}^u}$

[16] College students can temporarily register as urban residents during their study. They can easily register as permanent urban residents after graduation if they get a job in a city except in the few megacities such as Beijing and Shanghai. Fortunately, we do not include these cities in this study because these cities have a very limited agricultural sector.

quality of CHNS income measures. The estimates are weighted for obtaining a larger and representative sample making estimates more accurate. Figure 3.3 illustrates their estimated return to education of several provinces. There is no information about education returns before 1985, and we assumed that the education return rate before 1985 was the same as the education return in 1985. While the rate of return to education in 1985 is very small, it likely overstates the return in earlier years. Sensitivity tests reported in section 6 show that the results are robust to alternative assumptions about education returns before 1985.

3.4.8 Price and Cost

The price index and cost index of grain production come from China Trade and Price Statistics and China Agricultural Yearbooks. The price before 2000 is the procurement price of grain and the cost index is calculated by prices of all kinds of agricultural inputs. The price and cost indexes are calculated based on corresponding prices in 1950.

Table 3.1 reports the summary of grain production output, inputs, labor quality, and education return (i.e., Mincerian coefficient). We put detailed data summary by years in Table C.2 in the appendix.

Figure 3.4 shows the time paths of agricultural inputs used in grain production in China over the period from 1952 to 2008. Each input in this figure is weighted by the share of each province's input in 1980. Fertilizer and capital increase over time while farmers employ less land and labor for grain production. We scale the agricultural inputs by output, and Figure 3.5 shows the change across the period. For producing a ton of grain, less land and labor are used while the consumption of fertilizer and machinery rises steadily. The results indicate a technical change which substitutes labor and land with fertilizer and machinery. Figure 3.6 and Figure 3.7 illustrate the output and agricultural inputs scaled by labor and land, respectively. The average farmer is endowed with more agrarian inputs, especially for fertilizer and machinery. The grain production per person also rises substantially. For each hectare of land used in grain production, the output increases as well as fertilizer and machinery. However, fewer farmers are working on the land which indicates a drain of the labor force in grain production of China. The urbanization and migration from the rural to the urban support our findings here.

3.5 Results

This section reviews the results, but we summarize the most important. Labor efficiency for both skilled and unskilled labor declined during the Great Leap Forward (1959 - 1961). The output loss associated with reduced labor efficiency ranged from 6.9 to 35.2 percent compared with grain output in 1958. The technical frontier and labor efficiency expanded only modestly during the Cultural Revolution, and some provinces did not recover until the household-responsibility system was introduced after the rural economic reforms in 1978. When the economic reform was introduced, grain output increased by 10.4 percent compared with the output of1978 because of improved labor efficiency, accounting for 44 percent of the total increase in grain output. Furthermore, there was skill-biased technological progress for much of the period, but the input allocation did not takle advantage between 1952 and 1978.

3.5.1 Estimating Grain Production Function

We use (5) to estimate the grain production function. As mentioned previously, only a few provinces have the information on output and inputs before 1970, and five provinces (Fujian, Hunan, Jiangxi, Shandong, and Shanxi) have such information in the 1950s. We will focus on these five provinces when analyzing the labor efficiency and technological frontier after the Great Leap Forward.

Table 3.2 reports the estimation of (5) using a non-linear least square model. The first column of Table 3.2 lists the estimates assuming constant elasticities of various agricultural inputs after controlling the provincial fixed effect. The estimated elasticity of substitution between skilled labor and unskilled labor is equal to 2.638 (i.e., 1 / (1-0.621) = 2.638). Labor and Land are relatively more important than fertilizer and machinery in grain production[17].

Section II indicates that resource allocation and crop planting are centralized between 1952 and 1977. Under decentralized practice in agricultural production, decision making is usually determined by changes in microeconomic factors such as prices of grain output and agricultural inputs. Therefore, we add price and cost indexes into the regression and allow the elasticity of the input factor changes following a time trend. The second column of Table 3.2 indicates a technical change that favors land, fertilizer, and machinery. It implies skill-biased technological progress toward skilled labor since skilled labor complements to fertilizer and machinery. Fertilizer, machinery, and land become more critical, while labor input plays a decreasing role in grain production. Grain price and agricultural input prices significantly affect grain production. The null hypothesis that grain production achieves a constant return to scale cannot be rejected at the 5% significance level in any year of this period. Therefore, we impose a constraint of constant return to scale (CRS) and estimate grain production function again.

The third column of Table 3.2 presents results estimated under the condition of constant return to scale. The elasticity between skilled and unskilled labor is equal to 2.679 (1/1-0.629=2.679). Again, labor and land contribute more to grain production compared with fertilizer and machinery at the beginning. Fertilizer, machinery, and land become more crucial while the labor force becomes less important over time. Moreover, Hicksian technical progress, which is a time effect, is positive and significant. Higher output price encourages production while input's price reduces grain output.

[17] We do not estimate the elasticity between other inputs. It requires us to know the prices of other inputs if we assume substitution between the other inputs

We calculate the efficiencies of skilled and unskilled labor from the residual of (5). From now on, we use the estimates from the third specification, that grain production achieves the scale of economy, to calculate labor efficiency and conduct further analysis. Figure 3.8 illustrates the dynamic of calculated labor efficiency between 1952 and 2008. The efficiency of skilled labor caught up with unskilled labor efficiency in the early 1970s. From 1959 to 1961, when the Great Famine occurred, the efficiency of both skilled and unskilled labor declined. Until the Cultural Revolution ended in the late 1970s, there were only modest gains in efficiency by skill. The labor efficiency began to rise after the rural economy was decentralized in the early 1980s. Labor efficiency grew rapidly during the 1990s, and there is a substantial increase in labor efficiency after 2005. A possible explanation is China's agricultural tax abolition since 2016. This policy change provides additional incentives to farmers and improves their labor efficiency.

As mentioned, the growing elasticities of fertilizer and machinery indicate long-lasting technical progress in which fertilizer and machinery play an increasing role in grain production. Efficiently using these inputs requires farmers to have basic knowledge and skill. Consequently, skilled labor could benefit more from this transition. This conjecture is consistent with the data and our calculation. Figure 3.9 shows the ratio of efficiencies between skilled labor and unskilled labor (i.e., $\frac{A_s}{A_u}$). The ratio increases relatively slowly under collective farming, and it rises significantly after the mid-1980s. The increasing ratio between A_s and A_u implies that the technical progress in grain production is skilled biased. It also indicates that skilled labor was not fully utilized under the communal system and a huge loss of human capital in grain production.

3.5.2 Estimate The Technological Frontier

Based on the estimated coefficients for $\{\alpha_1, \alpha_2, \alpha_3, \alpha_4\}$ and the calculated labor efficiencies $\{A_s, A_u\}$, we can retrieve the technology frontier in (6). We use (9) to estimate "ω"

and retrieve "γ". Table 3.3 reports the estimation result of (9). The estimated coefficient of $ln\ (L^s/L^u)$, as exhibited as $\frac{\sigma}{\omega-\sigma}$ in (9), is equal to 0.588. The second order condition of producer's cost minimization problem, $w > \frac{\sigma}{1-\sigma}$, should be satisfied with the interior solution. The estimated value of ω is 1.692, and it is greater than $\frac{\sigma}{1-\sigma}$ when σ is equal to 0.627.

Table C.3 reports the technological frontier of multiple provinces (Fujian, Hunan, Jiangxi, Shandong, and Shanxi) with the parameters estimated above for the period 1952-1985. Several patterns are noticeable from the results in Table C.3. First, the height of the technological frontier, which is represented by "B", decreases significantly after the Great Leap forward. It means the feasible set of choices of A^s and A^u shrinks substantially, and the optimal choice of labor efficiency deteriorates. Figure 3.10 illustrates the technological frontier of various provinces after the Great Leap Forward. The possibility set of labor efficiency significantly shrank between 1959 and 1961.

Furthermore, this decline in the technological frontier persists for a decade. The height of the technological frontier in Fujian province is 4.9 in 1958, and it is higher than its height in 1985. Hunan finally regains its 1958 technological frontier in 1979 after the household-responsibility system was introduced. The technological frontier in Shandong and Shanxi surpasses its 1958 level in the mid-1970s. Third, the technological frontier in grain production grows rapidly after rural economic reform was launched in the late 1970s. Figure 3.11 exhibits technological frontiers of multiple provinces after rural economic reform. The technological frontier expands substantially expect Fujian.

Last but not least, provinces are not identically affected by these policy changes. For instance, the technological frontier reduced significantly in all regions expect Jiangxi after the Great Leap Forward. After rural economic reform, Fujian barely improves its technological frontier while each of the other four provinces experiences considerable technical progress. These results imply that each policy change has a spatially heterogenous impact on grain production.

The diminished technological frontier reduces labor efficiency. Table C.4 reports labor efficiency by the skill of the period 1952-1985. Labor efficiency drops significantly after the Great Leap Forward. Fujian, for example, experienced a 55 percent decline in labor efficiency in 1960 compared with 1958, while its grain output dropped by 28 percent from 4,455,000 tons to 3,235,000 tons. The adverse impact on labor efficiency endures until a decentralized system replaces collective farming. The introduction of the household-based system provides significant additional incentives to farmers and improves labor efficiency since the 1980s.

3.5.3 Impacts of Government Policies

To access the grain production loss caused by a reduced technology frontier and less efficient use of labor after the Great Leap forward, we calculate the difference between the actual grain output Y_0 and potential grain output Y_p. Suppose the actual technological frontier in year t $(\mathrm{t} \in 1959,1960,1961)$ as Ω_t and the technological frontier of 1958 as Ω_0. The potential grain output is the output produced with better technology between Ω_t and Ω_0, which means $Y_p = Y_{max(\Omega_t,\Omega_0)}$. Consequently, if the technological frontier in period t is higher than the frontier in 1958, the potential output will be equal to the actual production. The output loss is then equal to the difference between potential output and actual output, $Y_p - Y_t$.

Table 3.4 presents the calculated grain production loss caused by reduced labor efficiency. The grain production loss ranges from 2.5 million to 12.4 million tons, which accounts for 6.8 to 42.8 percent of the actual grain production. It means that grain output could potentially improve by 6.8 to 42.8 percent if each province still accesses to the technological frontier before the Great Leap Forward.

To further examine the loss in grain production after Great Leap Forward, we decompose the total percentage loss into changes of five components: total factor productivity, input elasticities, the number of agricultural inputs, labor efficiency, and price, cost and ratio of land used in grain production[18]. Table 3.5 reports the source of output loss between 1959 and 1976. There are three patterns in Table 3.5. First, there was a considerable output reduction associated with reduced labor efficiency after the Great Leap Forward. During the famine period (1959-1961), grain output dropped by 6.86 to 35.21 percent due to the inefficient use of labor. Second, the loss caused by reduced labor efficiency lasted over more than a decade although there was a modest gain in labor efficiency during the Cultural Revolution. There was still a 2.92 percentage output loss due to low labor efficiency by 1976.

Evaluating the production gain from improved labor efficiency after the rural economic reform follows the same procedure. In Table C.3, we had calculated the actual labor efficiency and corresponding technological frontiers from 1979 to 1984 when the household-responsibility system was gradually introduced in rural areas. To obtain the output gain associated with improved technological frontier and labor efficiency, we calculate the difference between the actual grain output Y_0 and counterfactual grain output Y_c. Denote the actual technological frontier in year t ($t \in 1979, 1980, \dots, 1984$) as Ω_t and the technological frontier of 1978 as Ω_0. The counterfactual grain output, Y_c, is the output produced with lower production frontier between Ω_t and Ω_0, which means $Y_c = Y_{min(\Omega_t, \Omega_0)}$. Note that if the technology frontier of the period t is lower than the frontier of 1978, counterfactual grain output will be the same to actual production,

[18] The method we decompose the change is included in the appendix.

which indicates a zero gain with the household-responsibility system. The output gain is therefore equal to $Y_t - Y_c$.

Table 3.6 presents the calculated grain production gain due to improved labor efficiency. For all twenty-five provinces in the sample, the output gain ranges from 3.81 to 43.86 million tons, which accounts for 1.23 to 11.28 percent of actual grain output. For five provinces studied for Great Leap Forward, the output gain ranges from 0.06 to 10.14 million tons, which accounts for 0.09 to 11.36 percent of actual grain output.

We also decompose the output change after the reform into five components, and Table 3.7 reports the source of output gain after rural economic reform. Compared with grain production in 1978, improved labor efficiency raised grain output by 10.4 to 13 percent in 1984. More inputs were used, and the increasing market price of grain crops contributed to the growth of grain output during this period.

From these results, it is evident that output gain associated with rural economic reform is smaller than the loss caused by reduced labor efficiency following the Great Leap Forward. There are two interpretations of this finding. The first is that labor contributes less in the production over time, so the magnitude of gain or loss caused by changed labor efficiency also becomes smaller. The second interpretation is that the experimental communist economy in the Great Leap forward had a more significant impact on food production compared with rural economic reform because the former one is compulsory.

Figure 3.12 illustrates the best technology of all twenty-five provinces between 1970 and 2008. The “best” technology refers to the highest technological frontier among all regions in a particular year. The frontier in 1980, however, is lower than that in 1970 and 1975. This result implies the failure of centrally planned food production in the 1970s and justifies the necessity of reform launched later in the early 1980s. With the household-responsibility system, the technological frontier expanded rapidly in the 1990s and 2000s. Figure 3.13 exhibits the "median" technological frontier of all provinces, in some sense, it is more representative than the "best" technological frontier. Two patterns are evident in Figure 3.13. First, there is almost no difference among technological frontiers of 1970, 1975 and 1980, which implies a stagnation in technological progress in the late 1970s and early 1980s. Second, the technological frontier rises significantly after rural economic reform, especially during the 1990s.

In conclusion, the efficiency of skilled and unskilled labor varies through the period of 1952-2008. There is a skilled biased technical progress during this period. The changing efficiency of labor reflects changes in the technological frontier of grain production. We use the model to analyze three policy changes in China's modern history: Great Leap Forward, Cultural Revolution and rural economic reform. Our results indicate that the technological frontier was much lower during the famine following the Great Leap Forward, and labor efficiency dropped substantially as well. It means that the experimental communist economy following Great Leap Forward depressed farmers' incentives. The technical progress is halting during the Cultural Revolution occurring in the mid-1960s and 1970s, and there was only modest gain in labor efficiency during this period. The economic reform initiating in 1978 introduced a household-responsibility system and provided additional incentives to individual farmers. The new system improved labor efficiency and it raised grain output by 10.4 to 13 percent in 1984.

3.6 Sensitivity Test

In the previous subsection, we make multiple assumptions to make it easy to analyze grain production. First, we assume the return to education before 1985 is the same as that in 1985. Second, we define skilled labor as the labor who complete primary school. In this sector, these conditions will be relaxed to test the robustness of our findings.

3.6.1 The Return to Education in An Egalitarian System

Figure 3.3 implies that the return to education is growing over time in rural China. To test whether our results are sensitive to the return to education, we now assume the education return rate is equal to zero before 1978. There are two reasons for this assumption. First, the growing return to education implies that the return is even smaller in earlier years. Since the return to education in 1985 is already very low, the return tends to be extremely small before 1985. Second, labor by skill is regarded as the same as each other under communal farming. Individual farmers work together and earn "working points" based on the length of working time and their performance judged by cadres and workmates. Their payment is then depended on the output of their teams and how many working points they collected. In an eghalitarian system, skill premium tends to be very limited when skilled workers are not able to receive significantly more working points than colleagues. Therefore, the education return rate "π" (i.e., Mincerian coefficient of education) in province i for the period 1952-2008 can be illustrated as:

$$\begin{cases} \pi_{it} = 0, \forall t \in (1952{,}1977) \\ \pi_{i,t} = \pi_{i,1985}, \forall t \in (1978{,}1984) \\ \pi_{it}, \forall t \in (1985{,}2008) \end{cases}$$

The first column of Table 3.8 reports the estimation of production function under this assumption. The estimation results do not fundamentally change compared with Table 3.2, in which we assume the education return rate of earlier years is the same as its level in 1985. The elasticity between skilled and unskilled labor is 2.742, which is slightly higher than that in baseline estimation. The first column in Table 3.9 lists the estimation of the technological frontier function. The calculated ω (1.743) is greater than $\frac{\sigma}{1-\sigma}$ (1.742).

