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THESIS ACCEPTANCE CERTIFICATE

The undersigned, appointed by the
Department of Population Health Sciences,
have examined a dissertation, entitled,

"Reproductive Health and Women's Well-being at Older Ages"

presented by

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Date: 16 December 2024

Reproductive Health and Women's Well-being at Older Ages

A dissertation submitted

by

Muqi Guo

to

the Department of Global Health and Population

in partial fulfillment of the requirements

for the Degree of

Doctor of Philosophy

in the subject of

Population Health Sciences

Harvard University

Cambridge, Massachusetts

December 2024

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Dissertation Advisor: David Canning Muqi Guo

Reproductive Health and Women's Well-being at Older Ages

Abstract

Currently, women comprise 55.7% of adults aged 65 and older. The leading causes of death and disability among these women are chronic diseases, including ischemic heart disease, stroke, and low back pain. A growing body of literature highlights the importance of examining women's health across their entire lifespan, particularly the links between reproductive health and chronic diseases in later life. Understanding the long-term impact of women's reproductive health carries significant public health implications. It enables a deeper understanding of sex-specific health risk factors, informs the development of early-stage health interventions, and helps identify modifiable risk factors during midlife.

These topics remain underexplored in low- and middle-income countries (LMICs), partly due to limited data availability, especially long-term cohort studies that track participants from youth to older age. Nonetheless, studying these issues in LMICs is highly valuable. The unique reproductive health experiences of women in LMICs may reveal novel drivers of later-life well-being. Additionally, the diverse social, economic, and cultural norms in LMICs may alter the relationship between reproductive health and later-life well-being observed in high-income countries. Furthermore, LMICs face a dual burden of malnutrition—high rates of both underweight and overweight populations—and the simultaneous challenges of infectious and non-communicable diseases. These complex dynamics highlight the need for new public health investigations, with women's reproductive health potentially being a contributing factor.

This dissertation aims to investigate the health and well-being of older women in China and India, two countries that have undergone rapid demographic transitions in part due to nationwide family planning campaigns. The well-being of these older women is assessed through measures of mental health, physical health, and the onset of menopause. Utilizing a life course approach, I examine the relationship between older women's mental health and their early and mid-life reproductive experiences. This includes factors such as early marriage, early parity, contraceptive use, sterilization, and exposure to family planning policies that have permanently altered reproductive behaviors. Like many other LMICs, China and India have limited panel data tracking individuals over their full life course. To address this challenge, I utilize statistical methods, such as synthetic cohort analysis, that match women from different birth cohorts in cross sectional studies in different years.

The first paper investigates the impact of exposure to family planning policies targeting strict birth control during reproductive years on Chinese women's mental health in later life. It is well-documented that older Chinese women experience significant mental health problems (Lei, Sun, et al. 2014; Chen et al. 2024), yet few studies have examined the role of China's stringent family planning policies in this context. Given that current older Chinese women spent most of their reproductive years under these policies, this study addresses a crucial gap in the literature. Using data from 8,024 women aged 45 or older from the China Health and Retirement Longitudinal Study (CHARLS), I assessed their exposure to three key policies during their reproductive years (ages 15 to 45) by utilizing province-level variations in policy initiation years. The findings reveal that exposure to the 'Later-Longer-Fewer' Policy (LLFP) and the 'One-and-a-Half-Child' Policy (OHCP)—which permitted a second child in rural areas under the One-Child Policy—is associated with worse mental health outcomes in older women, including higher

depressive symptoms and cognitive impairment. Furthermore, the study indicates that these policies have a direct effect on mental health problems, beyond potential mediating mechanisms such as education, marriage, and parity.

The second paper examines the impact of total fertility on the physical health of older Indian women. To address potential confounding factors, I used the sex of the first-born child as an instrumental variable, to create a quasi-random variation in total fertility, leveraging India's prevalent son preference culture. Utilizing data from 30,067 women and 25,950 men aged 45 or older, each with at least one biological child, from the Longitudinal Aging Study in India (LASI), I found that a higher number of births is associated with reduced grip strength among mothers. Contrary to previous studies, I also discovered that more births are associated with a lower body mass index (BMI) and a reduced likelihood of being overweight. This effect is possibly due to a nutrition deprivation mechanism, as the association is stronger among mothers without schooling, an indicator of poor economic status. Among fathers, an increased number of births is associated with a reduced waist-hip ratio.

The third paper examines the relationship between women's early life reproductive experiences and the onset of menopause before age 45. Early natural menopause is associated with increased risks of premature mortality and various chronic diseases. In India, 20% of women experience early menopause (Kundu and Acharya 2023), compared to less than 10% in high-income countries (Mishra et al. 2017; Zhu et al. 2018). Despite this significant disparity, there are few studies on the determinants of early menopause in India, and the reasons behind its high prevalence are unclear.

In this paper, I investigate the risk factors associated with early menopause among 155,353 women aged 35-44, surveyed in the National Family Health Survey (NFHS) in India

2019-2021 (NFHS-5). Existing studies of earlier menopause in India (Meher and Sahoo 2021; Ahuja 2016; Jungari and Chauhan 2017) use cross-section data such as this, but the cross-section approach means the risk factors for menopausal women might be measured after they have experience menopause, giving rise to possible reverse causality. To address this potential threat of reverse causality, I measure women's reproductive characteristics in 2005 approximately 15 years prior to the 2019-21 data collection on menopause status, to create a synthetic panel. This method utilized data from women surveyed in NFHS-3, matching them to the women in 2019-21 based on year of birth, and other time invariant characteristics. The findings reveal that giving birth before age 20, nulliparity, and having more than two births are associated with higher odds of early menopause. Conversely, sterilization and the use of oral contraceptives or IUDs are linked to a lower risk of early menopause.

In summary, this dissertation reveals the long-term impact of early life reproductive experiences on women's well-being in later life. The findings, situated in the contexts of China and India, contribute to a global comparison in life course studies on women's health.

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1 Introduction

1.1 The importance of studying women's well-being

This dissertation examines women's well-being at older ages, adopting a health-focused definition that emphasizes physical and mental well-being. This approach is guided by the World Health Organization's (WHO) definition of health as "a state of complete physical, mental, and social well-being, and note merely the absence of disease or infirmity"(World Health Organization 1946), and aligns with the emerging perspective that well-being is "the relative attainment of a state in which all aspects of a person's physical, mental, social, and spiritual life are good" (VanderWeele and Lomas 2022).

Currently, women make up 55.7% of adults aged 65 and older (United Nations Department of Economic and Social Affairs 2022). Due to their higher life expectancy, older women are more often affected by disabilities rather than premature death (Institute for Health Metrics and Evaluation 2024). According to the latest Global Burden of Disease report, the leading causes of death and disability among women in 2021 are primarily chronic diseases, with the exception of COVID-19. These include ischemic heart disease, stroke, low back pain, diabetes, and depressive disorders (Brauer et al. 2024).

Studies on women's health have long been focused primarily on sexual, reproductive and maternal health (Carcel et al. 2024; Conry 2023). However, health issues that affect women in later life stages, such as menopause and endometriosis, remain understudied (Langer et al. 2015; The White House 2023), particularly in low- and middle-income countries. A growing body of literature emphasizes the importance of examining women's health across their entire lifespan, exploring the connections between reproductive health and chronic diseases in later life (Rich-Edwards and Morton 2002; Mishra, Cooper, and Kuh 2010).

Under this theme, this dissertation aims to investigate women's reproductive health and well-being in older age. It examines early life reproductive experiences, including early marriage, early parity, contraceptive use, sterilization, and exposure to family planning policies that have permanently altered voluntary reproductive behaviors. The study assesses the impact of these factors on women's wellbeing in older age, focusing on mental health, physical health, and the early onset of natural menopause. The findings of this study contributes to addressing the data and research gaps related to diseases and conditions affecting women in midlife and beyond, as highlighted by the White House Initiative on Women's Health(The White House 2023).

1.2 Research gap in studying women's well-being in low- and middle-income countries

Evidence on determinants of women's health in later life are mainly based on high-income countries, with limited investigations in low- and middle-income countries (LMICs). This is partially due to the scarcity of data tracking individuals' life courses, capturing reproductive events at younger ages and health problems at older ages. Recently, some surveys in LMICs that initially focused on young adults have extended their follow-ups into older adulthood to conduct aging research. For example, the Malawi Longitudinal Study of Families and Health (MLSFH) has begun collecting aging-related health data (Kohler et al. 2020). However, many other LMICs still lack such panel data. By 2050, 80% of older people will be living in LMICs (World Health Organization 2022). Therefore, studying reproductive health and well-being in later life within LMICs has become both urgent and important.

Specifically, I studied this issue in China and India. China and India, the two most populous LMICs, have undergone rapid economic and demographic transitions since World War II(Choudhry and Elhorst 2010). To achieve these transitions, both countries implemented nationwide family planning policies targeting birth control (Wang 2012; Ledbetter 1984). In

China, currently older women spent most their reproductive years under these stringent family planning policies. These policies likely influenced their reproductive experiences, potentially impacting their mental health in later life. India, with its higher fertility rates compared to European countries and cultural practices of son-preference and dowries, may experience differential health implications related to fertility. In addition, female sterilization is the most common contraceptive method in India (Bansal, Dwivedi, and Ali 2022), while fewer studies investigate the implication of sterilization on women's future health, such as the timing of menopause.

By studying reproductive health and women's well-being in later life in China and India, this research enhances our understanding of how reproductive experiences, shaped by individual and historical events, affect women's well-being as they age. This global comparative perspective provides valuable insights into the long-term impacts of reproductive health policies on women's health at an older age.

1.3 Overview of Chapter 2

For this dissertation, I employed a life course approach to reproductive health, which examines the determinants of reproductive function across different stages of life, including intergenerational, in utero, childhood factors, and adult environment; it also explores the impact of reproductive function on women's chronic diseases in later life (Rich-Edwards and Morton 2002). This approach provides concepts and perspectives essential for understanding reproductive health and its effects throughout life, such as critical period and sensitive period(Mishra, Cooper, and Kuh 2010), the intersection of biography and history, and linked lives (George 2013). The life course approach also offers theoretical models to comprehend the mechanisms linking reproductive health to well-being in later life. These include the critical

period model, the accumulation of risk model, and chains of risk model(Mishra, Cooper, and Kuh 2010). By using a life course approach, I aim to identify risk factors early in life and propose timely interventions to mitigate their impact on women's health as they age.

The first paper of this dissertation investigates women's mental health in later life. I focused on this area because women are disproportionately affected by mental disorders. Compared to men, women experience a significantly higher loss of life and disability due to mental disorders, including depressive disorders, headache disorders, anxiety disorders, and Alzheimer's disease and other dementias. These conditions are among the leading causes of deaths and disability among women (Patwardhan et al. 2024). In China, 43% of women aged 45 and older exhibit high levels of depressive symptoms (Lei, Sun, et al. 2014). Additionally, women tend to have higher depressive symptoms and worse cognitive function compared to men (Lei, Smith, et al. 2014; Lei, Sun, et al. 2014). This highlights an urgent need to investigate the determinants of mental health among women. By addressing these factors, this research aims to contribute to a better understanding and improvement of mental health outcomes for older women.