The first three columns in Table 3.10 report the potential loss due to reduced labor efficiency after the Great Leap Forward. The magnitude of the loss is slightly greater than the previous results in Table 3.4. The potential output could be 7 to 43.1 percent more during the famine period (1959-1961). Similarly, the potential gain from rural economic reform also becomes more extensive. As Table 3.11 shows, the potential benefit from rural economic reform is around 12 percent in 1984. We also decompose the output loss and grain as before, and the results were put into Table C.5 and C.6 in the appendix. Compared with the baseline model, the results only change slightly.

3.6.2 Definition of Skilled Labor

In the previous section, skilled labor is defined as farmers who complete elementary schools (6 years). Now we define skilled labor in another way: farmers who complete junior high schools (9 years). We have two reasons to define skilled labor like this alternatively. First, effectively allocating agricultural inputs may require more knowledge than elementary schooling. For instance, using fertilizer and machinery may need some knowledge about chemistry and physics which are only available in middle school. Second, it is not sensible to define skilled labor as the workers completing more than nine years of education. As Figure 3.1 illustrates, the average education is less than 7 years by 2008. We also list the educational distribution of rural labor for each year between 1952 and 2008. Very few farmers complete more than 9 years of formal education in this period. Therefore, it is reasonable to alternatively define skilled labor as those who finish junior high schools (9 years).

The second column in Table 3.8 presents the estimated production function with the alternative definition of skilled labor. The elasticity between skilled and unskilled labor is 1.517 (i.e., 1/(1-0.341)=1.517), and it is smaller than what we found before. This result is intuitive since skilled workers are less substitutable by unskilled ones with a higher standard for skilled labor. From the second column of Table 3.9, the estimated "ω" is equal to 0.573, and it is greater than $\frac{\sigma}{1-\sigma}$ (0.517).

In the last three columns of Table 3.10 and last three columns of Table 3.11, we report the estimated loss and gain associated with changes in labor efficiency, respectively. While the magnitude of output loss or gain is slightly larger than baseline estimation, our findings do not fundamentally change with this alternative definition of skilled labor. The potential loss caused by reduced labor efficiency accounts for 7.2 to 43.3 percent of grain output between 1959 and 1961. The potential gain after rural economic reform is around 12.4 percent in 1984. We also decompose the output loss and grain as before, and the results were put into Table C.7 and C.8 in the appendix. The results are not significantly different from the ones from our baseline model.

In summary, we apply two sensitivity tests in which we assign a zero return to education before 1978, and we define skilled labor as workers who complete junior high school (9 years of education). The estimation results from these alternative specifications are not fundamentally different from the results from the baseline estimation. Still, labor efficiency declines and technological frontier contracts after the Great Leap Forward. On the contrary, labor efficiency increases, and technological frontier expands rapidly after rural economic reform in the early 1980s.

3.7 Conclusion

This study introduces a generalized model to analyze the technical change of China's food production in a dynamic dimension. The framework developed in this paper allows us to examine three significant policy changes in the modern history of China: the Great Leap Forward between 1958 and 1961, the Cultural Revolution occurring from 1966 to 1976, and rural economic reforms in 1978. We found that these policy changes significantly altered technological frontier and labor efficiency, which lead to substantially decline and growth in grain output.

Our result indicates that the efficiency of skilled labor grows continuously, and it increases substantially since the 1990s. Meanwhile, the efficiency of unskilled labor does not vary much until the late 1990s. The increasing importance of inputs such as fertilizer and machinery indicate skill-biased technological progress in China's grain production. This is also confirmed by a growing ratio of efficiencies between skilled labor and unskilled labor. Based on our calculation, labor efficiency dropped considerably after the Great Leap Forward, and it was a result of the deterioration in the technological frontier of grain production. The grain output dropped by 6.8 to 35.2 percent due to the collapse in labor efficiency in collective farming. During the period of the Cultural Revolution, labor efficiency gradually recovered but it still failed to recuperate the pre-collectivization labor efficiency in some provinces until the late 1970s. Since the household-responsibility system was initiated in the early 1980s, labor efficiency and technological frontier grow rapidly. Compared with pre-reform production, the improved labor efficiency increased the grain output by 10.4 percent by 1984, accounting for 44.6 percent of the total increase.

Future work should focus on the structural form of the grain production function. Our model has a simple CES functional form which does not include the complementarity between skilled labor and other inputs such as machinery and fertilizer. It is reasonable that skilled labor could use other agricultural inputs more efficiently than unskilled labor. It requires us to have more information about Chinese agricultural production such as inputs' prices which are not available currently.

Figures and Tables

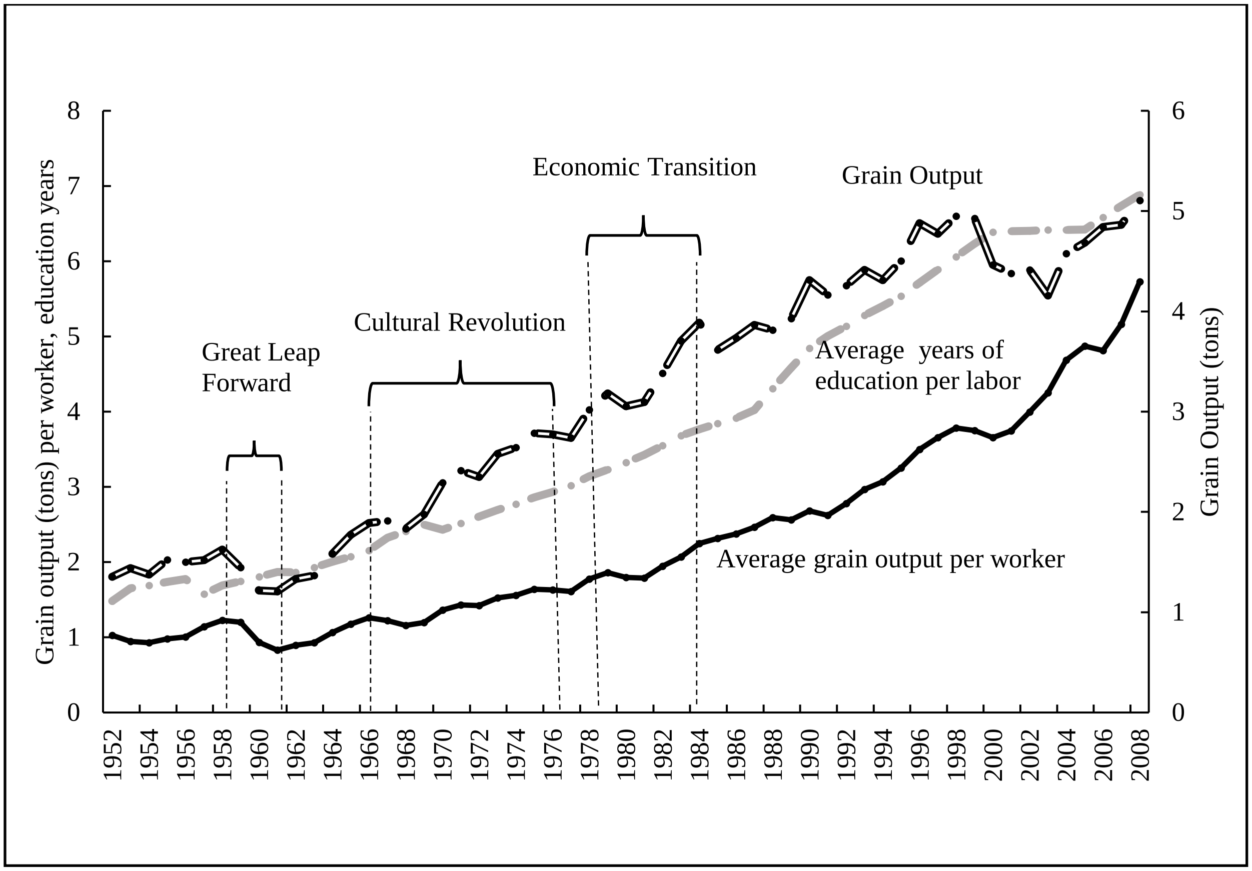

Figure 3.1 Average education length of rural labor in China

NOTES. The labor in all figures is raw labor.

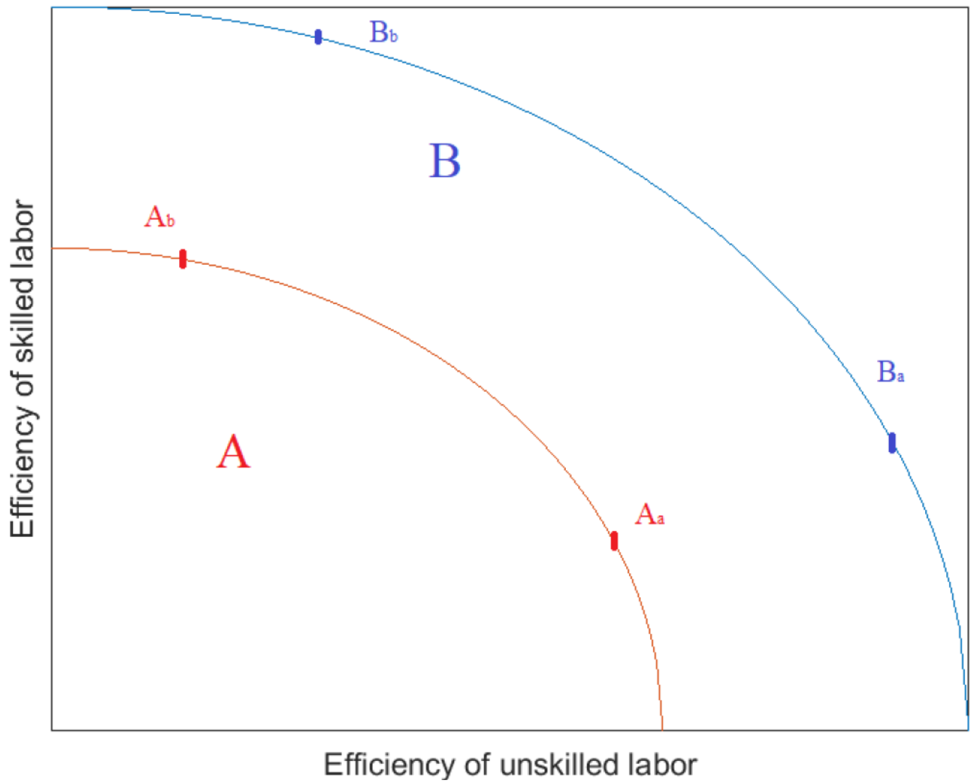

Figure 3.2 Technological frontier of labor efficiencies

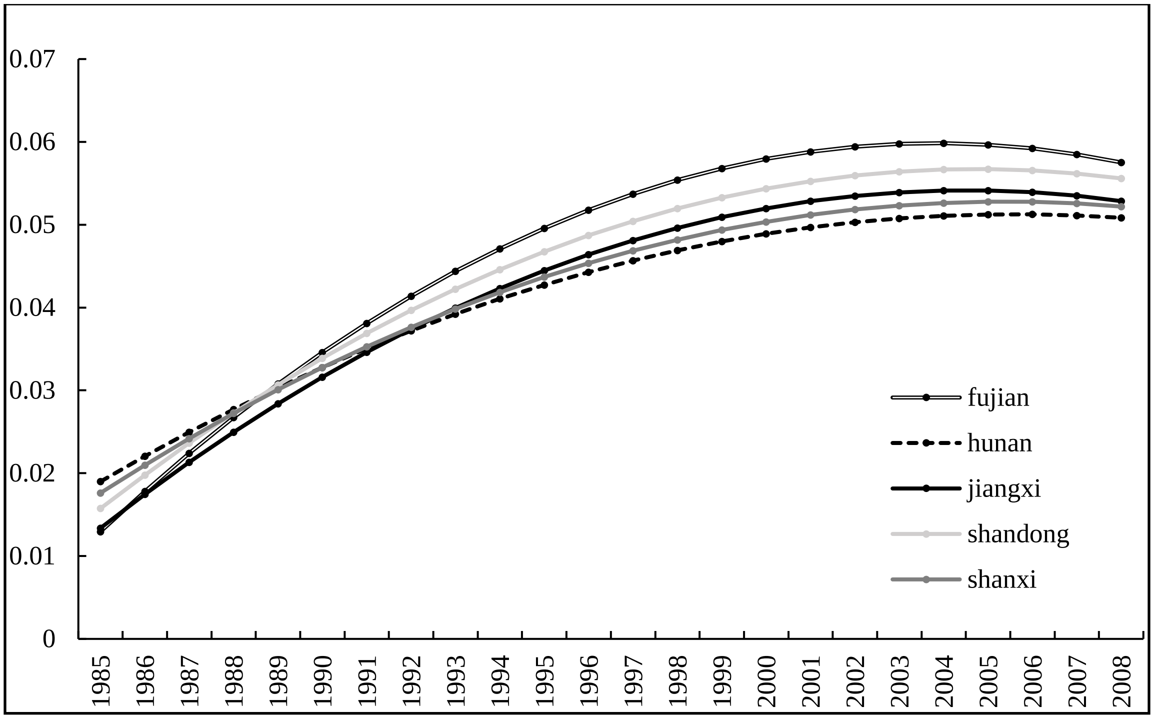

Figure 3.3 The return to education of five provinces

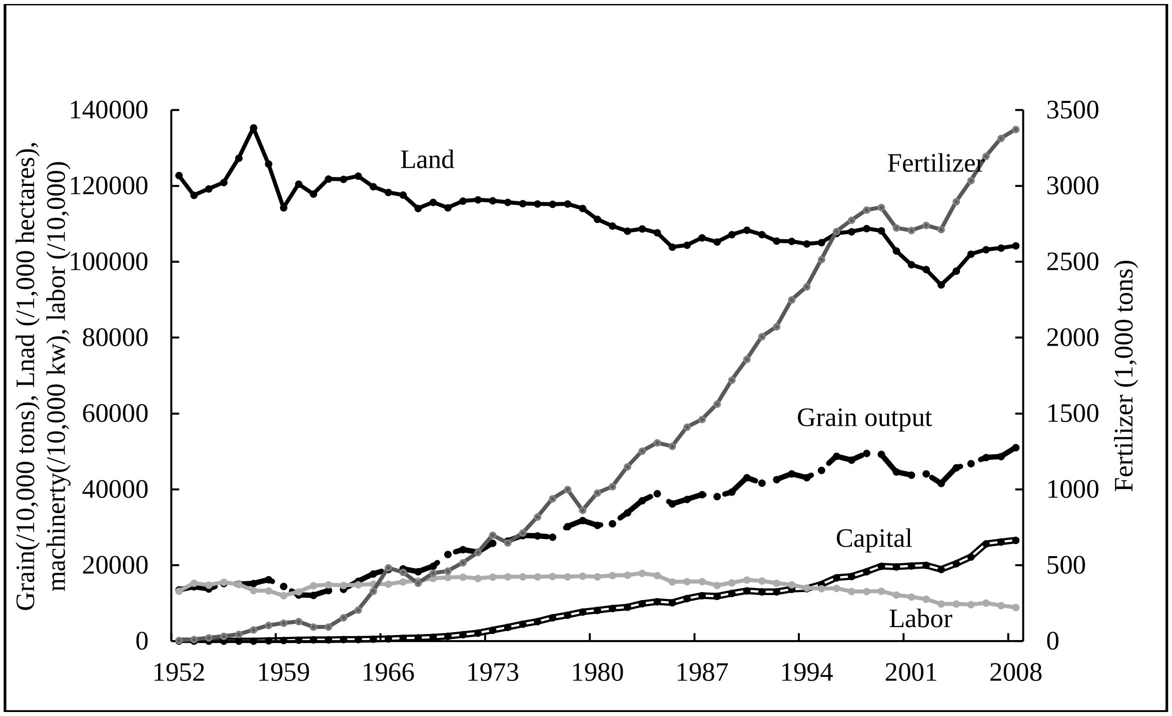

Figure 3.4 Inputs and Output of grain production

NOTES. The labor shown in this figure is raw labor. Same for following figures.

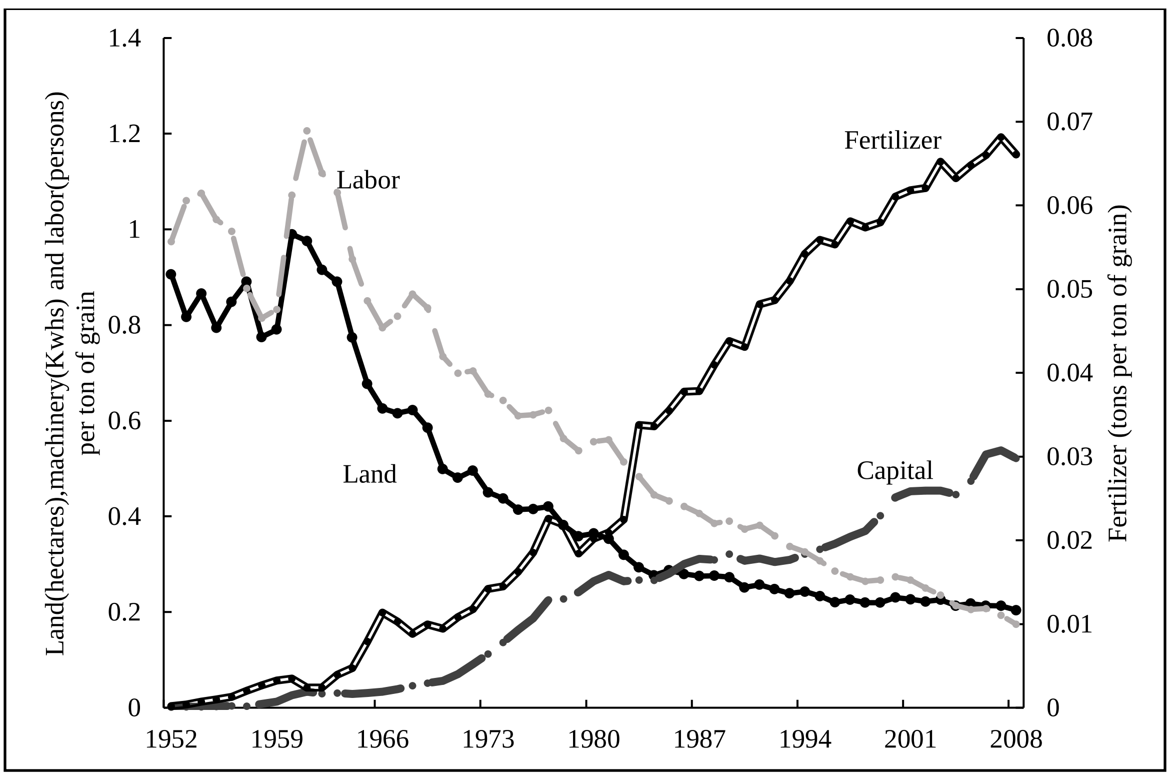

Figure 3.5 Agricultural inputs per ton of grain output

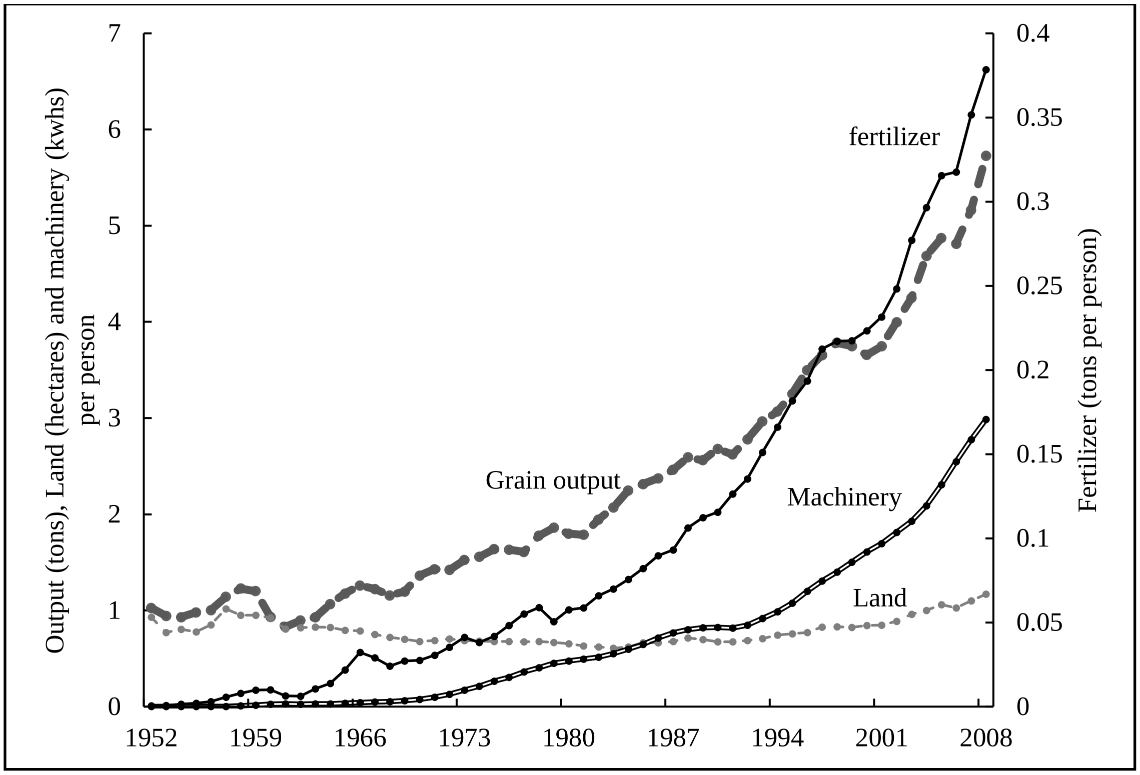

Figure 3.6 Grain output and agricultural inputs per labor

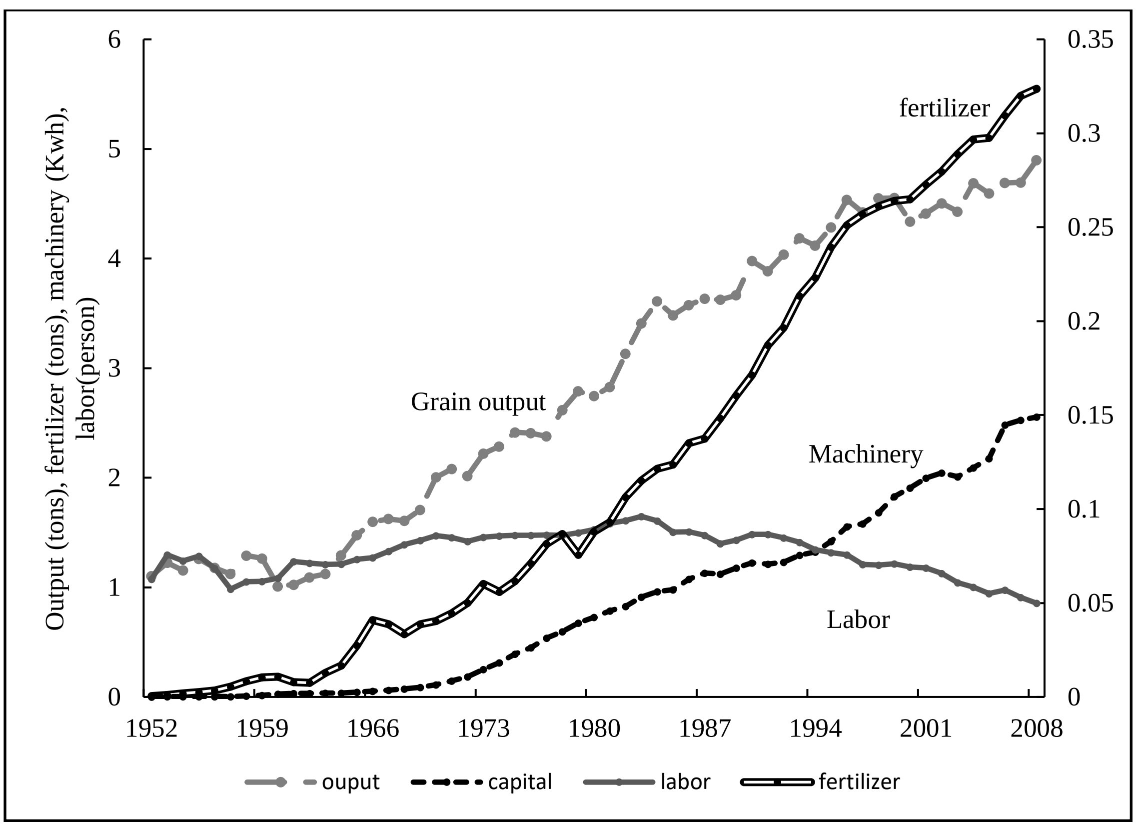

Figure 3.7 Grain output and agricultural inputs per hectare of land

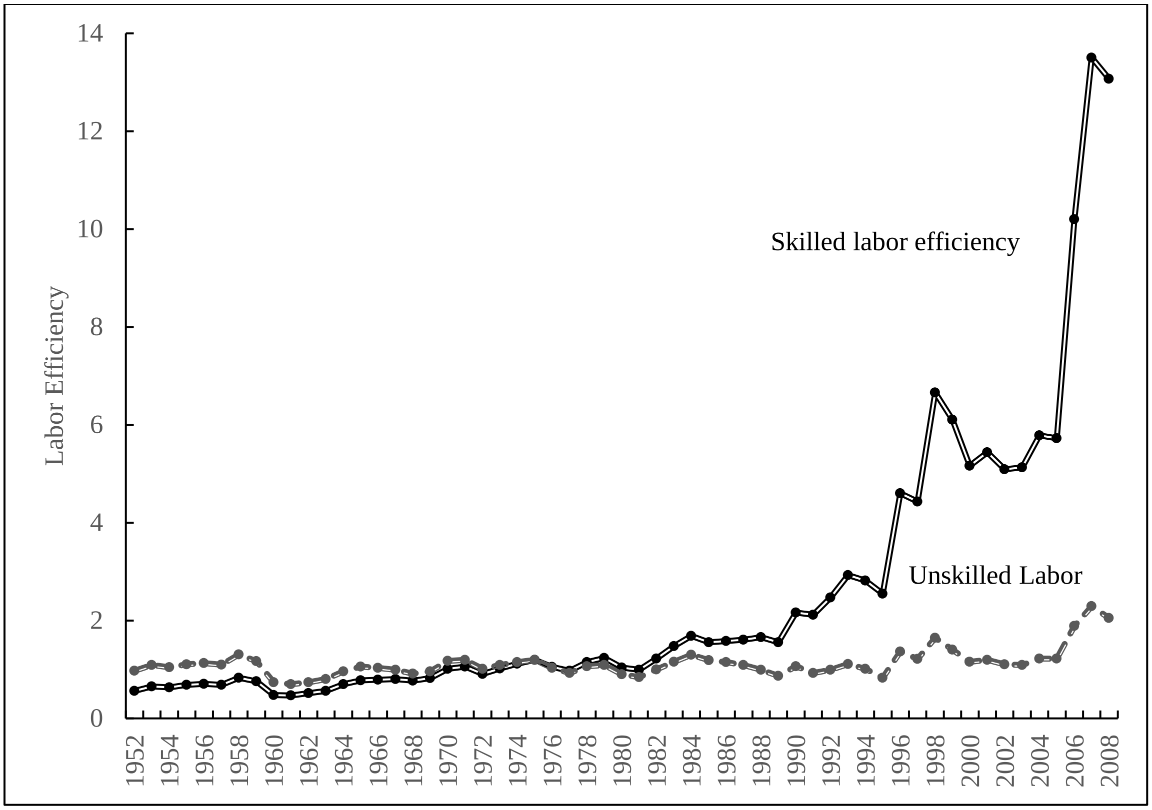

Figure 3.8 Efficiencies of skilled Labor and unskilled Labor

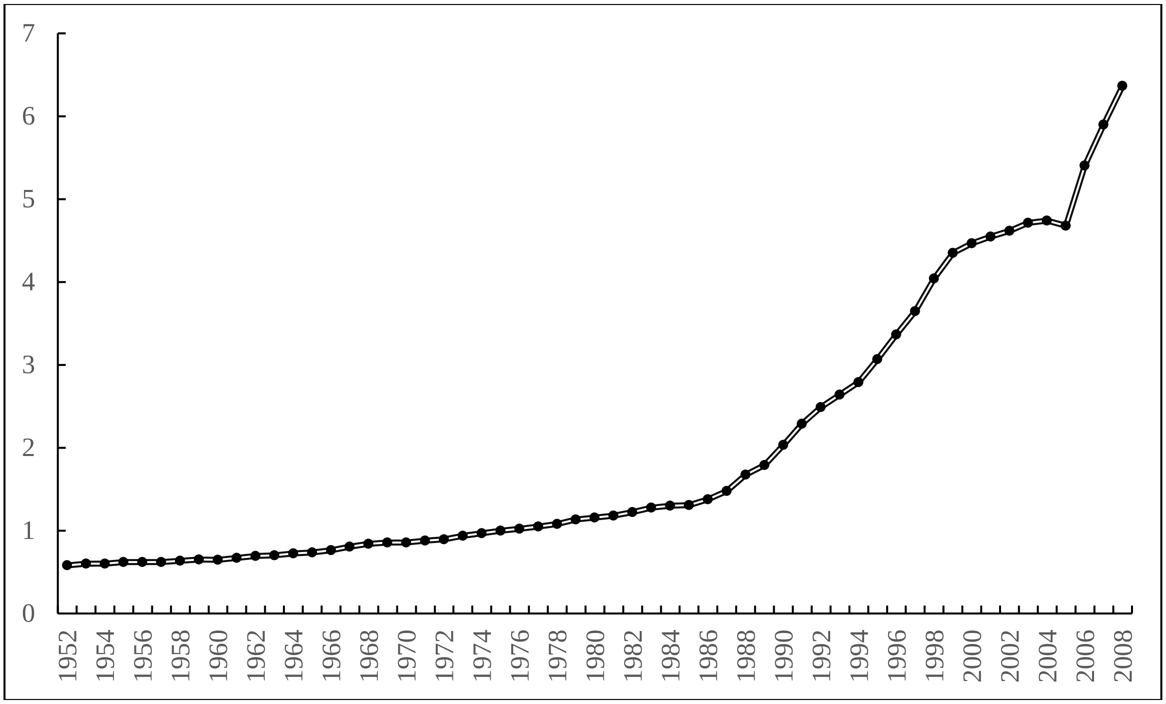

Figure 3.9 Ratio of efficiencies between skilled labor (L_s) and unskilled labor (L_u), $\frac{A_s}{A_u}$.