The first paper investigates the impact of exposure to stringent family planning policies during reproductive years on women's mental health in later life. From a life course perspective, individuals' life trajectories result from the join effects of personal biography and historical context (George 2013). China has implemented stringent family planning policies since the 1960s. During the 1960s and 1970s, China introduced the "later, longer, fewer" policy (LLFP), which encouraged couples to have fewer children by promoting later marriages and longer intervals between births. From the late 1970s until 2016, the one-child policy (OCP) was enforced nationwide, limiting each couple to one child. Some exceptions were made in rural

areas during the 1980s, including a significant relaxation allowing rural couples with only a daughter to have a second child, known as the 'one-and-a-half-child policy' (OHCP).

Exposure to these family planning policies during reproductive years can permanently alter a woman's voluntary trajectory regarding parity, education, marriage, and many other life plans. These policies may indirectly impact women's mental health in later life by influencing these life trajectories. Additionally, due to the stringent nature and long duration of these policies, there may also be a direct impact on women's mental health. This research explores both the direct and indirect effects of family planning policies on the mental health of women in their later year.

Current studies on the intersections of biography and history and their impact on mental health often focus on short-term shocks, such as war, famine, and natural disasters, and typically emphasize exposure during early life stages, such as in utero. For instance, early-life exposure to bombing during the American war in Vietnam negatively impacts the mental health of Vietnamese men and women in adulthood, potentially mediated by war-related malnutrition (Singhal 2019). Similarly, individuals born in cocoa-producing regions during periods of increased cocoa price exhibit a decreased likelihood of severe mental distress in adulthood, with maternal nutrition, reinforced childhood investments, increased height, and improved economic circumstances as possible mechanisms (Adhvaryu, Fenske, and Nyshadham 2019). In the context of Dutch Hunger Winter at the end of World War II, early prenatal exposure to famine is associated with higher risks of congenital anomalies of the central nervous system, schizophrenia, and schizophrenia spectrum personality disorders in adulthood (Hoek, Brown, and Susser 1998). In China, research has commonly focused on the impact of famine. One study found that in utero and early postnatal exposure to the 1959-1961 Chinese Famine is associated with increased mental illness in adulthood, particularly among women (Huang et al. 2013).

These studies highlight the lasting impact of early-life exposures to extreme events on mental health, underscoring the need to examine how long-term, stringent policies, such as family planning measures, similarly shape mental health outcomes over a lifetime.

These studies typically involve integrating data from various sources, such as the timing and intensity of famines or wars, cocoa prices, and mental health surveys at household or individual levels. Historical events are often treated as natural experiments, and researchers used econometric methods (e.g., instrumental variables, difference-in-differences) to conduct their investigations.

My investigation contributes to the field by examining the impact of family planning policies during young adulthood, while current research predominantly focuses on exposures at very early stages of life. I also integrate data from different sources. For family planning policies, I collected differential start years of each policy in each province and merge the data with aging data that had collected mental health measures. Specifically, using data from 8,024 women aged 45 or older from the China Health and Retirement Longitudinal Study (CHARLS), I assessed their exposure to three key policies at their reproductive ages between age 15 and age 45 by utilizing province-level variations in policy initiation years. Mental health outcomes were measured up to four times at baseline and subsequent follow-ups between 2011 and 2018. We used a generalized linear model with random effects and found that these policies increased depressive symptoms and cognitive impairment in women over 45, with no significant effect on substance use. LLFP and OHCP were the primary drivers of these impacts. LLFP was linked to fewer births, lower likelihood of early marriage, and higher education, while OHCP slightly increased births, and decreased higher education attainment, suggesting direct effects of the policies on mental health beyond mediation through these demographic channels. China's current

family planning policy still has birth limits. Findings of this study on the toll of family planning policies on later life worse mental health may help rethink the effectiveness of the current policy. Though China's family planning policies are unique, it may still have implications for other countries' population and development policies. A recent study revealed unwanted family planning policies in many developing countries (Canning and Karra 2023). Findings of this study supports a rights-based approach to family planning that recognizes the importance of free and informed choice of contraception by women.

1.4 Overview of Chapter 3

The second paper explores the impact of parity on women's physical health in India, contributing to the literature on the life course approach to reproductive health (Mishra, Cooper, and Kuh 2010; Rich-Edwards and Morton 2002). This approach investigates the link between reproductive function and chronic diseases later in life. Previous studies have shown that women with regular menstruation and uncomplicated pregnancies have a lower risk of cardiovascular diseases, whereas those experiencing conditions like late menarche, irregular cycles, ovulatory infertility, or preeclampsia, influenced by disrupted reproduction and lower estrogen levels over a lifetime, may face lower risks of breast cancer (Rich-Edwards and Morton 2002).

Recent findings indicate that women with hypertensive disorders during pregnancy are at increased risk of cardiovascular diseases even a decade after pregnancy (Arnott et al. 2020). Additionally, those with gestational diabetes mellitus (GDM) have a tenfold higher risk of developing type 2 diabetes mellitus compared to those without GDM (Vounzoulaki et al. 2020). Conducting such studies requires comprehensive measures of reproductive health status, including timing of menarche, menstrual cycle, infertility, pregnancy complications, timing of

menopause, menopausal symptoms, with long-term follow-up until the observation of chronic diseases at older ages.

Relevant studies usually use population register data in North European countries, such as studies on fertility and cause-specific mortality in Norway (E. Grundy and Kravdal 2010), or large prospective cohort studies, such as the Nurses' Health Study in the U.S. (Colditz, Philpott, and Hankinson 2016), which have supported investigations into abortion an premature mortality (Wang et al. 2021), and gestational diabetes with long-term cardiovascular disease (Tobias et al. 2017). The 1958 National Child Development Study, which has followed participants since birth, facilitated research on fertility and biomarkers in middle age (Sironi, Ploubidis, and Grundy 2020). Pooled data efforts like the International Collaboration for a Life Course Approach to Reproductive Health and Chronic Disease (InterLACE), pooling 200,000 women from over 13 studies of women's health across seven countries(Mishra et al. 2013), provides cross-cultural perspectives on infertility, recurrent pregnancy loss, and risks of dementia(Liang et al. 2024).

Recent studies have increasingly utilized biobank data containing demographic, medical, and genetic records, employing methods like mendelian randomization to assess causal relationships between reproductive factors—such as age at first birth, number of live births, age at menarche, and age at menopause—and cardiovascular outcomes (Ardissino et al. 2023).

Aging surveys provide another valuable type of data for these studies. Many such surveys, including the Health and Retirement Survey (HRS) and its international counterparts, feature retrospective questions about women's reproductive history. These studies often use complete fertility as a measure of exposure, due to the limited scope of reproductive health data available from retrospective surveys. Research in this area examines the relationship between fertility and various aspects of later life, such as depression(Grundy, Read, and Väisänen 2020), overall

health (Grundy and Read 2015), physical and mental health (Keenan and Grundy 2019), health changes (Read, Grundy, and Wolf 2011), and cognitive function (Read and Grundy 2017; Saenz, Díaz-Venegas, and Crimmins 2021). However, aging surveys often lack data on early life conditions, which could act as confounders between reproductive function and later life health. Some studies have employed instrumental variable methods to explore causal relationships by introducing external variations (Bonsang and Skirbekk 2022).

The studies and data mentioned above primarily originate from developed countries, leaving a gap in evidence from low- and middle-income countries. The second paper addresses this gap by investigating the impact of parity on women's physical health in India. This research focuses on key indicators such as blood pressure and body mass index (BMI), both of which are leading risk factors for the global disease burden (Brauer et al. 2024).

India has high fertility in history and a tradition of son preference (Chaudhuri 2012). Indian couples tend to keep giving births until having a son. In the second paper, I used son preference behavior as an instrumental variable (IV) to study parity and mothers' physical health, accounting for omitted confounding factors. Utilizing data from 30,067 women and 25,950 men aged 45 or older from the Longitudinal Aging Study in India (LASI), I applied Two-Stage Least Squares (2SLS) regressions. In the first stage, I regressed the total number of parity on whether the first-born child was a daughter, controlling for basic demographics. In the second stage, I regressed physical health measures on the predicted number of parity from the first stage, with the same controls. For fathers, I replicated this analysis. The findings show that more parity lead to lower BMI, and decreased grip strength in mothers, while fathers showed less statistically significant effects. Contrary to previous studies, this study also found increased parity are associated with reduced likelihood of being overweight, possibly through a nutrition deprivation

mechanism, as such association is stronger among mothers without schooling, an indicator of poor economic status. Findings of this study further provide evidence on the long-term impact of parity on mothers' life in the lifetime and contributes to global comparison. Future studies can investigate parity and chronic diseases, such as cardiovascular events or diabetes, which are closely related to the physical health measures of this study, while this is based on data availability.

1.5 Overview of Chapter 4

The third paper explores early life reproductive characteristics and their link to the early onset of menopause. Menopause is a universal experience for women. From a life course perspective, menopause transition is a turning point of women's life, when women may experience various symptoms, such as vasomotor symptoms, sleep disturbance, depression, and anxiety (El Khoudary et al. 2020). A U.S. study found that over half of women in the U.S. experience menopausal vasomotor symptoms (VMS) for more than seven years during the menopausal transition and for 4.5 years after their final menstrual period (Avis et al. 2015). These symptoms significantly disrupt women's quality of life. In 2020, the American Heart Association included the menopause transition as a sex-specific event for future cardiometabolic health in women(Nappi and Simoncini 2021). Another menopause-related risk factor is the early onset of natural menopause, defined as menopause occurring before age 45 (Mishra et al. 2017). Early onset of menopause is associated with heightened risks of premature mortality and various chronic diseases, including cardiovascular disease, neurological diseases, psychiatric diseases, osteoporosis, and Type 2 diabetes (Faubion et al., 2015; Muka et al., 2016; Shuster et al., 2010).

From a biological perspective, the onset of menopause typically hinges on the quantity of oocytes women being born with and the pace at which oocytes are depleted (Hansen et al. 2008).

Reproductive events such as pregnancy, breastfeeding, and contraceptive use, may interrupt regular ovulation, potentially slowing the rate of follicular atresia and consequently delay menopause (Cramer, Xu, and Harlow 1995).