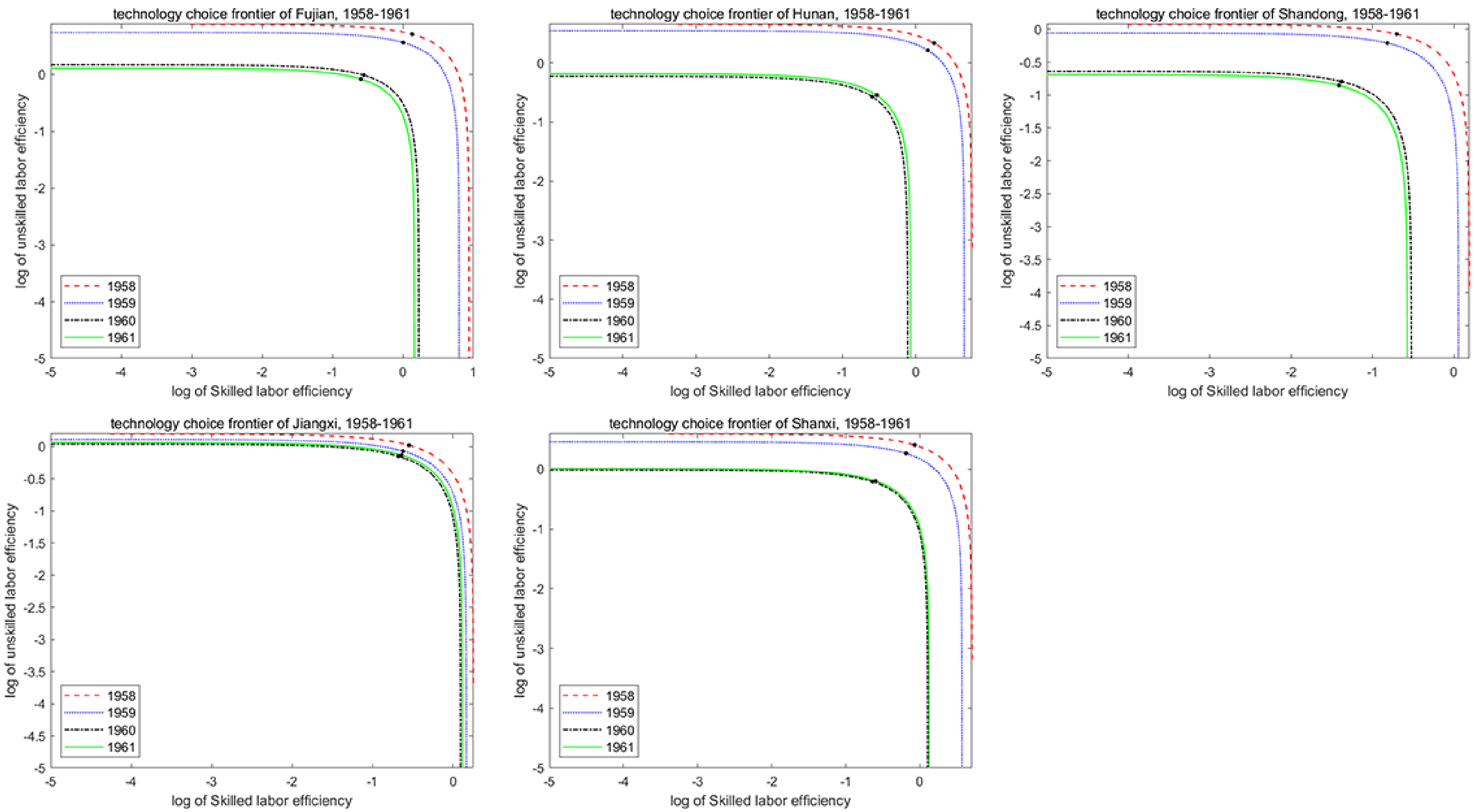

Figure 3.10 The technological frontiers of multiple provinces during the great famine (1959-1961)

NOTES. The points on the technological frontier represent the actual efficiencies of skilled labor and unskilled labor. These five provinces (Fujian, Hunan, Shandong, Jiangxi, and Shanxi) have output and input data for the period between 1958-1961.

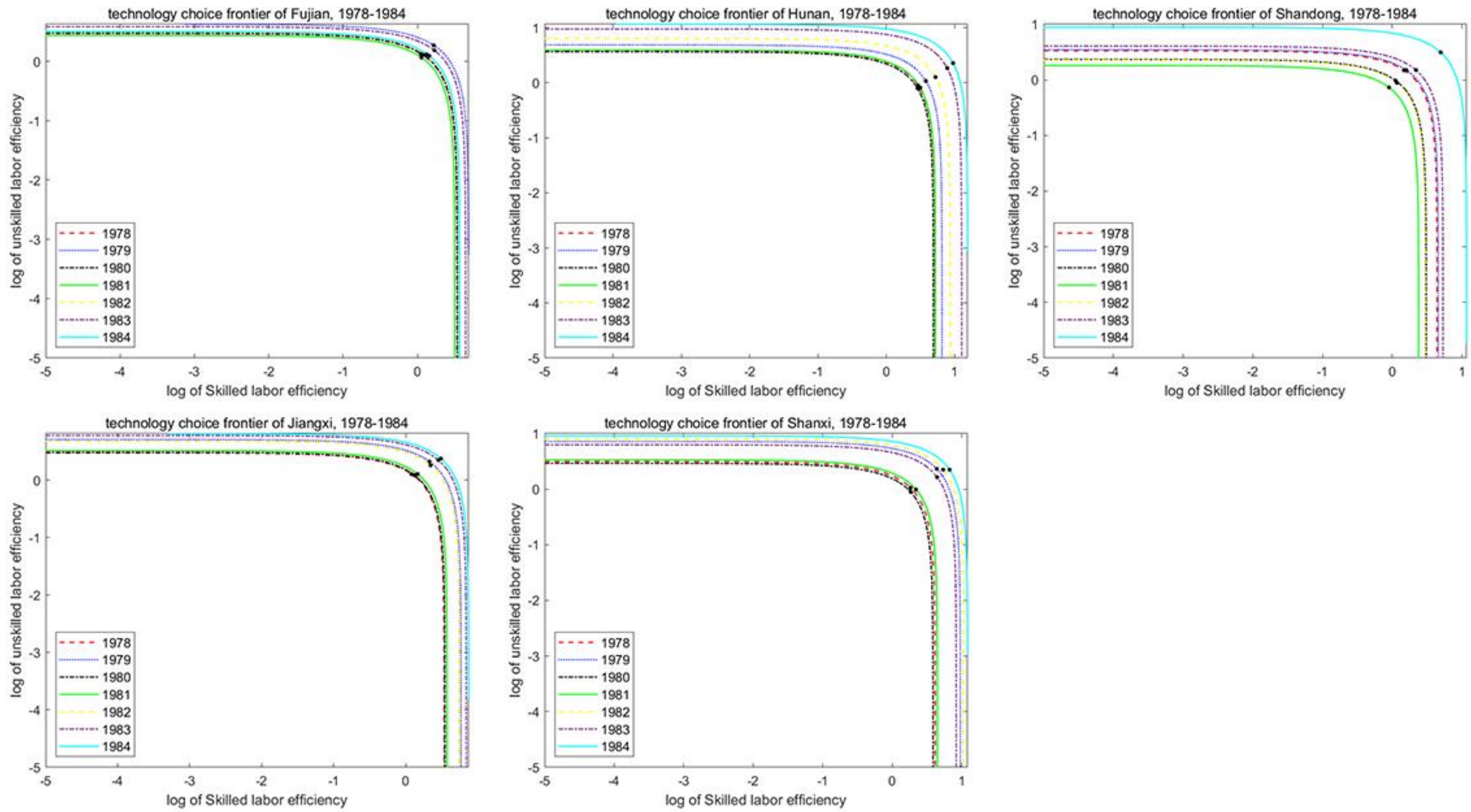

Figure 3.11 The technological frontiers of multiple provinces during the rural economic reform (1979-1984)

NOTES. The points on the technological frontier represent the actual efficiencies of skilled labor and unskilled labor

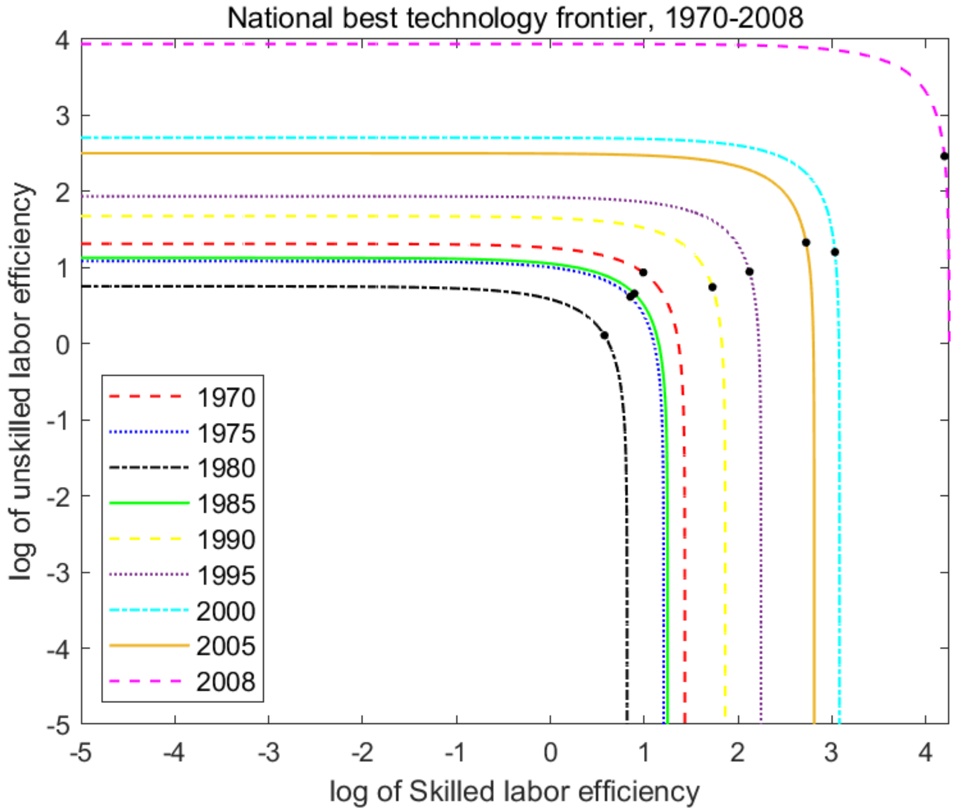

Figure 3.12 National "best" technology frontier, 1970-2008

NOTES. The figure shows the "highest" technological frontier among provinces in different years.

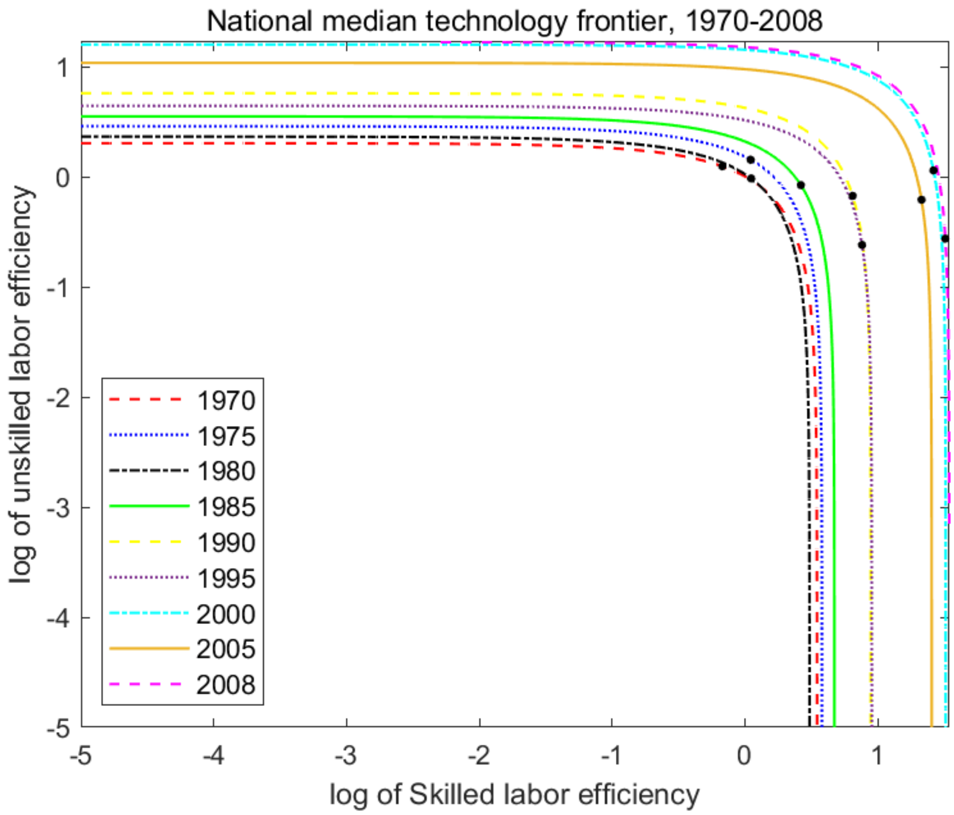

Figure 3.13 National "median" technology frontier, 1970-2008

NOTES. The figure shows the "middle-ranked" technological frontier among all provinces in different years.

Table 3.1 Data Summary

	N	Mean	Standard Dev.	Min	Max
Grain Output (/10,000 tons)	1081	1459.166	972.236	63.876	5365.5
Land (/1,000 hectares)	1081	4399.632	2329.257	244.7	12276
Machinery (/10,000 Kw)	1081	460.797	580.248	0.041	3569.438
Fertilizer (/10,000 tons)	1081	66.680	67.247	0.020	407.293
Labor (/10,000 person)	1081	590.777	412.732	24.454	2050.705
Average Education (years)	1081	4.310	1.747	1.137	7.848
Return to education	1081	0.032	0.015	0.008	0.064
Grain Price (Index)	1081	5.561	3.728	1.196	13.133
Cost of production (Index)	1081	2.093	1.260	0.999	4.708
Percentage of land for crop	1081	75.906	9.987	31.382	94.074
Year	1081	1986.168	13.766	1952	2008

Table 3.2 Nonlinear least square estimation of grain production function

	Grain output	Grain output	Grain output CRS
Land	0.380***	0.165	0.350***
	(0.050)	(0.154)	(0.119)
Machinery	0.073***	0.009	0.015
	(0.010)	(0.032)	(0.045)
Fertilizer	0.072***	-0.000	0.006
	(0.013)	(0.036)	(0.056)
Labor	0.390***	0.681***	0.629***
	(0.032)	(0.117)	(0.095)
Sigma,σ	0.621***	0.628***	0.627***
	(0.038)	(0.082)	(0.083)
Land×Trend		0.012***	0.004*
		(0.004)	(0.002)
Machinery×Trend		0.003***	0.003*
		(0.001)	(0.001)
Fertilizer×Trend		0.003*	0.004*
		(0.002)	(0.002)
Labor×Trend		-0.012***	-0.001***
		(0.003)	(0.002)
Trend (T)		-0.029	0.015*
		(0.017)	(0.007)
Grain Price (Index)		0.042***	0.042***
		(0.010)	(0.009)
Inputs Prices (Index)		-0.146***	-0.160***
		(0.039)	(0.037)
Percentage of grain crops		-0.008***	-0.004
		(0.003)	(0.003)
Province Fixed Effect	Y	Y	Y
N	1081	1081	1081
R^2	0.812	0.913	0.902

NOTES. t-statistics are reported in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Here we report R-squared within group.

Table 3.3 Estimate "ω"

	$\text{Ln}(A^s/A^u)$
$\text{Ln}(L^s/L^u)$	0.588***
	(0.004)
Yearly Fixed Effect	Y
Province Fixed Effect	Y
N	1,081
R^2	0.961

NOTES. t-statistics are reported in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Here we report R-squared within group.

Table 3.4 Potential grain production loss from reduced labor efficiency after Great Leap Forward

Year	Potential grain loss (/10,000 tons)	Actual output (/10,000 tons)	Ratio of the actual output (percentage)
Base year=1958			
1958	/	4023.85	/
1959	245.18	3592.36	6.83
1960	1242.77	2904.89	42.78
1961	1233.11	2931.11	42.07
1962	1017.52	3271.17	31.11
1963	955.92	3351.01	28.53
1964	588.80	3842.34	15.32
1965	556.39	4155.00	13.39
1966	466.79	4460.62	10.46
1967	469.44	4418.90	10.62
1968	608.77	4288.03	14.20
1969	580.09	4574.96	12.68
1970	538.54	5016.89	10.73
1971	358.16	5430.29	6.60
1972	445.72	5501.65	8.10
1973	324.57	5840.43	5.56
1974	465.62	5748.39	8.10
1975	238.92	6478.06	3.69
1976	345.08	6419.60	5.38

NOTES. The results are calculated from the grain production of Fujian, Hunan, Jiangxi, Shandong, and Shanxi.

Table 3.5 Decompose the percentage change in grain output after Great Leap Forward

Year	Time trend	Input Elasticity	Inputs	Labor Efficiency	Price and Cost +Grain Ratio	Total Change
Base=1958						
1959	1.51	-2.72	-4.17	-6.86	1.30	-10.93
	[-13.81]	[24.87]	[38.11]	[62.75]	[-11.92]	
1960	3.02	-4.19	4.35	-34.93	1.31	-30.43
	[-9.92]	[13.77]	[-14.29]	[114.77]	[-4.32]	
1961	4.53	-6.85	7.95	-35.21	0.15	-29.44
	[-15.39]	[23.27]	[-27.00]	[119.63]	[-0.52]	
1962	6.04	-9.58	11.90	-28.63	0.29	-19.99
	[-30.21]	[47.94]	[-59.51]	[143.22]	[-1.44]	
1963	7.55	-10.75	13.14	-24.67	-0.76	-15.49
	[-48.75]	[69.44]	[-84.86]	[159.29]	[4.88]	
1964	9.06	-13.38	14.80	-13.21	0.40	-2.32
	[-390.28]	[576.25]	[-637.67]	[568.98]	[-17.28]	
1965	10.57	-14.07	17.32	-12.28	2.27	3.81
	[277.68]	[-369.75]	[455.12]	[-322.72]	[59.66]	
1966	12.08	-14.68	19.16	-12.22	4.39	8.73
	[138.45]	[-168.27]	[219.59]	[-140.05]	[50.28]	
1967	13.59	-16.80	17.95	-13.02	5.62	7.34
	[185.12]	[-228.86]	[244.50]	[-177.36]	[76.60]	
1968	15.10	-18.95	18.48	-16.23	6.18	4.58
	[329.65]	[-413.77]	[403.50]	[-354.37]	[134.99]	
1969	16.61	-19.94	22.03	-13.89	6.98	11.80
	[140.81]	[-169.05]	[186.77]	[-117.71]	[59.18]	
1970	18.12	-20.94	27.26	-8.93	6.86	22.37
	[81.02]	[-93.63]	[121.90]	[-39.95]	[30.65]	
1971	19.63	-22.97	30.18	-4.00	7.18	30.02
	[65.38]	[-76.49]	[100.52]	[-13.34]	[23.93]	
1972	21.14	-22.35	30.15	-7.37	8.23	29.81
	[70.92]	[-74.97]	[101.16]	[-24.72]	[27.62]	
1973	22.65	-22.51	33.70	-7.40	8.80	35.23
	[64.29]	[-63.89]	[95.65]	[-21.01]	[24.97]	
1974	24.16	-24.64	33.45	-5.63	9.15	36.48
	[66.23]	[-67.56]	[91.70]	[-15.44]	[25.07]	
1975	25.67	-27.97	35.33	3.98	9.27	46.29
	[55.46]	[-60.42]	[76.32]	[8.60]	[20.03]	
1976	27.18	-25.96	35.45	-2.92	9.67	43.42
	[62.60]	[-59.79]	[81.65]	[-6.73]	[22.26]	

NOTES. The number in bucket represents the relative portion compared with the total change. The results are calculated from the grain production of Fujian, Hunan, Jiangxi, Shandong, and Shanxi.

Table 3.6 Potential gain from improved efficiencies of using labor during rural economic reform, 25 provinces

Year	Potential gain in output (/10,000 tons)	Actual output (/10,000 tons)	Ratio of the actual output (percentage)
Base year=1978	25 provinces		
1978	/	30192.15	/
1979	1553.70	31824.89	4.88
1980	484.19	30529.04	1.59
1981	381.02	30968.16	1.23
1982	1857.45	33841.76	5.49
1983	3075.07	37039.33	8.30
1984	4385.60	38867.13	11.28
Base year=1978	5 Provinces		
1978	/	6953.50	/
1979	341.00	7569.84	4.50
1980	6.56	7236.45	0.09
1981	32.12	7317.34	0.44
1982	378.53	7896.84	4.79
1983	627.29	8478.10	7.40
1984	1013.84	8924.45	11.36

Table 3.7 Decompose the percentage change in grain output after rural economic reform

Year	Time trend	Input Elasticity	Inputs	Labor Efficiency	Price and Cost +Grain Ratio	Total Change
Base year=1978, twenty-five provinces						
1979	1.51	-1.11	1.65	0.80	0.57	3.42
	[44.16]	[-32.49]	[48.16]	[23.43]	[16.74]	
1980	3.02	-1.79	2.34	-5.88	2.68	0.37
	[807.35]	[-479.84]	[626.59]	[-1570.71]	[716.61]	
1981	4.53	-2.61	2.74	-7.36	3.58	0.88
	[516.54]	[-297.87]	[312.16]	[-839.48]	[408.65]	
1982	6.04	-3.94	4.30	-1.28	4.34	9.46
	[63.84]	[-41.63]	[45.44]	[-13.54]	[45.89]	
1983	7.55	-5.86	6.96	5.88	4.03	18.56
	[40.68]	[-31.55]	[37.49]	[31.69]	[21.69]	
1984	9.06	-7.42	6.67	10.42	4.64	23.36
	[38.78]	[-31.78]	[28.55]	[44.61]	[19.84]	
Base year=1978, five provinces						
1979	1.51	-1.41	1.80	6.46	0.69	9.06
	[16.67]	[-15.56]	[19.89]	[71.35]	[7.65]	
1980	3.02	-2.21	1.82	-1.40	2.75	3.97
	[76.06]	[-55.77]	[45.77]	[-35.34]	[69.28]	
1981	4.53	-3.33	2.60	-1.54	3.57	5.84
	[77.60]	[-56.97]	[44.54]	[-26.37]	[61.20]	
1982	6.04	-4.96	3.24	5.26	4.46	14.03
	[43.04]	[-35.32]	[23.09]	[37.45]	[31.75]	
1983	7.55	-6.47	4.19	9.01	4.48	18.76
	[40.25]	[-34.48]	[22.32]	[48.02]	[23.89]	
1984	9.06	-8.18	4.70	13.02	4.79	23.40
	[38.72]	[-34.95]	[20.09]	[55.65]	[20.48]	

NOTES. The number in bucket represents the relative portion compared with the total change.

Table 3.8 Nonlinear least square estimation of grain production function

	Grain Output	Grain Output
	Egalitarian	Skilled labor complete middle schools
Land	0.350***	0.321***
	(0.096)	(0.093)
Machinery	0.021	0.022
	(0.045)	(0.045)
Fertilizer	0.001	0.007
	(0.055)	(0.054)
Labor	0.628***	0.650***
	(0.117)	(0.095)
Sigma,σ	0.635***	0.341***
	(0.079)	(0.077)
Land×Trend	0.006**	0.005**
	(0.003)	(0.002)
Machinery×Trend	0.002*	0.002**
	(0.001)	(0.001)
Fertilizer×Trend	0.003*	0.004*
	(0.002)	(0.002)
Labor×Trend	-0.011***	-0.011***
	(0.003)	(0.002)
Trend (T)	0.014*	0.012*
	(0.008)	(0.007)
Grain Price (Index)	0.037***	0.035***
	(0.008)	(0.008)
Cost of production (Index)	-0.138***	-0.134***
	(0.035)	(0.035)
Percentage of grain crops	-0.004	-0.004
	(0.003)	(0.003)
Province Fixed Effect	Y	Y
N	1081	1081
R^2	0.902	0.902

NOTES. We assume constant return to scale in these estimations. t-statistics are reported in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Here we report R-squared within group.

Table 3.9 Estimate "ω"

	Ln (A^s/A^u) $\beta = 0$, $\forall t < 1978$ Egalitarian	Ln (A^s/A^u) skilled labor has Nine years of schooling
Ln (L^s/L^u)	0.573***	1.879***
	(0.003)	(0.018)
Yearly Fixed Effect	Y	Y
Province Fixed Effect	Y	Y
N	1,081	1,081
R^2	0.966	0.918

NOTES. t-statistics are reported in parentheses,*** p<0.01, ** p<0.05, * p<0.1. Here we report R-squared within group.

Table 3.10 Potential grain production loss from reduced labor efficiency after Great Leap Forward

Year	Potential grain loss (/10,000 tons)	Actual output (/10,000 tons)	Ratio (percentage)	Potential grain loss (/10,000 tons)	Actual output (/10,000 tons)	Ratio (percentage)
	$\beta_t = 0, \forall\, t < 1978$, egalitarian			Skilled labor has nine years of education		
1958	/	4023.85	/	/	4023.85	/
1959	251.10	3592.36	6.99	259.00	3592.36	7.21
1960	1260.66	2904.89	43.40	1271.40	2904.89	43.77
1961	1264.04	2931.11	43.12	1269.57	2931.11	43.31
1962	1048.34	3271.17	32.05	1050.83	3271.17	32.12
1963	982.99	3351.01	29.33	997.15	3351.01	29.76
1964	609.04	3842.34	15.85	624.98	3842.34	16.27
1965	572.17	4155.00	13.77	589.60	4155.00	14.19
1966	473.13	4460.62	10.61	501.01	4460.62	11.23
1967	477.49	4418.90	10.81	496.53	4418.90	11.24
1968	617.07	4288.03	14.39	633.03	4288.03	14.76
1969	587.70	4574.96	12.85	603.07	4574.96	13.18
1970	548.31	5016.89	10.93	565.91	5016.89	11.28
1971	369.50	5430.29	6.80	387.57	5430.29	7.14
1972	457.88	5501.65	8.32	470.33	5501.65	8.55
1973	338.23	5840.43	5.79	341.44	5840.43	5.85
1974	479.28	5748.39	8.34	498.40	5748.39	8.67
1975	244.48	6478.06	3.77	287.69	6478.06	4.44
1976	352.02	6419.60	5.48	396.66	6419.60	6.18

NOTES. The results are calculated from the grain production of Fujian, Hunan, Jiangxi, Shandong, and Shanxi.

Table 3.11 Potential gain from improved efficiencies of using labor during rural economic reform, twenty-five provinces

Year	Potential gain (/10,000 tons)	Actual output (/10,000 tons)	Ratio (percentage)	Potential gain (/10,000 tons)	Actual output (/10,000 tons)	Ratio (percentage)
	$\beta_t = 0, \forall\, t < 1978$, egalitarian			Skilled labor has nine years of education		
	Twenty-five Provinces					
1978	/	30192.15	/	/	30192.15	/
1979	1558.26	31824.89	4.90	1582.70	31824.89	4.97
1980	502.35	30529.04	1.65	542.01	30529.04	1.78
1981	417.78	30968.16	1.35	484.61	30968.16	1.56
1982	1927.94	33841.76	5.70	2040.65	33841.76	6.03
1983	3177.31	37039.33	8.58	3416.25	37039.33	9.22
1984	4501.81	38867.13	11.58	4815.83	38867.13	12.39
	Five Provinces					
1978	/	6953.5	/	/	6953.5	/
1979	341.41	7569.84	4.51	343.84	7569.84	4.54
1980	8.56	7236.45	0.12	17.34	7236.45	0.24
1981	42.39	7317.34	0.58	49.98	7317.34	0.68
1982	392.43	7896.84	4.97	408.22	7896.84	5.17
1983	653.04	8478.10	7.70	695.61	8478.10	8.20
1984	1042.12	8924.45	11.68	1099.72	8924.45	12.32

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APPENDIX A. APPENDIX FOR CHAPTER 1

Table A.1 First stage results of 2SLS in Table 1.1

VARIABLES	Total Suspended particulate (mg/m^3) First Stage Results
Instrumental Variables	
Wind Speed	-0.059***
	(0.009)
Ground Air Pressure	0.006***
	(0.001)
Control variables	
Days with precipitation above 0.1cm	-0.001***
	(0.000)
Average temperature (ºC)	-0.004
	(0.004)
Humidity (%)	0.009***
	(0.001)
Sunshine Hours (hours)	0.000***
	(0.000)
Weak IV TEST (Cragg-Donald Statistics)	39.582***
Under identification Test (Anderson canon. corr. LM statistic)	11.683***
Overidentification Test (Sargan Statistics)	1.823
N	843
R^2	0.858

NOTES. These regressors are included in the estimation above, but their coefficients are not reported in this table: school quality and type, school grade fixed effects, expenditure on tutoring classes, family characteristics including parent's education, income, and children's siblings, birth order and gender, birth city fixed effect and birth year fixed effect. Error terms are double clustered by the birth city and birth year. Standard errors are reported in parentheses. *** indicates significance at the 1% level., ** indicates significance at the 5% level, and * indicates significance at the 10% level. Cragg-Donald Statistics is used to test the null hypothesis of weak instrumental variables, a rejection of the null hypothesis indicates the instruments are not weak. Anderson canon. corr. LM statistic is for the under-identification test. A rejection of the null hypothesis indicates full rank and there is no under-identification issue. Sargan Statistics is used for over-identification test, the null hypothesis is that all instruments are valid IVs. Failing to reject the null hypothesis indicates no over-identification issue.

Table A.2 Two-stage least squares estimation with accumulative exposure to TSPs

	(1) OLS Math	(2) OLS Language
Prenatal exposure to TSPs (mg/m^3)	-2.364	-6.309*
	(4.042)	(3.708)
Accumulative exposure to TSPs after the birth (mg/m^3)	-0.148	0.035
	(0.162)	(0.150)
Birth City FE	Y	Y
N	809	809
R^2	0.088	0.042

NOTES. All estimations above control school quality and type, school grade fixed effects, expenditure on tutoring classes, family characteristics including parent's education, income, and children's gender, siblings and birth order. I also control cities' GDP per capita in the birth year and test year (2008), and the weather in the birth year and test year. Error terms are double clustered by the birth city and birth year. Standard errors are reported in parentheses. *** indicates significance at the 1% level., ** indicates significance at the 5% level, and * indicates significance at the 10% level.