Current analyses and data on menopause are primarily derived from high income countries, such as the InterLACE, and Nurses' Health Study, as well as the Study of Women's Health Across the Nation (SWAN), a leading study in the U.S. investigating menopause determinants and intervention across different races. However, women from LMICs remain underrepresented in this research and have higher prevalence of early menopause. The prevalence of early natural menopause in high-income countries ranges from 2.5% to 9.6% (Mishra et al. 2017; Zhu et al. 2018). And in India, such number reaches to 20.4% (Kundu and Acharya 2023). The Demographic and Health Surveys in many LMICs, which recruit women aged between 15 and 49, covering their reproductive health, also collect menopause-related information. I used India data to examine the associations of early life reproductive characteristics with early natural menopause in India.

The study analyzed data from 156,050 women aged 35-44 surveyed in the National Family Health Survey (NFHS) in India 2019-2021 (NFHS-5). Existing papers use this data as a cross section which may lead to reverse causality. To address this, I construct a pseudo panel using data of women surveyed in NFHS-3 with the same birth years as study women and having available measures of contraceptive use by 2005. For each woman in 2019-2021 I measure fertility in 2005 using birth histories. I imputed contraceptive use in 2005 using Bayesian methods based on reported ever use in 2019-21. I impute other variables in 2015 using the multiple imputation by chained equations (MICE). I found that giving birth before age 20, nulliparity, and having more than two births were associated with higher odds of early

menopause. Sterilization and the use of oral pills or IUDs were linked to a reduced risk of early menopause. Findings of this study provides a better understanding of the role of early life reproductive characteristics on later life early onset of menopause in India and contributes to a global comparison.

In summary, this dissertation explores women's reproductive health in earlier life and its impact on their later life well-being from a life course perspective. The research focuses on China and India, countries that, along with many other LMICs, have been less studied in this context. The first paper examines the unique exposure of China's decades-long family planning policies. The second and third papers apply advanced statistical techniques, such as instrumental variable methods and multiple imputation, to address issues of omitted confounding and reverse causality. The study design and findings of this dissertation aim to initiate further research into the long-term impact of reproductive health in LMICs and contribute to global comparative studies.

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2 Family planning policies and women's mental health at older ages in China

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2.1 Abstract

Mental disorders are prevalent among older Chinese women. Their exposure to multiple stringent family planning policies in earlier life potentially affects their mental health in later years. We analyzed the association between lifetime exposure to these policies and mental health outcomes, including depressive symptoms, cognitive impairment, and substance use. First, we measured differential exposure to three key policies: the "later, longer, fewer" policy (LLFP), the one-child policy (OCP), and the subsequent relaxation of the OCP in rural areas (OHCP, often referred to as the 'one-and-a-half-child policy'), by leveraging province-level variations in the initiation year of these policies. Secondly, we examined the associations of policy exposures with demographic outcomes (e.g., education, early marriage, and fertility) and mental health outcomes among a sample of 8,024 female participants aged 45 and older in 2013, drawn from the China Health and Retirement Longitudinal Study (CHARLS). We found exposure to an average level of each policy was associated with an increase in depressive symptoms by 0.46 standard deviations (95% CI: 0.28 to 0.63), impaired recall by 0.18 S.D. (95% CI: 0.02 to 0.34), impaired cognitive orientation by 0.34 S.D. (95% CI: 0.17 to 0.51), self-reported memory problems by 0.29 S.D. (95% CI: 0.14 to 0.44), and no significant differences in current smoking and drinking behavior. The associations were primarily driven by exposure to LLFP and OHCP, which showed different directions of association with demographic outcomes. OHCP exposure was associated with an

increase in births and a decreased probability of completing high school, which were opposite to the outcomes found for the earlier restrictions. This suggests that the effects of the policies on mental health are not entirely mediated through these channels, indicating that more direct effects are possible.

Keywords: Family planning policies, China, older Chinese women, mental health

2.2 Introduction

Older Chinese women have high prevalence of depressive symptoms and worse cognitive function (Lei, Smith, et al. 2014; Lei, Sun, et al. 2014). 43% of women aged 45 and over had a CES-D (the Center for Epidemiologic Studies – Depression scale) score at 10 and over, indicating high depressive symptoms (Lei, Sun, et al. 2014). About 30% of older women adults aged 65 and over have cognitive impairment while such proportion is about 10% lower among male older adults (Huashuai Chen et al. 2024). Understanding risk factors driving older women's mental health issues is crucial and urgent. Current studies on risk factors of mental health in older Chinese women usually focus on contemporary or individual factors (Yang et al. 2020) while a variety of social, economic, and physical environments individuals experienced at different stages of life may also affect their mental health (Allen et al. 2014).

Family planning campaigns have been significant social events in China, driven by stringent and continuous family planning programs over the past four decades (Scharping 2003; Wang 2012). The most well-known of these, the One-Child Policy, lasted for more than three decades before being relaxed in 2016 (Feng, Gu, and Cai 2016). Older Chinese women today spent most of their reproductive years under some form of family planning policy. These policies not only restricted their total number of births (Gu et al. 2007), and influenced their contraceptive use (Wang 2014),

but also had wide-ranging implications on their education, marriage, migration, and labor force participation (Huang, Lei, and Sun 2021; Zhang 2017; Y. Chen and Zhao 2022).

Emerging studies investigate the long term impact of family planning policies on individuals' health in later life (Y. Chen and Fang 2021; Islam and Smyth 2015). However, the relationship between family planning policies and older women's mental health remains understudied. In addition, previous studies focused on individual family planning policies while women may experience more than one policy in their reproductive years. This study will follow a life course approach to assess women's exposure to multiple family planning policies and their mental health in later life, examining potential mechanisms through education attainments, early marriage, total births and abortion.

2.3 Family planning policies in China

In the 1950s and 1960s, China underwent a period of rapid population growth (Coale and Chen 1987) with the total population exceeding 800 million (The Central People's Government of the People's Republic of China 2009). This surge in population exerted considerable strain on vital resources, the environment, and society at large. In the early 1970s, following Chairman Mao Zedong's directive that "it is not feasible to allow anarchism in human beings' childbearing; planned births are needed" (The State Council in China 1971), the State Council embarked on policies to promote family planning among the Han Chinese population, with certain minority groups exempted. In 1973, the State Council formalized its fertility policy, officially terming it as the Later-Longer-Fewer policy (LLFP). 'Later' pertained to delaying marriage, with men required to be at least 25 years old and women at least 23 before marriage. Women were only permitted to give birth after reaching the age of 24. 'Longer' mandated a minimum spacing of three years between births. 'Fewer' stipulated that each couple should have no more than two births in their lifetime. These policies yielded a notable reduction in the population growth rate, declining from

an annual rate of 23.4‰ in 1971 to 12.1‰ in 1977 (The Central Party Committee in China 1978). Nonetheless, the total population size had swelled to 970 million by 1979 (The World Bank 2022).

In 1979, China initiated the Universal One-Child Policy (OCP), which mandated that every couple could have only one child throughout their lifetime. This policy was formalized in the National People's Congress in 1980. The OCP introduced more stringent measures, limiting each couple to just one birth in their lifetime, and retained the emphasis on delayed marriage, as in the LLFP.

The stringent fertility policy encountered significant resistance, particularly in rural areas. Within rural regions, children were considered vital for supporting their parents, both in terms of agricultural labor and providing care in old age. In 1982, the Central Committee of the Communist Party of China and the State Council introduced revisions to OCP that in rural areas, couples facing practical challenges could apply for a second birth with local government approval. Simultaneously, a more robust enforcement mechanism was introduced, accompanied by penalties for unauthorized second or multiple births, a strategy colloquially referred to as "opening a small hole and closing the big hole" (Greenhalgh 1986).

Further adjustments were made in 1984, expanding exceptions for second births in rural areas, though these changes were implemented at the provincial level at different times (Greenhalgh 1986; Scharping 2003). Approximately 20 different circumstances were considered for granting permission for a second child in rural areas, but the majority of these conditions applied to specific, small population groups. For instance, if a first child was disabled or deceased. By far the most important exception is to allow rural couples with an only daughter to have a second child. This policy was informally termed the one-and-a-half child policy (OHCP) as it was expected to increase 0.5 birth on average in addition to the one birth.

Throughout the 1980s, 19 out of 31 provinces implemented the OHCP in rural areas. Four municipality cities (Beijing, Tianjin, Shanghai, and Chongqing) and two provinces (Jiangsu and Sichuan) never implemented OHCP and consistently implemented OCP. The other six provinces (Hainan, Ningxia, Xinjiang, Qinghai, Yunnan, and Xizang) which have high proportions of minority ethnicities implemented less restrictive fertility policies. The OCP and OHCP remained in effect for nearly three decades until the end of 2015 when they were gradually replaced by the current universal three-child policy.

China's family planning policies primarily targeted the Han Chinese population, which constitutes 93% of the total population (State Council Census Office and National Bureau of Statistics 1982). The implementation and enforcement of these policies were extensive (Huang, Lei, and Sun 2021). The central government established a five-tier family planning network to effectively execute the birth control program, comprising national, provincial, prefectural, county, and township/village levels. Local officials were entrusted with meeting population targets, and their job security and prospects for promotion were closely tied to their ability to enforce policies diligently at the local level.

However, the specific rules, penalties, and the execution of these policies often varied at the local level (Gu et al. 2007). Following the issuance of new policies by the Party Central Committee and the State Council, each province established its own regulations under the central policy guidelines, allowing for some variations to align with local conditions (Greenhalgh 1986). It's worth noting that the introduction of LLFP and OHCP commenced in different years in various provinces, unlike OCP, which was uniformly implemented nationwide in 1979.

Within provinces, there was heterogeneity in enforcement between urban and rural areas (Zhang 2017). Urban residents faced more stringent enforcement, as many worked for state-owned enterprises or government agencies, risking job loss and the forfeiture of related social welfare

programs if they exceeded birth quotas. Rural residents received fewer government benefits that could be withdrawn but were subject to fines for violating family planning policies.

During the era of LLFP, the enforcement of family planning policies relied mainly on propaganda, promotion of contraceptive use, and social pressure. However, with the introduction of OCP and OHCP during the 1980s and 1990s, family planning policies adopted a more rigorous enforcement approach (Wang 2012). This included intensive mass education programs, annual abortion-sterilization campaigns conducted by local governments, mandatory long-term contraceptive use for couples after having their first child (e.g., intrauterine devices insertion, abortion for unauthorized pregnancies, and sterilizations for couples with two or more children), as well as cash penalties that often amounted to several times a couple's annual income.

2.4 Methods

Study sample and data

We focused on a sample of Han Chinese women aged 45 or older drawn from the China Health and Retirement Longitudinal Study (CHARLS). CHARLS is a nationally representative survey of individuals aged 45 and above in China.

CHARLS employed a stratified, multistage probability sampling approach to select households. From each selected household, one eligible person and their spouse were randomly chosen for interviews. In 2011, CHARLS collected baseline data from 17,708 participants belonging to 10,257 households across 450 communities in 150 counties within 28 provinces across China. Subsequently, CHARLS conducted follow-up surveys every two to three years. We used CHARLS 2011-2018 data Version D released in June 2021 by the Gateway to Global Aging Data. Additionally, we also used CHARLS life history survey data collected in 2014. This survey collected data on major life events, including birth histories and migration and residence histories.

We combined the life history data with survey data to construct detailed information about participants' fertility, province of residence, rural status based on household registration hukou status, and exposure to family planning policies each year, from age 15 to age 45. Our study focused on 9,888 participants, all Han Chinese women born in 1968 or earlier, who were aged 45 or older in 2013, when their life history data was collected. We excluded three groups from analysis: 1) 882 participants without a complete province residence history during their reproductive years; 2) 391 participants with missing Hukou data either at age 15 or in 1979; and 3) 591 participants who resided in provinces that implemented a universal two-child policy since 1979 during their reproductive years. These exclusions resulted in a study sample comprising 8,024 participants. Each of these participants was tracked through up to four survey waves, providing us with a total of 32,096 observations of our mental health outcome variables.

Mental health outcomes

For mental health we measured depressive symptoms, recall memory impairment, orientation impairment, self-reported memory problems, current smoking, and daily drinking. Our selection of these specific measures to evaluate mental health is influenced by both the availability of data and the World Health Organization's (WHO) definition of mental health, which encompasses three core dimensions: thought, emotion, and behavior (World Health Organization 2001). Depressive symptoms serve as a proxy for the emotional dimension of mental health. Recall memory score, orientation score, and self-reported memory contribute to the assessment of the thought dimension of mental health. Smoking and daily drinking address the behavioral dimension of mental health. CHARLS used the same assessment questions and collected data on each of these mental health outcomes during multiple survey waves, resulting in a total of up to four repeated measurements for each participant.

The depressive symptoms score in our study is derived from the Center for Epidemiologic Studies Depression Scale (Andresen et al. 1994). It has been demonstrated to possess sufficient reliability and validity when applied to older adults in China (Huajuan Chen and Mui 2014). This score is based on responses to ten specific questions that inquire about the participants' feelings and behaviors during the week leading up to the interview. The resulting depressive symptoms score ranges from 0 to 30, where a higher score signifies a greater presence of depressive symptoms.

Recall memory impairment in our study is assessed through a reversed sum score of immediate recall and delayed recall. This evaluation hinges on a participant's capacity to promptly reproduce ten Chinese nouns after the interviewer reading them aloud (immediate recall) and followed by the ability to recall the same set of words four minutes later (delayed recall). Participants receive one point for each correctly recalled word. The recall memory score spans a range between 0 and 20. We reversed the sum score of recall, so a higher score indicates more impaired recall memory capability. The recall memory data gathered in CHARLS 2018 could potentially exhibit biases, especially among illiterate or rural older adults. This is attributed to the utilization of a new word list in CHARLS 2018, which included words that might not be familiar to older individuals, such as "queen" or "butter." Additionally, variations in the time gap for delayed recall might further contribute to discrepancies in the data (The CHARLS Team 2023). We thus only used CHARLS 2011, 2013, and 2015 data for recall memory.

The orientation score is an indicator of the participant's ability to recognize and correctly respond to questions about the day of the month, month, year, and day of the week. Participants can earn a maximum of four points if they answer all four questions correctly. As for memory, we reversed the sum score, with a higher score indicating a more pronounced impairment in orientation capability.

Self-reported memory is assessed through participants' self-evaluation of their memory, with scores ranging from 1 (Excellent) to 5 (Poor). Current smoking is represented as a binary variable that indicates whether participants are currently engaged in smoking. Similarly, daily drinking is another binary variable that reflects the respondent's highest frequency of alcohol consumption in the last year—specifically, whether they consumed alcohol at least once daily or not. Given that these mental health outcomes are measured using different scales, we standardized these health outcomes by centering the values with mean at zero and standard deviation at one.

Intermediate demographic outcomes

We also assessed four intermediate demographic outcomes that might link family planning policies to the later life health of women: early marriage, total births, induced abortions, and educational attainment. Early marriage is defined as a binary variable, with women categorized as having experienced early marriage if they were married before age 23. Total births and abortions were mainly obtained from the life history survey data and we used information in earlier survey waves (CHARLS 2011 and 2013) for respondents who were not interviewed in the life history survey. Educational attainment is assessed through a binary variable that signifies whether participants graduated from high school or not.

Family planning policies exposure

We followed the approach of Chen and Fang (Y. Chen and Fang 2021) who estimated the relationship between exposure to LLFP and health at older ages using differential exposure based on province's year of policy initiation and each individual's birth year. Our measurement of exposure to the LLFP is identical to theirs; we used the province’s year of policy initiation, and the person’s birth year, to calculate the proportion of reproductive life (ages 15-45) they were

exposed to the policy assuming the policy continued thereafter. Additionally, we considered age-specific fertility rates in the province in the base year, 1969, to weigh the exposure. Each year of exposure is weighted by the 1969 fertility rate at that age in the province. The idea of this weighting is that we expected the effect of policies to be larger in provinces where the baseline fertility rate was higher.

Formally, the LLFP exposure for woman i, from birth year $c(i)$ living in province $P(i,a)$ at each age a is given by:

$$LLFP_i = \sum_{a=15}^{45} [AFR_{1969}(P(i,a),a) * I[c(i) + a > T_{LLFP}(P(i,a))]]$$

Where c(i) is the woman's birth cohort (c=1900,…,1968); $AFR_{1969}(P(i,a),a)$ is province-level age-specific fertility rates in 1969 for each province age pair; $T_{LLFP}(P(i,a))$ is the province-specific policy start year (T=1969,…,1975); I is a binary (0 or 1) variable indicating whether the year (persons birth cohort plus age) exceeds the policy start year.

We introduced two more policy exposure variables into our analysis. The first is the OCP. This policy was introduced nationwide in 1979. We gauged the proportion of an individual's reproductive life exposed to the OCP, similarly weighing it by the age-specific fertility rate in the year 1979. Note that we assume exposure to the LLFP persists along with the OCP so our estimates for the effect of the OCP is additional effect over and above the effect of exposure to the LLFP.

Formally we calculated each woman's exposure to the OCP as

$$OCP_i = \sum_{a=15}^{45} [AFR_{1979}(P(i,a),a) * I[c(i) + a > T_{OCP}(P(i,a))]]$$

Where $AFR_{1979}(P(i,a),a)$ is province-level age-specific fertility rates in 1979 for each province age pair and $T_{OCP}\big(P(i,a)\big) = 1979$ the year the OCP was introduced.

We also measured exposure to the OHCP. Exposure is set to zero each year for women not residing in rural areas where the policy had been implemented and one for each year they lived in a rural area that had implemented OHCP. In this case we do not weigh the exposure. The LLFP and OCP had fixed fertility targets that imply larger effects on fertility when baseline fertility was high. However, the OHCP was a relaxation relative to the uniform OCP limit and we expect a fairly uniform increase of up to 0.5 children per woman for all women exposed.

Formally we have

$$OHCP_i = \sum_{a=15}^{45} I[c(i) + a > T_{OHCP}\big(P(i,a)\big)] * R(i,a)$$

Where $T_{OHCP}(P)$ is the start year of the OHCP in province P and $R(i,a)$ is a binary indicator for whether woman i was living in a rural area at age a.

Data on policy start years came from published studies or legal or administrative documents (Y. Chen and Fang 2021; Scharping 2003). Data of province-level age-specific fertility rates in 1969 and 1979 came from Coale and Chen's book (Coale and Chen 1987).

Participant characteristics, including their year of birth, province of residence, and urban/rural status during their reproductive years, are crucial variables for constructing policy exposure metrics. In harmonized CHARLS data, the year of birth was primarily based on participants' self-report, with additional confirmations in subsequent follow-up surveys. This confirmation process involved inquiries about the self-reported year of birth based on either the solar or lunar calendar, the participant's current age at the time of the interview and cross-referencing with the date of birth information found on their Chinese ID cards. The CHARLS life history data, particularly

the 2014 survey, contained comprehensive information on women's rural/urban status, province of residence, and the timing of changes in these statuses since birth. We predominantly utilized the life history survey data to establish participants' province of residence at each age within their reproductive years, spanning from ages 15 to 45. For those individuals who were not part of the CHARLS 2014 survey but were present in earlier waves (2011 and 2013), we employed the province of residence information collected during those years. This data enabled us to identify individuals who had not migrated out of their current province of residence since the age of 15. Employing a similar methodology, we also constructed information regarding participants' rural/urban residence status during their reproductive years.

It's crucial to emphasize that the effects of our three policy variables accumulate over time. The LLFP exposure has long-term implications beyond 1979, when it was replaced by OCP. Therefore, when we estimate the effect of the OCP, it represents the additional impact of the OCP beyond what would have occurred if the LLFP had merely been extended without any changes. Similarly, we measured women as being exposed to the OCP even after the OHCP is introduced. As a result, we anticipated that OHCP would lead to an increase in fertility since its effect was measured relative to the effect of the OCP.

The exposures specified above were used for our models of mental health, completed fertility, and abortion. We define early marriage as marriage before age 23 and high school attainment is usually completed before age 23. Consequently, our policy exposure measures for these two outcomes are based solely on participants' exposures to family planning policies between the ages of 15 and 22 rather than over the age range 15-45.

Model specification

We examine four intermediate demographic outcomes: early marriage, completed fertility, number of abortions, and educational attainment. Additionally, we investigated six mental health outcomes: depressive symptoms, recall memory, self-reported memory, orientation, current smoking, and daily drinking. For our analysis, we employed linear regression models to explore the relationships between these outcomes and policy exposure variables. The models for the intermediate demographic outcomes were structured below.

$$Y_i = \beta_0 + \beta_1 * LLFP_i + \beta_2 * OCP_i + \beta_3 * OHCP_i + \beta_4 * Rural_{i,age=15} + \gamma_{p15(i)} + \varphi_{p15(i)} * c_i + u_i$$

Where Y_i is the demographic outcome for woman i , and the $LLFP_i$, OCP_i, $OHCP_i$ are the family planning exposure policies defined above. We control for $Rural_{i,age=15}$, rural residence at age 15, as urban and rural residents have distinguished differences in demographic and health outcomes. We also control for province fixed effects $\gamma_{p15(i)}$ and province specific trends in fertility by birth cohort $\varphi_{p15(i)} * c_i$ based on the woman's province of residence at age 15. u_i is an error term; we adjusted the standard errors by clustering at the community level, recognizing that outcomes may be correlated across women within the same community.