Table A.3 Data summary of migrant's children

	N	Mean	Standard Dev.	Min	Max
Z-score math	172	0.049	0.995	-3.946	1.309
Z-score language	172	0.083	0.975	-4.074	1.777
Prenatal exposure to TSPs (mg=1000 µg)	172	0.263	0.117	0.103	0.705
Accumulative exposure of TSPs after the birth	161	2.76	1.403	0.832	7.582
Gender (Girls=1)	172	0.547	0.499	0	1
Ln (Father's annual income)	172	7.46	1.029	0	9.798
Ln (Mother's annual income)	172	6.227	2.703	0	9.21
Father's years of education	172	8.215	2.134	2	12
Mother's years of education	172	7.035	2.296	1	12
Number of siblings	172	1.285	0.567	1	3
Birth order	172	1.564	0.694	1	4
Attending average school	172	0.657	0.476	0	1
Attending better than average school	172	0.279	0.45	0	1
Attending worse than average school	172	0.012	0.108	0	1
Attending best school	172	0.052	0.223	0	1
Attending public School	172	0.744	0.438	0	1
Attending private School	172	0.174	0.381	0	1
Attending boarding school	172	1.866	0.341	1	2
Expenditure on tutoring classes	172	100.082	456.491	0	5000
Birth year	172	1996.384	3.434	1989	2002

Source: China household Income Project 2008, migrant's sample; World Bank's Development Economics Research Group (DECRG), China Environmental Yearbooks.

Table A.4 Test scores and exposures to TSPs around the birth year

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	OLS	OLS	OLS	OLS
	Math	Math	Math	Language	Language	Language
Prenatal Exposure to TSPs ($TSPs_t$)	-2.403**	-2.786**	-2.705*	-1.598*	-0.915	-0.551
	(1.039)	(1.087)	(1.404)	(0.880)	(0.935)	(1.274)
$TSPs_{t-1}$	0.111		-0.058	-0.298		-0.561
	(0.862)		(0.891)	(0.903)		(0.963)
$TSPs_{t+1}$		0.633	0.477		-1.226	-1.148
		(1.192)	(1.234)		(1.000)	(1.049)
$\sum TSP_s$	-2.292***	-2.153**	-2.286**	-1.895***	-2.141***	-2.260***
	(0.712)	(0.903)	(0.932)	(0.605)	(0.742)	(0.808)
Birth Year FE	Y	Y	Y	Y	Y	Y
Birth City FE	Y	Y	Y	Y	Y	Y
N	837	804	798	837	804	798
R^2	0.112	0.103	0.102	0.105	0.107	0.102

NOTES. All estimations above control school quality and type, school grade fixed effects, expenditure on tutoring classes, family characteristics including parent's education, income, and children's siblings, birth order and gender. I also control cities' GDP per capita in the birth year and test year (2008), and the weather in the birth year and test year. Error terms are double clustered by the birth city and birth year. Standard errors are reported in parentheses. *** indicates significance at the 1% level., ** indicates significance at the 5% level, and * indicates significance at the 10% level.

APPENDIX B. APPENDIX FOR CHAPTER 2

Table B.1 Education interruption by the Cultural Revolution for various cohorts

Education level	Primary School	Middle School	High School	College	
Age beginning the school	6	12	15	18	
Birth Year					Cohort
1946	1952	1958	1961	**1964**	**1**
1947	1953	1959	1962	**1965**	
1948	1954	1960	1963	**1966**	
1949	1955	1961	**1964**	**1967**	**2**
1950	1956	1962	**1965**	**1968**	
1951	1957	1963	**1966**	**1969**	
1952	1958	**1964**	**1967**	**1970**	**3**
1953	1959	**1965**	**1968**	**1971**	
1954	1960	**1966**	**1969**	**1972**	
1955	**1961**	**1967**	**1970**	**1973**	**4**
1956	**1962**	**1968**	**1971**	**1974**	
1957	**1963**	**1969**	**1972**	**1975**	
1958	**1964**	**1970**	**1973**	**1976**	
1959	**1965**	**1971**	**1974**	1977	**5**
1960	**1966**	**1972**	**1975**	1978	
1961	**1967**	**1973**	**1976**	1979	
1962	**1968**	**1974**	1977	1980	**6**
1963	**1969**	**1975**	1978	1981	
1964	**1970**	**1976**	1979	1982	
1965	**1971**	1977	1980	1983	**7**
1966	**1972**	1978	1981	1984	
1967	**1973**	1979	1982	1985	
1968	**1974**	1980	1983	1986	**8**
1969	**1975**	1981	1984	1987	
1970	**1976**	1982	1985	1988	
1971	1977	1983	1986	1989	**9**
1972	1978	1984	1987	1990	
1973	1979	1985	1988	1991	

NOTES. Cultural Revolution occurred between 1966 and 1976.

Table B.2 The decomposition of wage differentials between cohorts by years

	$ln(w_1)$	$ln(w_0)$	Difference	Return to Education	Return to Experience	Education	Experience	N
1955-58 vs 1965-1967								
1995	8.733	8.465	0.268***	-0.260**	-0.070	-0.055***	0.059	2111
			(0.027)	(0.120)	(0.064)	(0.011)	(0.046)	
2002	9.052	9.015	0.037	0.329*	0.015	-0.049***	0.072*	1052
			(0.046)	(0.180)	(0.094)	(0.014)	(0.038)	
2007	9.631	9.602	0.029	0.171	-0.208*	-0.068***	0.165***	761
			(0.067)	(0.241)	(0.118)	(0.022)	(0.045)	
2013	9.792	9.835	-0.042	-0.021	0.009	-0.077***	0.065**	652
			(0.068)	(0.232)	(0.117)	(0.023)	(0.025)	
1955-58 vs 1968-1970								
1995	8.733	8.315	0.418***	-0.193	-0.149**	-0.048***	0.212**	2005
			(0.035)	(0.157)	(0.064)	(0.014)	(0.085)	
2002	9.052	8.860	0.192***	-0.399	-0.631***	-0.113***	0.635***	1046
			(0.070)	(0.287)	(0.163)	(0.029)	(0.133)	
2007	9.631	9.738	-0.107*	0.436**	0.026	-0.068***	0.095**	861
			(0.056)	(0.217)	(0.096)	(0.021)	(0.045)	
2013	9.792	9.859	-0.067	-0.077	-0.010	-0.103***	0.095***	789
			(0.064)	(0.234)	(0.106)	(0.024)	(0.033)	
1955-58 vs 1971-1973								
1995	8.733	8.183	0.550***	-0.148	-0.143**	-0.036***	0.404**	1958
			(0.034)	(0.160)	(0.061)	(0.012)	(0.166)	
2002	9.052	8.860	0.192**	-0.525	-0.430**	-0.210***	0.750***	938
			(0.087)	(0.376)	(0.197)	(0.054)	(0.275)	
2007	9.631	9.795	-0.164***	0.125	-0.156**	-0.162***	0.300***	784
			(0.054)	(0.225)	(0.078)	(0.031)	(0.068)	
2013	9.792	9.915	-0.123*	0.204	-0.031	-0.107***	0.143***	750
			(0.063)	(0.232)	(0.096)	(0.022)	(0.048)	

NOTES. This table includes workers in the state-owned enterprises. t-statistics in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table B.3 birth cohort 1959-1961 (primary, middle, high)

Year	Income Loss (/CNY in 2013)	Ratio of Income	Income Loss	Ratio of Income	Income Loss	Ratio of Income
	Same with 1965-1967		Same with 1968-1970		Same with 1971-1973	
1995	2502451	10.471	4669036	19.536	-750930.4	-3.142
2002	1675582	5.466	10493289	34.233	31789859	103.711
2007	3384773	16.388	2552863	12.361	4588925	22.219
2013	2463265	14.088	4307482	24.636	1346887	7.703
Total	10026073	10.817	22022671	23.760	36974742	39.891

Table B.4 birth cohort 1962-1964 (primary, middle)

Year	Income Loss (/CNY in 2013)	Ratio of Income	Income Loss	Ratio of Income	Income Loss	Ratio of Income
	Same with 1965-1967		Same with 1968-1970		Same with 1971-1973	
1995	3349626	14.016	5581028	23.352	-24856	-0.104
2002	317397	1.035	8775243	28.628	29222757	95.336
2007	4979997	24.112	4066699	19.690	6196188	30.001
2013	-648988	-3.712	979110	5.600	-1471380	-8.415
Total	7998032	8.629	19402081	20.932	33922709	36.598

APPENDIX C. APPENDIX FOR CHAPTER 3

C.1 Tables

Table C.1 Educational attainment of rural labor force

year	No schooling	Primary school,6 years	Junior High school,3 years	Senior High school, 3 years	College, 4 years
1952	0.778	0.181	0.032	0.008	0.001
1953	0.751	0.207	0.033	0.008	0.001
1954	0.746	0.211	0.034	0.008	0.001
1955	0.739	0.216	0.036	0.008	0.001
1956	0.733	0.220	0.037	0.009	0.001
1957	0.765	0.192	0.035	0.008	0.001
1958	0.746	0.209	0.036	0.008	0.001
1959	0.738	0.216	0.037	0.008	0.001
1960	0.729	0.223	0.038	0.008	0.001
1961	0.719	0.231	0.040	0.009	0.001
1962	0.723	0.223	0.042	0.010	0.002
1963	0.714	0.230	0.044	0.011	0.002
1964	0.704	0.236	0.047	0.011	0.002
1965	0.695	0.241	0.049	0.012	0.002
1966	0.684	0.247	0.053	0.013	0.002
1967	0.657	0.273	0.054	0.014	0.002
1968	0.646	0.279	0.059	0.015	0.002
1969	0.634	0.285	0.064	0.015	0.002
1970	0.647	0.269	0.067	0.015	0.002
1971	0.635	0.276	0.071	0.015	0.002
1972	0.622	0.285	0.075	0.016	0.002
1973	0.610	0.295	0.078	0.016	0.002
1974	0.598	0.302	0.080	0.017	0.002
1975	0.586	0.310	0.084	0.018	0.002
1976	0.576	0.316	0.087	0.018	0.002
1977	0.565	0.322	0.092	0.020	0.002
1978	0.550	0.328	0.098	0.022	0.002
1979	0.541	0.330	0.103	0.024	0.002
1980	0.531	0.331	0.109	0.028	0.002
1981	0.520	0.332	0.115	0.031	0.002
1982	0.508	0.333	0.122	0.036	0.002
1983	0.494	0.335	0.130	0.040	0.002
1984	0.484	0.337	0.134	0.042	0.002

Table C.1 Continued
Educational attainment of rural labor force

year	No schooling	Primary school,6 years	Junior High school,3 years	Senior High school, 3 years	College, 4 years
1985	0.475	0.341	0.139	0.044	0.001
1986	0.467	0.342	0.144	0.045	0.001
1987	0.455	0.344	0.153	0.047	0.001
1988	0.422	0.354	0.170	0.052	0.002
1989	0.389	0.366	0.186	0.057	0.002
1990	0.357	0.379	0.202	0.060	0.002
1991	0.338	0.385	0.216	0.059	0.003
1992	0.321	0.390	0.228	0.058	0.003
1993	0.303	0.396	0.241	0.057	0.003
1994	0.287	0.403	0.251	0.056	0.003
1995	0.270	0.409	0.263	0.055	0.003
1996	0.248	0.414	0.278	0.056	0.004
1997	0.229	0.416	0.294	0.057	0.004
1998	0.210	0.419	0.309	0.058	0.005
1999	0.191	0.420	0.325	0.059	0.005
2000	0.176	0.416	0.342	0.060	0.006
2001	0.176	0.412	0.347	0.058	0.006
2002	0.177	0.408	0.351	0.057	0.007
2003	0.176	0.405	0.356	0.056	0.007
2004	0.178	0.400	0.361	0.055	0.007
2005	0.179	0.394	0.367	0.053	0.008
2006	0.163	0.391	0.384	0.054	0.008
2007	0.147	0.389	0.399	0.055	0.009
2008	0.132	0.389	0.413	0.056	0.010

NOTES. This table lists the distribution of education levels among rural labor in all twenty-five provinces.

Table C.2 Data summary by years of 1952, 1960, 1970, 1985, 2000, and 2008

	N	Mean	Standard Dev.	Min	Max
1952					
Grain Output (/10,000 tons)	5	796.734	303.911	372	1032.05
Land (/1,000 hectares)	5	6000.11	4214.944	1938.87	12276
Machinery (/10,000 Kw)	5	0.929	1.72	0.106	4.006
Fertilizer (/10,000 tons)	5	0.317	0.354	0.041	0.76
Labor (/10,000 person)	5	705.407	379.011	253.183	1151.445
Average Education (years)	5	1.513	0.366	1.137	2.122
Return to education	5	0.016	0.007	0.008	0.026
Grain Price (Index)	5	1.196	0	1.196	1.196
Cost of production (Index)	5	1.025	0	1.025	1.025
1960					
Grain Output (/10,000 tons)	6	644.115	265.974	329.5	959.8
Land (/1,000 hectares)	6	5374.328	2796.214	2017.33	10033
Machinery (/10,000 Kw)	6	16.457	11.819	2.682	30.307
Fertilizer (/10,000 tons)	6	7.459	8.94	1.048	23.629
Labor (/10,000 person)	6	612.446	351.752	251.138	1214.633
Average Education (years)	6	1.837	0.441	1.407	2.697
Return to education	6	0.014	0.004	0.008	0.019
Grain Price (Index)	6	1.521	0	1.521	1.521
Cost of production (Index)	6	1.139	0	1.139	1.139
1970					
Grain Output (/10,000 tons)	24	905.708	500.346	64.897	1756.1
Land (/1,000 hectares)	24	4442.927	2270.385	450.5	9414.667
Machinery (/10,000 Kw)	24	48.039	36.64	3.688	141.433
Fertilizer (/10,000 tons)	24	18.077	26.493	0.718	109.175
Labor (/10,000 person)	24	655.199	442.898	40.336	1533.86
Average Education (years)	24	2.406	0.575	1.476	3.601
Return to education	24	0.02	0.008	0.008	0.039
Grain Price (Index)	24	1.949	0	1.949	1.949
Cost of production (Index)	24	1.039	0	1.039	1.039
1985					
Grain Output (/10,000 tons)	25	1446.7	919.814	100.32	3137.7
Land (/1,000 hectares)	25	4154.443	2223.39	386.57	9029.3
Machinery (/10,000 Kw)	25	406.1	329.05	34.381	1251.273
Fertilizer (/10,000 tons)	25	51.363	35.406	2.317	136.509
Labor (/10,000 person)	25	625.418	473.369	41.843	2023.193
Average Education (years)	25	3.82	0.831	2.493	5.34
Return to education	25	0.02	0.008	0.008	0.039
Grain Price (Index)	25	3.342	0	3.342	3.342
Cost of production (Index)	25	1.18	0	1.18	1.18

Table C.2 continued
Data summary by years of 1952, 1960, 1970, 1985, 2000, and 2008

	N	Mean	Standard Dev.	Min	Max
2000					
Grain Output (/10,000 tons)	25	1785.253	1090.737	82.7	4101.5
Land (/1,000 hectares)	25	4114.851	2235.033	322.72	9029.6
Machinery (/10,000 Kw)	25	785.004	784.785	50.357	2941.969
Fertilizer (/10,000 tons)	25	108.986	75.38	4.197	289.173
Labor (/10,000 person)	25	488.183	340.789	36.25	1560.624
Average Education (years)	25	6.294	0.784	4.384	7.346
Return to education	25	0.049	0.007	0.033	0.062
Grain Price (Index)	25	9.231	0	9.231	9.231
Cost of production (Index)	25	3.593	0	3.593	3.593
2008					
Grain Output (/10,000 tons)	25	2041.966	1339.152	101.8	5365.5
Land (/1,000 hectares)	25	4168.793	2622.712	271.99	10988
Machinery (/10,000 Kw)	25	1064.646	984.666	50.719	3500.868
Fertilizer (/10,000 tons)	25	134.938	91.848	4.289	407.293
Labor (/10,000 person)	25	356.63	229.988	24.454	1053.383
Average Education (years)	25	6.829	0.734	5.076	7.848
Return to education	25	0.052	0.005	0.038	0.062
Grain Price (Index)	25	13.133	0	13.133	13.133
Cost of production (Index)	25	4.708	0	4.708	4.708