For our mental health outcomes, we have measures in four waves of CHARLS and thus we used the model

$$Y_{i,w} = \beta_0 + \beta_1 * LLFP_i + \beta_2 * OCP_i + \beta_3 * OHCP_i + \beta_4 * Rural_{i,age=15} + \gamma_{p15(i)} + \varphi_{p15(i)} * c_i + \delta_w + u_i + \varepsilon_{wi}$$

Where $Y_{i,w}$ is the outcome measured for woman i in wave w. For this model we add a wave specific dummy variable δ_w and we now interpret u_i as a woman specific random effect and ε_{wi} as wave specific measurement error in the outcome. Using data from the four waves in 2011, 2013, 2015, and 2018 gives us repeated measures of the same mental health outcomes and reduces measurement error in our model.

An issue is that our family planning exposure measures are complex and is difficult to interpret the magnitude of the estimated coefficients of the policies. We therefore also report effect sizes of the policies in terms of the expected change in the outcome variable for a women with the average policy exposure level versus a counterfactual of zero exposure to that policy. This is the average estimated effect of exposure to the policy for women in our sample.

Our analytical approach is similar to that in Chen and Fang's study (Y. Chen and Fang 2021). Notably, for mental health outcomes, we chose not to control for completed fertility, abortions, marital status, or educational attainment. These variables represent potential mediators of the fertility policy's impact and including them would dilute the estimated effects of the policies. Similarly, we refrained from including other potential controls, such as work history, income, and wealth. In contrast to Chen and Fang's study, which focused on a single exposure variable, our analysis estimates three coefficients, β_1, β_2, and β_3 to quantify the impact of three distinct fertility policies: LLFP, OCP, and OHCP. We also gave estimates for the total effect of exposure to the policies, which is a counterfactual estimate that quantifies expected outcome for a woman exposed to an average level of each policy in the sample.

Finally, it's important to emphasize that the relationship between family planning policies and mental health is complex, with multiple pathways at play. While our list of potential mediators is not exhaustive, examining sociodemographic factors other than fertility has the potential to show that the impact of policies is not exclusively attributable to direct effects of fertility, and there are potentially multiple mechanisms at work.

2.5 Results

Figure 2.1 shows the differential start years of LLFP and OHCP in study provinces. Compared to LLFP, there are more variations in OHCP start years across provinces. Figure 2.2 shows the total

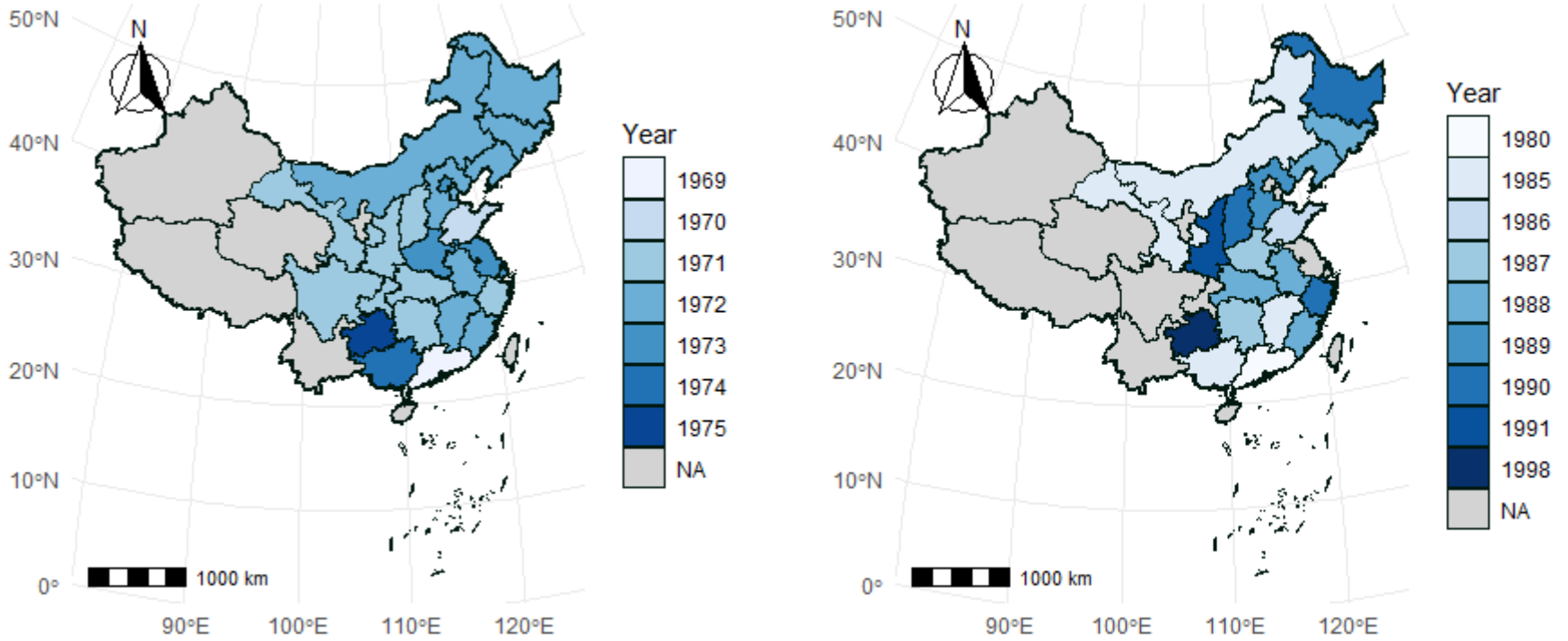

Figure 2.1 "Later-Longer-Fewer" Policy (LLFP) and "One-and-a Half Child Policy" (OHCP) start years in study provinces of China
Note: NA- Not applicable. Provinces highlighted in gray (NA) are not part of the study. Among them, five have a predominantly ethnic minority population and enacted population policies that were notably more lenient compared to the study provinces, where the majority of the population is Han ethnicity.

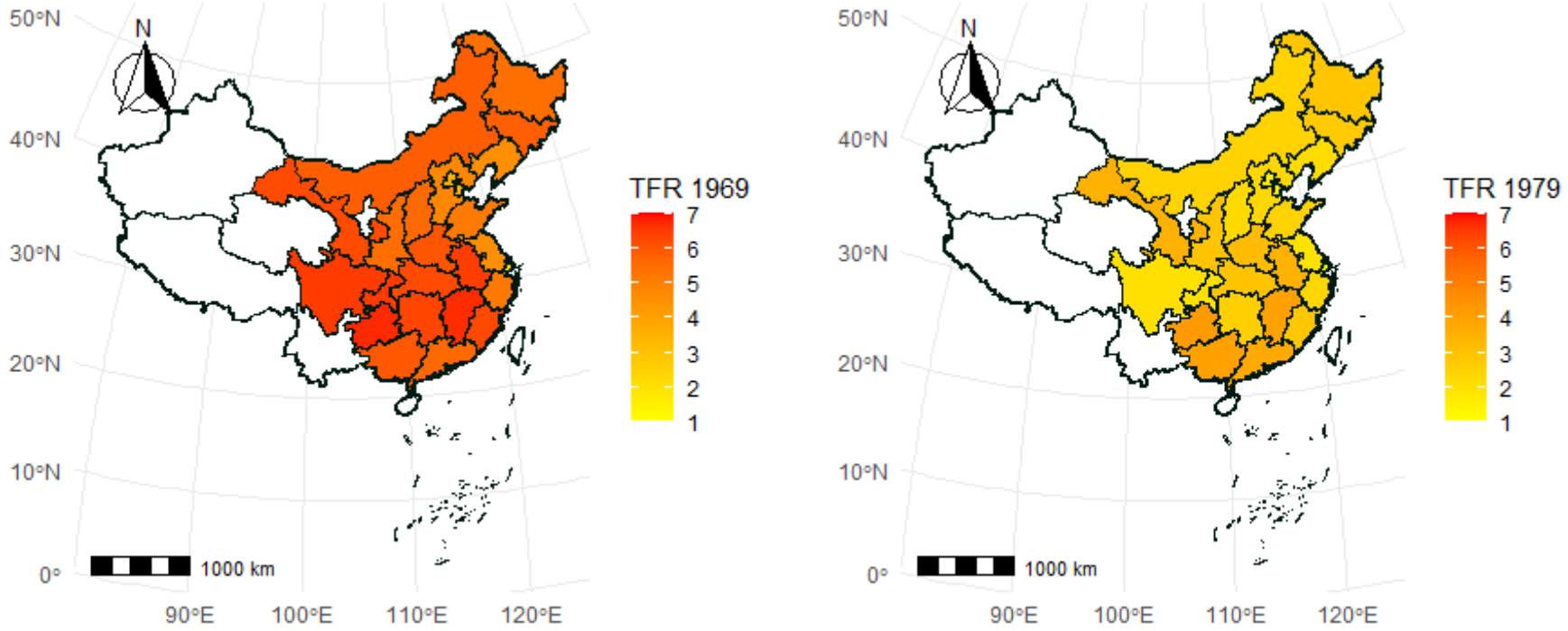

Figure 2.2 Total fertility rates (TFR) in 1969 and 1979 in study provinces of China
Note: Provinces in white are not part of the study. Among them, five have a predominantly ethnic minority population and enacted population policies that were notably more lenient compared to the study provinces, where the majority of the population is Han ethnicity.

fertility rate (TFR) by study provinces in 1969 and 1979. Fertility rates in 1969 were much higher and have less differences across provinces. Fertility rates in 1979 declined in all provinces and were slightly higher in southern provinces. Figure 2.3 shows the average age specific fertility rates in our study provinces in 1969 and 1979. Fertility rates declined at each age group from 1969 to 1979, with greater decline for older age groups.