Table C.3 Technology frontiers (1952-1985)

Province	Fujian		Hunan		Jiangxi		Shandong		Shanxi	
Year	γ	B	γ	B	γ	B	γ	B	γ	B
1952	1.096	2.113	1.219	2.627	1.096	1.211				
1953	1.097	2.368	1.220	2.872	1.097	1.305			1.215	2.221
1954	1.097	2.353	1.220	2.211	1.097	1.325			1.215	2.127
1955	1.097	2.553	1.221	3.114	1.097	1.513			1.215	1.625
1956	1.097	3.283	1.221	2.361	1.097	1.555			1.215	2.267
1957	1.098	3.753	1.221	3.394	1.098	1.677	1.213	1.008	1.215	1.439
Great Leap Forward (1958-1962)										
1958	1.098	4.895	1.222	3.687	1.098	1.531	1.213	1.377	1.216	3.291
Great Famine (1959-1961)										
1959	1.098	3.852	1.222	3.080	1.098	1.322	1.214	1.100	1.216	2.622
1960	1.098	1.465	1.223	0.833	1.098	1.168	1.214	0.413	1.217	1.192
1961	1.099	1.323	1.224	0.893	1.099	1.218	1.214	0.379	1.217	1.231
1962	1.099	1.508	1.224	1.542	1.099	1.193	1.215	0.466	1.217	1.374
1963	1.099	2.182	1.225	1.090	1.100	1.208	1.215	0.571	1.218	1.940
1964	1.100	2.662	1.225	1.682	1.100	1.369	1.216	0.832	1.218	3.394
1965	1.100	2.877	1.226	1.460	1.100	1.769	1.216	1.126	1.219	2.353
Cultural Revolution (1966-1976)										
1966	1.100	2.124	1.226	1.870	1.101	1.674	1.217	1.429	1.220	2.068
1967	1.101	1.830	1.227	1.915	1.101	1.571	1.217	1.306	1.220	2.395
1968	1.101	1.739	1.227	2.342	1.101	1.804	1.218	0.802	1.221	1.787
1969	1.101	1.828	1.228	1.920	1.102	1.805	1.219	1.000	1.221	2.310
1970	1.102	2.691	1.228	2.470	1.102	2.411	1.219	0.817	1.222	2.286
1971	1.102	2.511	1.228	3.007	1.103	2.279	1.220	0.967	1.223	3.653
1972	1.103	2.923	1.229	2.509	1.103	2.324	1.220	1.070	1.223	1.969
1973	1.103	2.059	1.229	2.695	1.104	1.576	1.221	1.323	1.224	3.002
1974	1.103	2.152	1.230	2.771	1.104	1.927	1.221	0.872	1.225	4.375
1975	1.104	2.107	1.230	2.975	1.104	2.523	1.222	1.959	1.225	5.700
1976	1.104	1.506	1.230	2.594	1.105	2.042	1.222	1.942	1.226	3.967
1977	1.104	2.006	1.231	2.373	1.105	2.365	1.223	1.286	1.226	3.472
Rural economic reform (1978-1984)										
1978	1.105	2.449	1.231	3.330	1.106	2.455	1.223	2.972	1.227	2.843
1979	1.105	3.197	1.232	3.964	1.106	3.651	1.224	3.057	1.228	5.240
1980	1.106	2.476	1.232	3.208	1.106	2.503	1.224	2.283	1.228	2.699
1981	1.106	2.330	1.232	3.378	1.107	2.639	1.225	1.898	1.229	3.001
1982	1.106	2.582	1.233	4.852	1.107	3.495	1.225	2.242	1.229	5.670
1983	1.107	2.988	1.233	6.458	1.107	4.136	1.226	3.432	1.230	4.753
1984	1.107	2.603	1.233	7.477	1.108	4.363	1.226	6.077	1.231	6.264
1985	1.107	2.528	1.233	7.530	1.108	4.638	1.227	8.283	1.231	6.956

Table C.4 Labor's efficiency (1952-1985)

Province	Fujian		Hunan		Jiangxi		Shandong		Shanxi	
Year	A^s	A^u	A^s	A^u	A^s	A^u	A^s	A^u	A^s	A^u
1952	0.638	1.271	0.958	1.216	0.462	0.913				
1953	0.694	1.353	1.025	1.270	0.492	0.949			0.699	1.209
1954	0.701	1.342	0.892	1.079	0.503	0.954			0.688	1.175
1955	0.747	1.402	1.110	1.307	0.552	1.027			0.593	0.998
1956	0.878	1.619	0.957	1.099	0.568	1.039			0.729	1.211
1957	0.962	1.745	1.205	1.348	0.601	1.082	0.404	0.777	0.563	0.923
Great Leap Forward (1958-1962)										
1958	1.141	2.032	1.289	1.397	0.577	1.020	0.495	0.930	0.933	1.495
Great Famine (1959-1961)										
1959	1.004	1.756	1.181	1.238	0.537	0.931	0.441	0.810	0.829	1.299
1960	0.575	0.986	0.555	0.564	0.506	0.860	0.252	0.452	0.529	0.810
1961	0.550	0.923	0.589	0.579	0.528	0.876	0.244	0.426	0.550	0.819
1962	0.605	0.990	0.828	0.786	0.531	0.859	0.282	0.478	0.598	0.866
1963	0.764	1.224	0.687	0.630	0.545	0.859	0.326	0.534	0.751	1.051
1964	0.873	1.367	0.903	0.801	0.597	0.918	0.417	0.662	1.069	1.446
1965	0.928	1.422	0.843	0.725	0.706	1.060	0.509	0.785	0.881	1.151
Cultural Revolution (1966-1976)										
1966	0.789	1.179	0.992	0.824	0.696	1.017	0.599	0.895	0.836	1.052
1967	0.734	1.071	1.020	0.823	0.681	0.972	0.579	0.842	0.933	1.132
1968	0.724	1.031	1.163	0.913	0.752	1.045	0.445	0.624	0.804	0.938
1969	0.759	1.053	1.048	0.798	0.767	1.035	0.520	0.702	0.959	1.074
1970	0.970	1.310	1.228	0.913	0.927	1.214	0.472	0.615	0.977	1.049
1971	0.948	1.245	1.394	1.012	0.914	1.161	0.535	0.671	1.319	1.359
1972	1.056	1.348	1.266	0.895	0.943	1.160	0.582	0.702	0.937	0.926
1973	0.874	1.083	1.335	0.918	0.766	0.909	0.673	0.785	1.228	1.165
1974	0.913	1.099	1.371	0.918	0.879	1.010	0.536	0.606	1.565	1.429
1975	0.917	1.072	1.446	0.940	1.050	1.168	0.882	0.965	1.867	1.638
1976	0.763	0.871	1.346	0.853	0.941	1.019	0.891	0.949	1.533	1.299
1977	0.789	1.179	0.992	0.824	0.696	1.017	0.599	0.895	0.836	1.052
Rural economic reform (1978-1984)										
1978	0.917	1.020	1.291	0.794	1.042	1.097	0.710	0.734	1.442	1.176
1979	1.046	1.135	1.592	0.952	1.081	1.107	1.184	1.190	1.302	1.025
1980	1.242	1.314	1.781	1.036	1.388	1.381	1.225	1.192	1.900	1.441
1981	1.081	1.117	1.580	0.905	1.126	1.090	1.049	0.988	1.304	0.953
1982	1.054	1.068	1.643	0.916	1.177	1.111	0.955	0.873	1.407	0.995
1983	1.132	1.124	2.054	1.110	1.408	1.293	1.070	0.949	2.077	1.420
1984	1.254	1.206	2.438	1.308	1.569	1.415	1.406	1.193	1.908	1.240
1985	1.172	1.097	2.654	1.432	1.628	1.452	2.004	1.640	2.280	1.421

Table C.5 Decompose the percentage change in grain output after Great Leap Forward, Egalitarian

Year	Time trend	Input Elasticity	Inputs	Labor Efficiency	Price and Cost +Grain Ratio	Total Change
Base=1958						
1959	1.37	-1.61	-4.30	-6.99	0.60	-10.93
	[-12.53]	[14.74]	[39.32]	[63.96]	[-5.50]	
1960	2.74	-2.04	4.19	-35.32	-0.01	-30.43
	[-9.00]	[6.70]	[-13.77]	[116.05]	[0.03]	
1961	4.11	-3.59	8.09	-35.88	-2.17	-29.44
	[-13.96]	[12.19]	[-27.50]	[121.89]	[7.39]	
1962	5.48	-5.28	11.97	-29.32	-2.84	-19.99
	[-27.41]	[26.42]	[-59.87]	[146.67]	[14.18]	
1963	6.85	-5.69	12.44	-25.35	-3.74	-15.49
	[-44.23]	[36.73]	[-80.34]	[163.67]	[24.18]	
1964	8.22	-7.44	13.88	-13.80	-3.18	-2.32
	[-354.10]	[320.29]	[-597.72]	[594.41]	[137.12]	
1965	9.59	-7.60	15.85	-12.56	-1.47	3.81
	[251.94]	[-199.61]	[416.30]	[-330.07]	[-38.56]	
1966	10.96	-7.56	17.38	-12.29	0.23	8.73
	[125.61]	[-86.62]	[199.19]	[-140.83]	[2.64]	
1967	12.33	-8.77	16.26	-13.02	0.54	7.34
	[167.96]	[-119.43]	[221.47]	[-177.34]	[7.34]	
1968	13.70	-10.00	16.90	-16.18	0.17	4.58
	[299.09]	[-218.41]	[368.94]	[-353.31]	[3.69]	
1969	15.07	-10.46	20.12	-13.66	0.72	11.80
	[127.76]	[-88.65]	[170.52]	[-115.78]	[6.14]	
1970	16.44	-11.07	24.98	-8.62	0.65	22.37
	[73.51]	[-49.51]	[111.68]	[-38.56]	[2.89]	
1971	17.81	-12.43	27.82	-3.70	0.52	30.02
	[59.32]	[-41.40]	[92.64]	[-12.31]	[1.75]	
1972	19.18	-11.30	27.66	-6.96	1.23	29.81
	[64.35]	[-37.90]	[92.78]	[-23.35]	[4.13]	
1973	20.55	-11.12	31.05	-6.87	1.62	35.23
	[58.33]	[-31.55]	[88.13]	[-19.49]	[4.59]	
1974	21.92	-12.54	30.89	-5.08	1.29	36.48
	[60.09]	[-34.37]	[84.68]	[-13.94]	[3.54]	
1975	23.29	-15.43	32.66	4.60	1.16	46.29
	[50.32]	[-33.33]	[70.56]	[9.94]	[2.51]	
1976	24.66	-13.04	32.67	-2.21	1.34	43.42
	[56.80]	[-30.03]	[75.24]	[-5.09]	[3.08]	

NOTES. The number in bucket represents the relative portion compared with the total change. The results are calculated from the grain production of Fujian, Hunan, Jiangxi, Shandong, and Shanxi.

Table C.6 Decompose the percentage change in grain output after rural economic reform, Egalitarian

Year	Time trend	Input Elasticity	Inputs	Labor Efficiency	Price and Cost +Grain Ratio	Total Change
Base year=1978, twenty-five provinces						
1979	1.37	-0.46	1.23	0.92	0.36	3.42
	[40.06]	[-13.48]	[35.95]	[26.93]	[10.54]	
1980	2.74	-0.54	1.52	-5.43	2.09	0.37
	[732.50]	[-145.15]	[405.82]	[-1450.94]	[557.78]	
1981	4.11	-0.77	1.74	-6.72	2.52	0.88
	[468.65]	[-88.13]	[198.55]	[-766.06]	[286.99]	
1982	5.48	-1.56	2.90	-0.48	3.12	9.46
	[57.92]	[-16.48]	[30.67]	[-5.06]	[32.95]	
1983	6.85	-2.95	5.32	6.79	2.55	18.56
	[36.91]	[-15.88]	[28.66]	[36.58]	[13.73]	
1984	8.22	-4.01	4.79	11.43	2.93	23.36
	[35.19]	[-17.15]	[20.49]	[48.91]	[12.56]	
Base year=1978, five provinces						
1979	1.37	-0.78	1.06	6.59	0.82	9.06
	[15.13]	[-8.60]	[11.69]	[72.77]	[9.01]	
1980	2.74	-1.01	0.56	-0.98	2.65	3.97
	[69.00]	[-25.35]	[14.18]	[-24.69]	[66.86]	
1981	4.11	-1.56	1.16	-0.92	3.04	5.84
	[70.41]	[-26.67]	[19.93]	[-15.75]	[52.08]	
1982	5.48	-2.69	1.36	6.07	3.82	14.03
	[39.05]	[-19.14]	[9.68]	[43.22]	[27.19]	
1983	6.85	-3.70	2.03	9.91	3.67	18.76
	[36.52]	[-19.71]	[10.81]	[52.82]	[19.57]	
1984	8.22	-4.91	2.38	14.02	3.70	23.40
	[35.13]	[-20.99]	[10.15]	[59.90]	[15.81]	

NOTES. The number in bucket represents the relative portion compared with the total change.

Table C.7 Decompose the percentage change in grain output after Great Leap Forward, skilled labor has nine years of schooling

Year	Time trend	Input Elasticity	Inputs	Labor Efficiency	Price and Cost +Grain Ratio	Total Change
Base=1958						
1959	1.19	-1.56	-3.99	-7.22	0.65	-10.93
	[-10.89]	[14.24]	[36.51]	[66.08]	[-5.95]	
1960	2.38	-1.97	4.67	-35.54	0.03	-30.43
	[-7.82]	[6.46]	[-15.33]	[116.78]	[-0.08]	
1961	3.57	-3.49	8.77	-35.98	-2.30	-29.44
	[-12.13]	[11.85]	[-29.79]	[122.25]	[7.83]	
1962	4.76	-5.15	12.88	-29.32	-3.16	-19.99
	[-23.81]	[25.74]	[-64.40]	[146.66]	[15.81]	
1963	5.95	-5.49	13.85	-25.61	-4.19	-15.49
	[-38.42]	[35.46]	[-89.44]	[165.33]	[27.06]	
1964	7.14	-7.17	15.46	-14.08	-3.67	-2.32
	[-307.57]	[308.74]	[-665.88]	[606.68]	[158.03]	
1965	8.33	-7.24	17.95	-13.25	-1.98	3.81
	[218.84]	[-190.32]	[471.57]	[-348.04]	[-52.06]	
1966	9.52	-7.16	19.69	-13.04	-0.28	8.73
	[109.11]	[-82.01]	[225.62]	[-149.48]	[-3.23]	
1967	10.71	-8.35	18.64	-13.65	-0.01	7.34
	[145.89]	[-113.78]	[253.90]	[-185.91]	[-0.10]	
1968	11.9	-9.59	19.42	-16.76	-0.39	4.58
	[259.79]	[-209.27]	[423.95]	[-365.87]	[-8.61]	
1969	13.09	-9.98	22.93	-14.32	0.08	11.80
	[110.97]	[-84.60]	[194.41]	[-121.42]	[0.64]	
1970	14.28	-10.50	28.15	-9.46	-0.10	22.37
	[63.85]	[-46.95]	[125.85]	[-42.30]	[-0.44]	
1971	15.47	-11.80	31.10	-4.52	-0.23	30.02
	[51.52]	[-39.30]	[103.59]	[-15.05]	[-0.77]	
1972	16.66	-10.68	31.12	-7.78	0.50	29.81
	[55.89]	[-35.83]	[104.39]	[-26.11]	[1.67]	
1973	17.85	-10.42	34.85	-8.01	0.97	35.23
	[50.66]	[-29.58]	[98.91]	[-22.74]	[2.75]	
1974	19.04	-11.78	34.85	-6.40	0.78	36.48
	[52.19]	[-32.30]	[95.53]	[-17.55]	[2.13]	
1975	20.23	-14.48	36.89	2.93	0.72	46.29
	[43.71]	[-31.28]	[79.70]	[6.32]	[1.56]	
1976	21.42	-12.14	37.10	-3.90	0.94	43.42
	[49.34]	[-27.97]	[85.45]	[-8.99]	[2.17]	

NOTES. The number in bucket represents the relative portion compared with the total change.