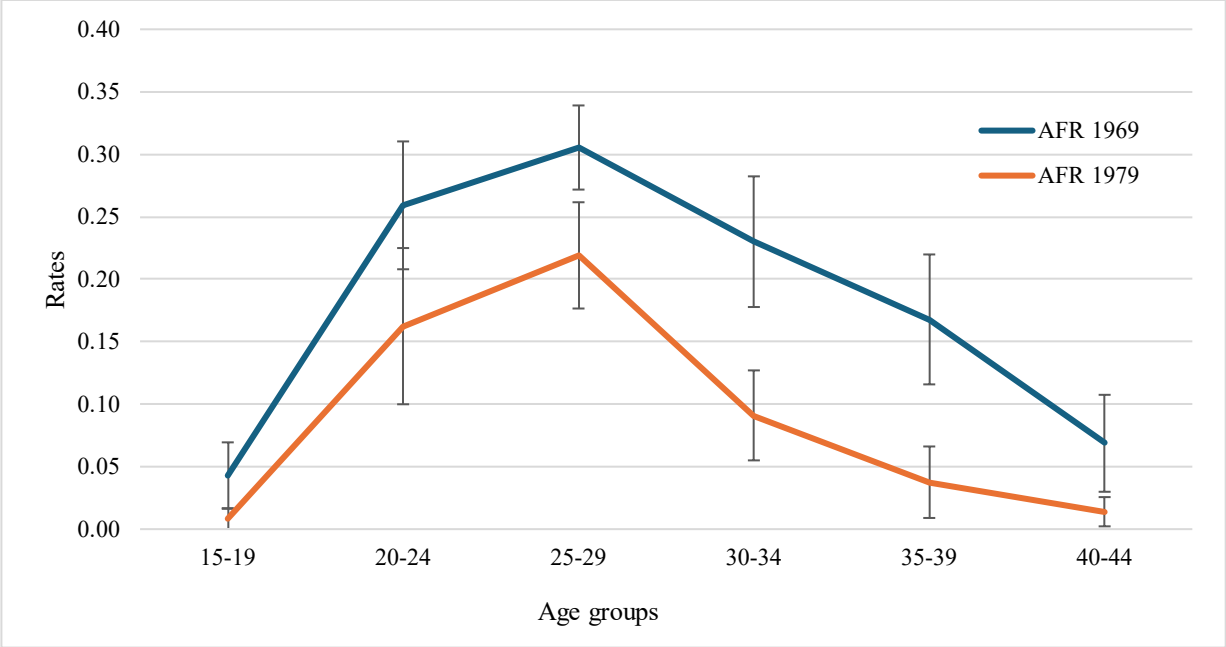

Figure 2.3 Age-specific fertility rates in 1969 and 1979 in study provinces of China

In Figure 2.4, we present the average exposure to three family planning policies between ages 15 and 45 by birth years. The left y-axis represents the years of exposure to LLFP or OCP, which are weighted by the provincial age-specific fertility rates prior to the initiation of each policy. The right y-axis gives the average exposure to OHCP measured in years. Overall, women born in later years tend to have higher exposure to each policy, though exposure plateaus among women born later due to being exposed over the full reproductive age range. Figure 2.5 shows average exposures to the family planning policies from age 15 to age 22 by birth years across different provinces, which shows similar trends as those found in Figure 2.4, but with less variations in absence of age-specific fertility rates adjustment.

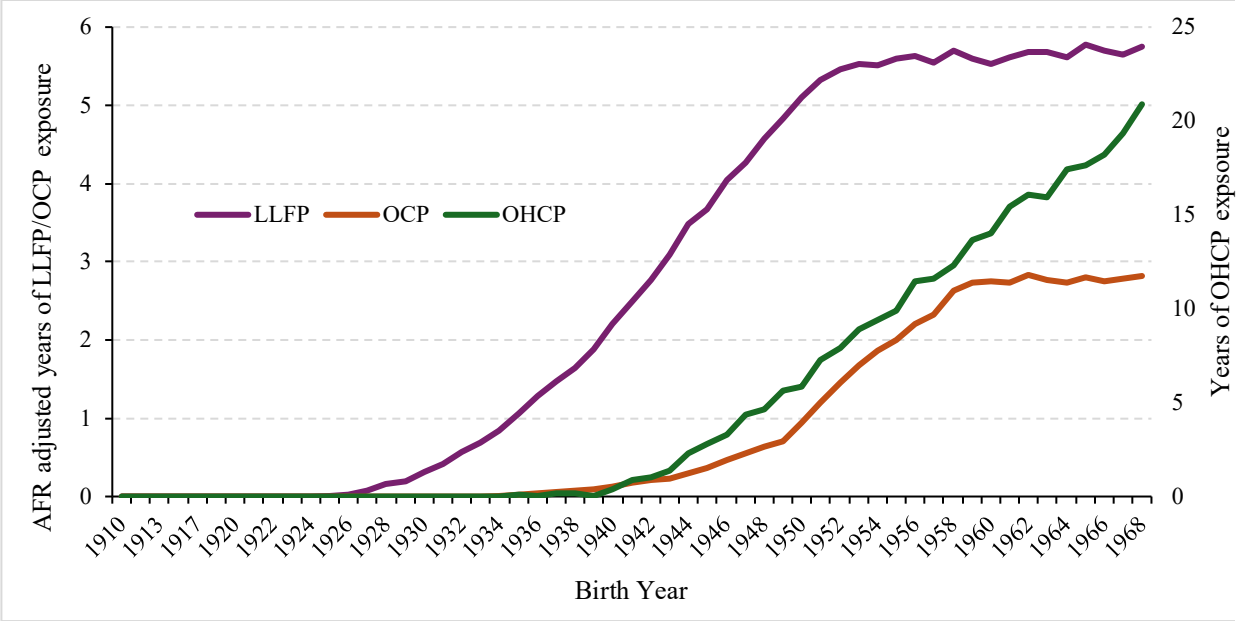

Figure 2.4 Policies exposure during reproductive ages (15-45 years)
Notes: AFR: age-specific fertility rate. LLFP: Later-Longer-Fewer Policy. OCP: One-Child Policy. OHCP: One-and-a-Half Child Policy.

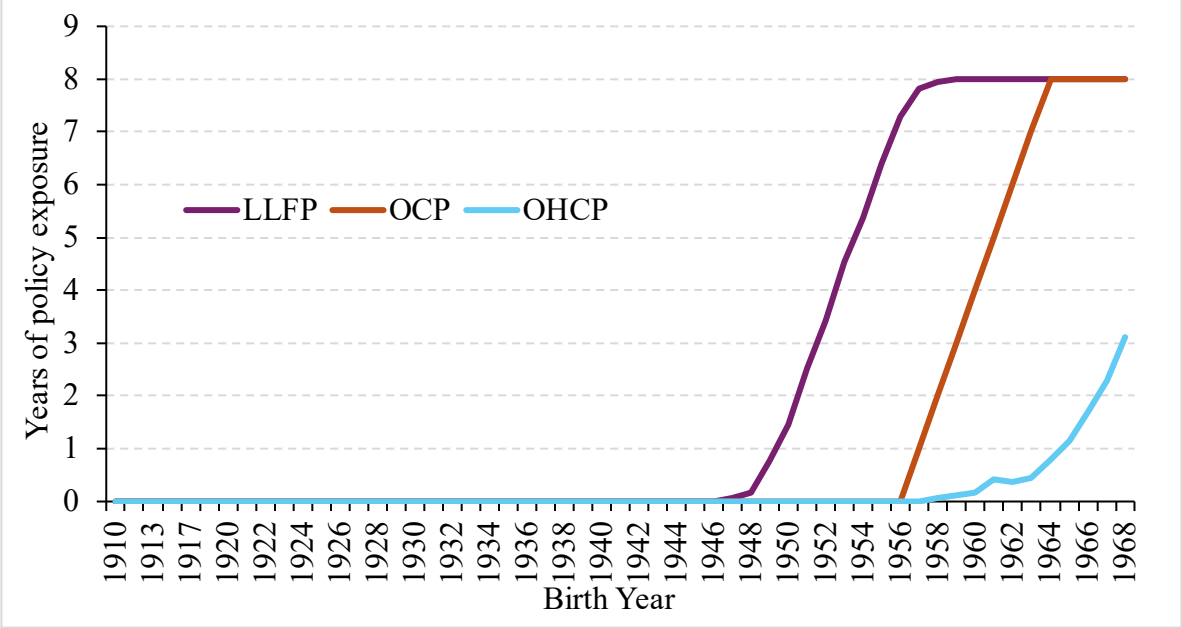

Figure 2.5 Years of policy exposure at ages 15-22
Notes: LLFP: Later-Longer-Fewer Policy. OCP: One-Child Policy. OHCP: One-and-a-Half Child Policy.

Table 2.1 presents descriptive statistics summarizing key characteristics of our sample. On average, exposure to LLFP, OCP, and OHCP in our sample were 25.4, 20.4 and 9.8 years, respectively.

Table 2.1 Descriptive characteristics of study participants in CHARLS 2011-2018

	Mean	S.D.	Observations
Time-invariant characteristics in 2011			
Policy exposures			
Age-specific fertility rate adjusted years of LLFP	4.73	1.66	8,024
Years of LLFP	25.40	7.47	8,024
Total fertility rate at province level in 1969	5.48	1.11	25
Age-specific fertility rate adjusted years of OCP	1.68	1.17	8,024
Years of OCP	20.35	9.17	8,024
Total fertility rate at province level in 1979	2.69	0.81	25
Years of OHCP	9.81	9.69	8,024
Rural residence in 1979	0.87	0.33	8,024
Years of LLFP at ages 15-22	4.61	3.53	8,024
Years of OCP at ages 15-22	2.50	3.32	8,024
Years of OHCP at ages 15-22	0.37	1.23	8,024
Early marriage	0.74	0.44	8,024
Fertility			
Number of births throughout lifetime	3.08	1.86	7,932
Number of induced abortions throughout lifetime	0.24	0.60	7,512
Education			
High school or higher degrees attainment	0.08	0.28	8,024
Covariates			
Rural residence at age 15	0.89	0.31	8,024
Time-changing characteristics between 2011 and 2018			
Mental health outcomes			
Depressive symptoms (0-30)	9.01	6.52	25,894
Impaired recall summary score (0-20)[1,2]	13.15	3.62	18,166
Impaired cognition orient (0-4)[2]	1.13	1.19	24,068
Self-reported memory (1 Excellent -- 5 Poor)	4.22	0.80	25,961
Current smoking	0.05	0.22	27,419
Drink once a day or more	0.02	0.15	27,501

Notes: LLFP: "Later-Longer-Fewer" policy; OCP: one-child policy; OHCP: One- and a half-child policy. S.D. standard deviation. [1] We only used data in 2011, 2013, and 2015 for the recall memory variable, because CHARLS 2018 used new words list and method to test recall memory, which potentially has bias among illiterate or rural older adults (The CHARLS Team, 2023). [2] We reversed the score so that a higher score indicates poorer cognitive function.

LLFP exposure has a greater value on average compared to OCP exposure because of more years of exposure, and higher age-specific fertility rates in 1969 compared to 1979. The average number of children per woman in their lifetime is approximately 3.1, with an average of 0.2 reported abortions. Early marriage was widespread among the study participants, with 74% of women getting married before reaching the age of 23. Educational attainment was generally low, as only a small percentage of female participants had completed high school or higher education, with just 8% holding a high school degree. Appendix Figure 2.1 shows how our demographic and mental health outcome variables vary by birth year in our sample. There is a strong year of birth trends in our outcomes, which we adjusted for in our analysis.

Approximately 89% of the participants resided in rural areas at the age of 15. Older women in the study reported facing multiple mental health challenges, with their average level of self-reported memory close to "poor". The prevalence of smoking and daily drinking among older Chinese women was relatively low.

Table 2.2 presents result of estimating the effects of family planning policies on older women demographic outcomes. The first part of the table gives coefficient estimates for the effects of the policies on the total number of births. Greater exposure to LLFP was associated with a reduction in the total number of births, and while exposure to OCP was also associated with fewer births, this association did not reach statistical significance. Furthermore, exposure to OHCP was linked to an increase in births. The Counterfactual estimates report the expected effect on births for a women exposed to the average level of policy exposure in the sample. Overall, we estimate the exposure to average level of each policy reduced fertility in the sample by 2.18 (95% CI: -2.52 to -1.83) children per woman. Most of the decrease was due to the LLFP, we estimated an average level of exposure to LLFP reduced births by 2.12 (95% CI: -2.41 to -1.84). The average exposure

to OCP is estimated to have further reduced the number of births by only 0.16 and the estimate is not statistically significant. The average exposure to the OHCP is estimated to have led to an increase in 0.11 (95% CI: 0.01 to 0.21) children in our sample.

The rest of Table 2.2 provides estimates for the effect of exposure to the policies on reported abortions, educational attainment, and early marriage. The abortion effects of the policies are in general not well determined, perhaps due to measurement errors in abortion reporting.

We found that overall, an average exposure to each family planning policy combined in China were estimated to raise the probability a women graduated from high school by 0.06 (95% CI: 0.04, 0.07), with most of the effect being due to the LLFP, while the OHCP was associated with a slight reduction in the likelihood of high school completion. We found a substantial reduction in early marriage (before age 23) in women exposed to an average level of LLFP up to age 23, a decrease in the probability by 0.15 (95% CI: -0.18, -0.12). The OCP reversed this move to later marriage to a large extent, increasing the probability of early marriage by 0.08 (95%CI: 0.06, 0.09), suggesting a shift to emphasizing the lower fertility target rather than late marriage. The results for the counterfactual outcomes in Table 2.2 are presented graphically in Figure 2.6.

Table 2.2 Family planning policies and demographic outcomes

	Coefficients	95% Confidence Interval
Number of births		
LLFP exposure	-0.45***	(-0.51, -0.39)
OCP exposure	-0.1	(-0.22, 0.02)
OHCP exposure	0.01*	(0.001, 0.02)
Counterfactual		
Average policy exposures	-2.18***	(-2.52, -1.83)
Average level exposure to LLFP	-2.12***	(-2.41, -1.84)
Average level exposure to OCP	-0.16	(-0.37, 0.04)
Average level exposure to OHCP	0.11*	(0.01, 0.21)
Number of abortions		
LLFP exposure	-0.01	(-0.03, 0.01)
OCP exposure	0.01	(-0.03, 0.04)
OHCP exposure	-0.01	(-0.01, 0.0005)
Counterfactual		
Average policy exposures	-0.11	(-0.24, 0.03)
Average level exposure to LLFP	-0.06	(-0.16, 0.03)
Average level exposure to OCP	0.01	(-0.06, 0.08)
Average level exposure to OHCP	-0.05	(-0.11, 0.005)
High school education and above		
LLFP exposure	0.01***	(0.01, 0.02)
OCP exposure	0.01**	(0.002, 0.01)
OHCP exposure	-0.03***	(-0.03, -0.02)
Counterfactual		
Average policy exposures	0.06***	(0.04, 0.07)
Average level exposure to LLFP	0.05***	(0.04, 0.07)
Average level exposure to OCP	0.01**	(0.01, 0.02)
Average level exposure to OHCP	-0.01***	(-0.01, -0.01)
Early marriage		
LLFP exposure	-0.03***	(-0.04, -0.03)
OCP exposure	0.03***	(0.03, 0.04)
OHCP exposure	0.01	(-0.01, 0.02)
Counterfactual		
Average policy exposures	-0.07***	(-0.11, -0.04)
Average level exposure to LLFP	-0.15***	(-0.18, -0.12)
Average level exposure to OCP	0.08***	(0.06, 0.09)
Average level exposure to OHCP	0.002	(-0.004, 0.01)

*Notes: ***p<0.001, **p<0.01, *p<0.05. Linear regression models were used and additionally controlled for fixed effects of province and province-specific linear effect of year of birth. Community-level cluster-robust standard errors were applied. Totally there are 414 communities. Policies exposure for birth and abortion outcomes refer to exposure during whole reproductive ages from age 15 to age 45. Policies exposures for education and early marriage outcomes refer to exposure during ages 15-22.*

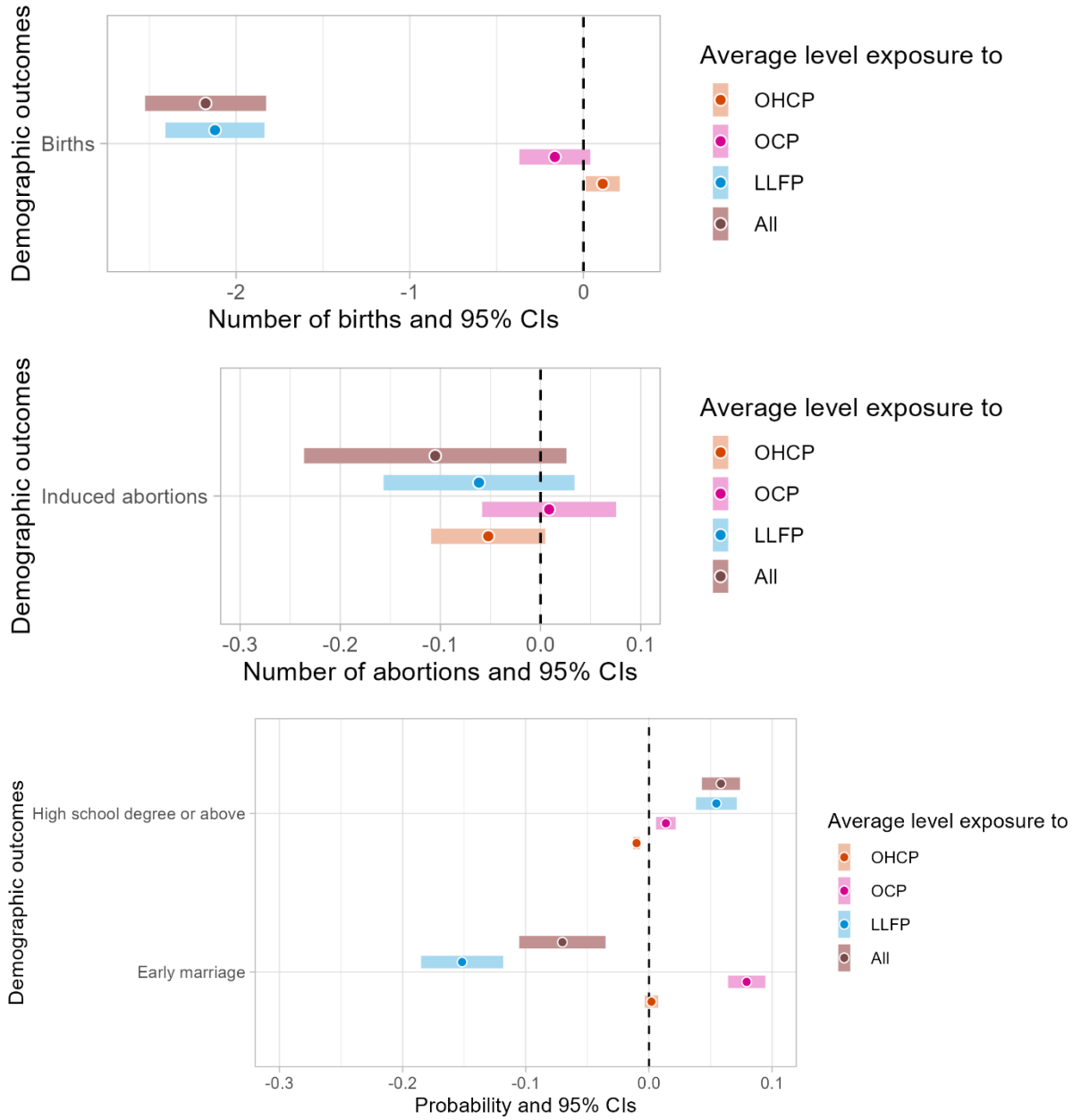

Figure 2.6 Average exposure to fertility policies and demographic outcomes

Notes: All refers to all types of fertility policies, including the later-longer-fewer policy (LLFP), the One-Child Policy (OCP), and One-and-a-Half-Child Policy (OHCP). Average level exposure to ALL types of policies refers to an average exposure to each type of fertility policy. Each outcome was based on a linear regression model, controlling rural hukou status at age 15, fixed effect of provinces, and province-specific linear trend of birth cohorts. Standard errors accounted for community clusters. Average levels exposure to LLFP, OCP, and OHCP between ages 15 and 45 respectively are 4.7 years adjusted for baseline fertility rates, 1.7 years adjusted for baseline fertility rates, and 9.8 years, which were used for births and abortion outcomes. Average levels exposure to LLFP, OCP, and OHCP between ages 15 and 22 respectively are 4.6 years, 2.5 years, and 0.4 years, which were used for education and early marriage outcomes.

Table 2.3 and Figure 2.7 report our estimates of the effects of family planning policies on mental health outcomes. In order to facilitate meaningful comparisons, we standardized the health outcome measures with a standard deviation of one and mean value of zero. We again focused on the counterfactual outcome estimates, the effect of the average level of policy exposure in the sample relative to a counterfactual of no exposure.

Exposure to the policies overall raised depressive symptoms by 0.46 standard deviations (95% CI: 0.28, 0.63), with most of the effect coming from the LLFP. Surprisingly, exposure to the OHCP also raised depressive symptoms, despite its effect on fertility, education, and early marriage going in the opposite direction compared to the effects from the LLFP. Similarly, we found that overall exposure to the family planning policies was associated with worse outcomes for recall scores, orientation self-reported memory. In particular we found that exposure to OHCP was associated with worsened outcomes for all three cognitive function measures. We found evidence that exposure to the OCP was associated with reduced smoking among our sample of older women. However, we found no clear association between the other policy exposures and either smoking or drinking.