Table C.8 Decompose the percentage change in grain output after rural economic reform, skilled labor has nine years of schooling

Year	Time trend	Input Elasticity	Inputs	Labor Efficiency	Price and Cost +Grain Ratio	Total Change
Base year=1978, twenty-five provinces						
1979	1.19	-0.42	1.34	0.92	0.40	3.42
	[34.80]	[-12.42]	[39.25]	[26.80]	[11.58]	
1980	2.38	-0.49	1.77	-5.29	2.01	0.37
	[636.26]	[-132.30]	[472.09]	[-1414.01]	[537.97]	
1981	3.57	-0.71	2.08	-6.49	2.43	0.88
	[407.07]	[-81.04]	[236.90]	[-740.15]	[277.21]	
1982	4.76	-1.46	3.30	-0.06	2.92	9.46
	[50.31]	[-15.38]	[34.85]	[-0.68]	[30.90]	
1983	5.95	-2.77	5.77	7.32	2.30	18.56
	[32.06]	[-14.94]	[31.09]	[39.42]	[12.38]	
1984	7.14	-3.78	5.21	12.14	2.66	23.36
	[30.56]	[-16.18]	[22.29]	[51.96]	[11.37]	
Base year=1978, five provinces						
1979	1.19	-0.70	1.20	6.55	0.82	9.06
	[13.14]	[-7.71]	[13.29]	[72.28]	[9.00]	
1980	2.38	-0.88	0.79	-0.83	2.51	3.97
	[59.94]	[-22.09]	[19.84]	[-20.98]	[63.29]	
1981	3.57	-1.36	1.47	-0.77	2.93	5.84
	[61.16]	[-23.30]	[25.13]	[-13.24]	[50.25]	
1982	4.76	-2.38	1.74	6.23	3.69	14.03
	[33.92]	[-16.96]	[12.40]	[44.36]	[26.28]	
1983	5.95	-3.30	2.40	10.22	3.49	18.76
	[31.72]	[-17.60]	[12.77]	[54.50]	[18.61]	
1984	7.14	-4.42	2.69	14.50	3.48	23.40
	[30.52]	[-18.88]	[11.51]	[61.97]	[14.89]	

NOTES. The number in bucket represents the relative portion compared with the total change.

C.2 Decomposition of The Change in Grain Output

The grain production function a province i is:

$$Y_t = A_t D_t^{\alpha_{1t}} M_t^{\alpha_{2t}} F_t^{\alpha_{3t}} [(A_t^s L_t^s)^\sigma + (A_t^u L_t^u)^\sigma]^{\alpha_{4t}/\sigma}$$

Where $\alpha_{4t} = 1 - \alpha_{1t} - \alpha_{2t} - \alpha_{3t}$ under the condition of constant return to scale. Take the logarithm of this equation, we have:

$$y_t = ln(A_t) + \alpha_{1t} d_t + \alpha_{2t} m_t + \alpha_{3t} f_t + \frac{\alpha_{4t}}{\sigma} ln[(A_t^s L_t^s)^\sigma + (A_t^u L_t^u)^\sigma]$$

Therefore, the percentage change of grain output between year t and t' is:

$$\begin{aligned}
\Delta y &= y_{t'} - y_t \\
&= lnA_{t'} - lnA_t + \alpha_{1t'} d_{t'} - \alpha_{1t} d_t + \alpha_{2t'} m_{t'} - \alpha_{2t} m_t + \alpha_{3t'} f_{t'} - \alpha_{3t} f_t \\
&\quad + \frac{\alpha_{4t'}}{\sigma} ln\left[\left(A_{t'}^s L_{t'}^s\right)^\sigma + \left(A_{t'}^u L_{t'}^u\right)^\sigma\right] - \frac{\alpha_{4t}}{\sigma} ln[(A_t^s L_t^s)^\sigma + (A_t^u L_t^u)^\sigma] \\
&= \theta_1(t' - t) + \rho(p_{t'} - p_t) + \phi(c_{t'} - c_t) + \mu(r_{it'} - r_{it}) + \alpha_{1t}(d_{t'} - d_t) \\
&\quad + \alpha_{2t}(m_{t'} - m_t) + \alpha_{3t}(f_{t'} - f_t) + (\alpha_{1t'} - \alpha_{1t}) d_{t'} + (\alpha_{2t'} - \alpha_{2t}) m_{t'} \\
&\quad + (\alpha_{3t'} - \alpha_{3t}) f_{t'} + \frac{(\alpha_{4t'} - \alpha_{4t})}{\sigma} ln\left[\left(A_{t'}^s L_{t'}^s\right)^\sigma + \left(A_{t'}^u L_{t'}^u\right)^\sigma\right] \\
&\quad + \frac{\alpha_{4t}}{\sigma}\left\{ln\left[\left(A_{t'}^s L_{t'}^s\right)^\sigma + \left(A_{t'}^u L_{t'}^u\right)^\sigma\right] - ln[(A_t^s L_t^s)^\sigma + (A_t^u L_t^u)^\sigma]\right\} \\
&= \theta_1(t' - t) + \rho(p_{t'} - p_t) + \phi(c_{t'} - c_t) + \mu(r_{it'} - r_{it}) \\
&\quad + (\alpha_{1t'} - \alpha_{1t}) d_{t'} + (\alpha_{2t'} - \alpha_{2t}) m_{t'} + (\alpha_{3t'} - \alpha_{3t}) f_{t'} \\
&\quad + \frac{(\alpha_{4t'} - \alpha_{4t})}{\sigma} ln\left[\left(A_{t'}^s L_{t'}^s\right)^\sigma + \left(A_{t'}^u L_{t'}^u\right)^\sigma\right] \\
&\quad + \alpha_{1t}(d_{t'} - d_t) + \alpha_{2t}(m_{t'} - m_t) + \alpha_{3t}(f_{t'} - f_t) \\
&\quad + \frac{\alpha_{4t}}{\sigma}\left\{ln\left[\left(A_t^s L_{t'}^s\right)^\sigma + \left(A_t^u L_{t'}^u\right)^\sigma\right] - ln[(A_t^s L_t^s)^\sigma + (A_t^u L_t^u)^\sigma]\right\} \\
&\quad + \frac{\alpha_{4t}}{\sigma}\left\{ln\left[\left(A_{t'}^s L_{t'}^s\right)^\sigma + \left(A_{t'}^u L_{t'}^u\right)^\sigma\right] - ln\left[\left(A_t^s L_{t'}^s\right)^\sigma + \left(A_t^u L_{t'}^u\right)^\sigma\right]\right\}
\end{aligned}$$

The first row represents the change caused by total factor productivity, and the second factor in the first row is the part correlated with output price and prices of agricultural inputs. The second and third rows represent the change related to varying returns to agricultural inputs.

The fourth and fifty rows report the change associated with changing agricultural inputs. The last row represents the output change correlated with the change of labor efficiency.

C.3 Existence and Uniqueness of Symmetric Equilibrium

Suppose a farmer choose optimal use of agricultural inputs facing factor prices p_d, p_m, p_f, w_s and w_u, which represent the price of land, machinery, fertilizer, skilled labor, and unskilled labor respectively. He also has a given technology, $A^s$and A^u. The production function is (1), that is $Y = AD^{\alpha_1}M^{\alpha_2}F^{\alpha_3}[(A^sL^s)^\sigma + (A^uL^u)^\sigma]^{(\alpha_4)/\sigma}$, where $\alpha_4 = 1 - \alpha_1 - \alpha_2 - \alpha_3$.

The following shows the solution to the cost-minimization problem:

$$C(Y, p_d, p_m, p_f, w_s, w_u) = Y\lambda p_d^{\alpha_1} p_m^{\alpha_2} p_f^{\alpha_3} \left[\left(\frac{w_s}{A^s}\right)^{\frac{\sigma}{\sigma-1}} + \left(\frac{w_u}{A^u}\right)^{\frac{\sigma}{\sigma-1}}\right]^{(1-\alpha_1-\alpha_2-\alpha_3)(\sigma-1)/\sigma} \quad (10)$$

Where $\lambda = \frac{(1-\alpha_1-\alpha_2-\alpha_3)^{\alpha_1+\alpha_2+\alpha_3}}{A\alpha_1{}^{\alpha_1}\alpha_2{}^{\alpha_2}\alpha_3{}^{\alpha_3}}$

Proof:

The production function is $Y = AD^{\alpha_1}M^{\alpha_2}F^{\alpha_3}[(A^sL^s)^\sigma + (A^uL^u)^\sigma]^{(\alpha_4)/\sigma}$, from the first-order condition of input use, we have:

$$\frac{MP_D}{MP_{L^s}} = \frac{\alpha_1[(A^sL^s)^\sigma + (A^uL^u)^\sigma]}{\alpha_4 D(A^s)^\sigma(L^s)^{\sigma-1}} = \frac{p_d}{w_s}$$

$$\frac{MP_{L^s}}{MP_{L^u}} = \frac{(A^s)^\sigma(L^s)^{\sigma-1}}{(A^u)^\sigma(L^u)^{\sigma-1}} = \frac{w_s}{w_u}$$

From the two equations above, they easily derive

$$p_dD = w_s\frac{\alpha_1}{\alpha_4}\left(L^s + \frac{(A^uL^u)^\sigma}{(A^s)^\sigma(L^s)^{\sigma-1}}\right) = w_s\frac{\alpha_1}{\alpha_4}\left(L^s + \frac{w_u}{w_s}L^u\right) = \frac{\alpha_1}{\alpha_4}(w_sL^s + w_uL^u)$$

$$p_mM = \frac{\alpha_2}{\alpha_4}(w_sL^s + w_uL^u), \quad (12)$$

$$p_fF = \frac{\alpha_3}{\alpha_4}(w_sL^s + w_uL^u). \quad (13)$$

Therefore, the cost function $C(Y, p_d, p_m, p_f, w_s, w_u)$ is equal to:

$$C = p_d D + p_m M + p_f F + w_s L^s + w_u L^u$$

$$= \frac{1}{\alpha_4}(w_s L^s + w_u L^u)$$

$$\stackrel{\text{def}}{=} \frac{1}{\alpha_4}\tilde{C}$$

Here we define $\tilde{C} = (w_s L^s + w_u L^u)$.

Put (11), (12) ,and (13) into the production function, we have

$$Y = A\left(\frac{\alpha_1 \tilde{C}}{\alpha_4 P_d}\right)^{\alpha_1}\left(\frac{\alpha_2 \tilde{C}}{\alpha_4 P_m}\right)^{\alpha_2}\left(\frac{\alpha_3 \tilde{C}}{\alpha_4 P_f}\right)^{\alpha_3}\left(\frac{w_u L^u}{(A^u L^u)^\sigma}\right)^{-\frac{\alpha_4}{\sigma}}\tilde{C}^{\frac{\alpha_4}{\sigma}}$$

$$= A\left(\frac{\alpha_1}{\alpha_4 P_d}\right)^{\alpha_1}\left(\frac{\alpha_2}{\alpha_4 P_m}\right)^{\alpha_2}\left(\frac{\alpha_3}{\alpha_4 P_f}\right)^{\alpha_3}\left(\frac{w_u L^u}{(A^u L^u)^\sigma}\right)^{-\frac{\alpha_4}{\sigma}}\tilde{C}^{\frac{\alpha_4}{\sigma}+\alpha_1+\alpha_2+\alpha_3}$$

$$L^u = \left[\frac{(A^u)^\sigma}{w_u}\right]^{\frac{1}{1-\sigma}} Y^{\frac{-\sigma}{\alpha_4(1-\sigma)}}\tilde{C}^{\left(\alpha_1+\alpha_2+\alpha_3+\frac{\alpha_4}{\sigma}\right)\frac{\sigma}{\alpha_4(1-\sigma)}} \times$$

$$\left(\frac{\alpha_1}{\alpha_4 p_d}\right)^{\frac{\alpha_1\sigma}{\alpha_4(1-\sigma)}}\left(\frac{\alpha_2}{\alpha_4 p_m}\right)^{\frac{\alpha_2\sigma}{\alpha_4(1-\sigma)}}\left(\frac{\alpha_3}{\alpha_4 p_f}\right)^{\frac{\alpha_3\sigma}{\alpha_4(1-\sigma)}} A^{\frac{\sigma}{\alpha_4(1-\sigma)}}$$

Since $L^s = \left[\frac{w_s}{w_u}\left(\frac{A^u}{A^s}\right)^\sigma\right]^{1/\sigma-1} L^u$, we can express $\tilde{C}$ as

$$\tilde{C} = w_s L^s + w_u L^u$$

$$= \left[\frac{(A^u)^\sigma}{w_u}\right]^{\frac{1}{1-\sigma}} Y^{\frac{-\sigma}{\alpha_4(1-\sigma)}}\tilde{C}^{\left(\alpha_1+\alpha_2+\alpha_3+\frac{\alpha_4}{\sigma}\right)\frac{\sigma}{\alpha_4(1-\sigma)}} \times$$

$$\left(\frac{\alpha_1}{\alpha_4 p_d}\right)^{\frac{\alpha_1\sigma}{\alpha_4(1-\sigma)}}\left(\frac{\alpha_2}{\alpha_4 p_m}\right)^{\frac{\alpha_2\sigma}{\alpha_4(1-\sigma)}}\left(\frac{\alpha_3}{\alpha_4 p_f}\right)^{\frac{\alpha_3\sigma}{\alpha_4(1-\sigma)}} A^{\frac{\sigma}{\alpha_4(1-\sigma)}} \times$$

$$\left\{1 + \left[\frac{w_s}{w_u}\left(\frac{A^u}{A^s}\right)^\sigma\right]^{1/\sigma-1}\frac{w_s}{w_u}\right\}$$

After a simple algebraic transformation, we could solve $\tilde{C}$ in the form of (10). Next, we define $\theta = \frac{\sigma}{\omega(1-\sigma)}$, $\widetilde{A^s} = (A^s)^{\omega}$ and $\widetilde{A^u} = (A^u)^{\omega}$, the cost minimization function is:

$$C = Y\lambda p_d^{\alpha_1} p_m^{\alpha_2} p_f^{\alpha_3} \left[w_s^{\frac{\sigma}{\sigma-1}} \left(\widetilde{A^s} \right)^{\theta} + w_u^{\frac{\sigma}{\sigma-1}} \left(\widetilde{A^u} \right)^{\theta} \right]^{(1-\alpha_1-\alpha_2-\alpha_3)(\sigma-1)/\sigma}$$

$$s.t. \widetilde{A^s} + \gamma \widetilde{A^u} = B$$

Therefore, the interior solution is a unique equilibrium solution when $\theta < 1$, that is $\omega > \sigma/(1-\sigma)$.