Table 2.3 Family planning policies and mental health outcomes

	Coefficients	95% Confidence Interval
Depressive symptoms		
LLFP exposure	0.08***	(0.06, 0.11)
OCP exposure	-0.01	(-0.07, 0.05)
OHCP exposure	0.01**	(0.002, 0.01)
Counterfactual		
Average policy exposures	0.46***	(0.28, 0.63)
Average level exposure to LLFP	0.39***	(0.26, 0.52)
Average level exposure to OCP	-0.01	(-0.11, 0.09)
Average level exposure to OHCP	0.08**	(0.02, 0.13)
Impaired recall summary score		
LLFP exposure	-0.01	(-0.03, 0.02)
OCP exposure	0.05	(-0.002, 0.1)
OHCP exposure	0.01***	(0.01, 0.02)
Counterfactual		
Average policy exposures	0.18*	(0.02, 0.34)
Average level exposure to LLFP	-0.04	(-0.16, 0.08)
Average level exposure to OCP	0.08	(-0.003, 0.17)
Average level exposure to OHCP	0.14***	(0.09, 0.19)
Impaired cognition orient (summary date naming)		
LLFP exposure	0.02	(-0.01, 0.05)
OCP exposure	0.12***	(0.06, 0.17)
OHCP exposure	0.01*	(0.001, 0.01)
Counterfactual		
Average policy exposures	0.34***	(0.17, 0.51)
Average level exposure to LLFP	0.08	(-0.05, 0.21)
Average level exposure to OCP	0.19***	(0.1, 0.28)
Average level exposure to OHCP	0.06*	(0.01, 0.11)
Self-reported memory (1 Excellent -- 5 Poor)		
LLFP exposure	0.04**	(0.02, 0.07)
OCP exposure	0.01	(-0.04, 0.05)
OHCP exposure	0.01**	(0.004, 0.01)
Counterfactual		
Average policy exposures	0.29***	(0.14, 0.44)
Average level exposure to LLFP	0.2**	(0.08, 0.31)
Average level exposure to OCP	0.01	(-0.07, 0.09)
Average level exposure to OHCP	0.08**	(0.03, 0.13)
Current smoking		
LLFP exposure	0.01	(-0.01, 0.02)
OCP exposure	-0.05***	(-0.08, -0.02)
OHCP exposure	0.002	(-0.002, 0.005)
Counterfactual		
Average policy exposures	-0.05	(-0.13, 0.04)

Average level exposure to LLFP	0.03	(-0.05, 0.1)
Average level exposure to OCP	-0.09***	(-0.14, -0.04)
Average level exposure to OHCP	0.02	(-0.01, 0.05)
Drink once a day or more		
LLFP exposure	0.01	(0, 0.02)
OCP exposure	-0.01	(-0.03, 0.01)
OHCP exposure	0.00001	(-0.002, 0.002)
Counterfactual		
Average policy exposures	0.03	(-0.04, 0.09)
Average level exposure to LLFP	0.05	(-0.01, 0.1)
Average level exposure to OCP	-0.02	(-0.05, 0.02)
Average level exposure to OHCP	0.0001	(-0.02, 0.02)

*Notes: ***p<0.001, **p<0.01, *p<0.05. Linear regression models were used and additionally controlled for fixed effects of province and province-specific linear effect of year of birth. Community-level cluster-robust standard errors were applied. Totally there are 414 communities. Policies exposure for birth and abortion outcomes refer to exposure during whole reproductive ages from age 15 to age 45. Policies exposures for education and early marriage outcomes refer to exposure during ages 15-22.*

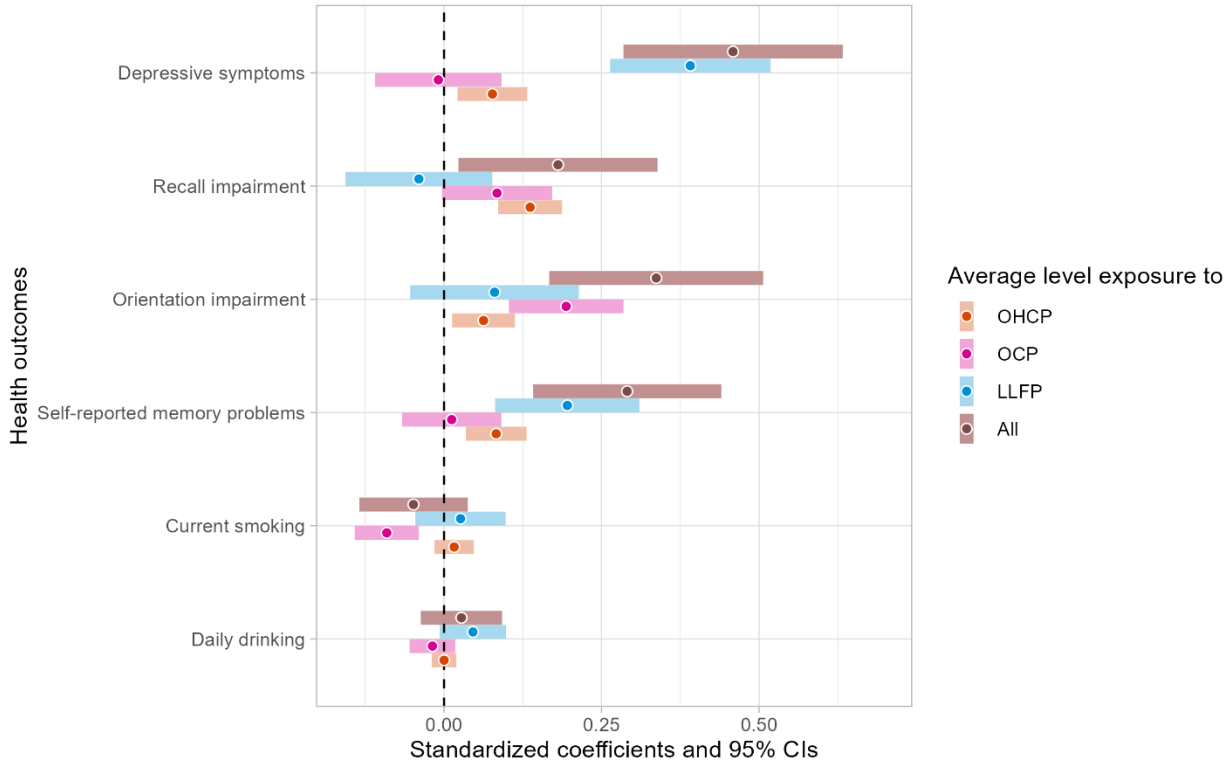

Figure 2.7 Average exposure to fertility policies and mental health outcomes

Notes: All refers to all types of fertility policies, including the later-longer-fewer policy (LLFP), the One-Child Policy (OCP), and One-and-a-Half-Child Policy (OHCP). Average level exposure to ALL types of policies refers to an average exposure to each type of fertility policy. Each outcome was based on a Generalized Least Squares (GLS) random-effects (RE) model, controlling rural hukou status at age 15, fixed effect of provinces, and province-specific linear trend of birth cohorts. Standard errors accounted for community clusters. Average levels exposure to LLFP, OCP, and OHCP between ages 15 and 45 respectively are 4.7 years adjusted for baseline fertility rates, 1.7 years adjusted for baseline fertility rates, and 9.8 years.

2.6 Discussion

This study shows a strong association between exposure to family planning policies in China and women's mental health during their post-reproductive years. Greater exposure to LLFP and OHCP separately increased women's depressive symptoms, recall impairment, and memory problems. Women exposed to OCP reported a higher level of orientation impairment and were less likely to smoke.

Our findings regarding family planning policy exposures and demographic outcomes align with previous studies (Gu et al. 2007; Huang, Lei, and Sun 2021; Zhang 2017; Y. Chen and Fang 2021; Whyte, Wang, and Cai 2015). This alignment supports the validity of our measures of family planning policies and also provides understanding of the mechanisms linking family planning policies and mental health outcomes in later life.

Exposure to LLFP reduced women's lifetime births in our sample and their likelihood of getting married early while increased their chance of having at least a high school degree. Exposure to OCP increased women's likelihood of getting a high school degree or above while also increasing women's chance of being married early. Exposure to OHCP was associated with increased births, while reducing women's likelihood of having a high school degree or above. Despite the fact that the OHCP relaxed fertility controls relative to the OCP, and moved the number births, and educational attainment, in the opposite direction than the LLFP and OCP, it was also associated, like them, with worse mental health outcomes. This suggests that not all of the effect of the policy is mediated through the demographic outcomes we measure.

Our finding that exposure to the LLFP is associated with later life depressive symptoms in women is consistent with existing literature (Y. Chen and Fang 2021). Our study further found exposure to LLFP also increased women's cognitive impairment (e.g. recall impairment and self-

reported memory problems). We went further than Chen and Fang's study (Y. Chen and Fang 2021) and examined the effect of the OCP and OHCP.

A major difference in our approach relative to the existing literature is that we estimated the effect of exposure to family planning policies directly on later life mental health, without the common assumption that all the effect on later life health is due to changes in a woman's total births. For example, Chen and Fang's study (Y. Chen and Fang 2021) employed an instrumental variable (IV) approach to investigate the relationship between the number of children and older people's well-being assuming that all of the effect of the LLFP on older peoples outcomes was through the effect on the number of children. Another study (Islam and Smyth 2015) estimated the effect of the OHCP on health outcomes in later life, again using an instrumental variable (IV) approach assuming that all of the effect goes through the number of children born. They found the OHCP led to increased births and then worsened self-reported health, but with no significant impact on their mental health measure. Another study (Mu and Xie 2014) , again employed the instrumental variable approach to explore the relationship between the number of children and parental well-being, but focused on younger parents (ages between 20 and 50), and found that OHCP was associated with more births, and this was then linked to improved parental subjective well-being.

Our study's finding on the association of policy exposure with multiple demographic outcomes suggests that using an Instrumental variable (IV) approach, assuming that family planning policies affect later life outcomes only through fertility, which is dominant in the literature, may not be appropriate for analyzing the impact of family planning on mental health in later life.

Our study has several limitations. Firstly, we used the year of introduction of major policies to define province level family planning policies. However, family planning policies in China also

had more local variations over time in the intensity of administrative and legal enforcement, such as the size of financial penalties for an above-quota birth, which we do not investigate. Secondly, our approach is to use province level fixed effects and time trends to identify what would have happened without the policies. This counterfactual is complicated by the fact that the timing of the family planning policies overlapped with China's economic reform initiatives and changes to the educational system (Zhang 2017) and there is a potential that the timing of family planning policies at the province level may have been correlated with the timing of other reforms. Thirdly, there might be other mechanisms, such as divorce, labor force participation, and migration (Y. Chen and Zhao 2022; Zhang 2017), that may also play a role, but these are beyond the scope of this analysis. In addition, the experience of the policies might also affect mental health directly. Further studies should investigate whether population policies disproportionally affect disadvantaged groups, such as parents who have lost their only adult child and are unlikely to have another birth later in life.

Finally, this analysis may have limited application outside China. The family planning policies in China particularly the OCP, were more coercive than in other countries, with forced contraception use and abortion, and large financial penalties for breaking fertility limits, though there is some evidence of unwanted family planning in other settings as well (Canning and Karra 2023). However, our results do suggest that exposure to these coercive policies had negative effect on the mental health of women at older ages, adding a positive benefit to a rights-based approach to family planning that recognizes the importance of free and informed choice of contraception by women.

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3 Completed fertility and women's physical health in later life - evidence from India

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3.1 Abstract

Childbirth imposes significant physical stress on women during both pregnancy and the postpartum period. However, the long-term effects of childbirth on women's physical health in older age remain understudied, and research in this area is often complicated by confounding variables. Using data from the Longitudinal Aging Study in India (LASI), conducted between 2017 and 2019, we investigated the long-term health implications of completed fertility. To address the issue of unmeasured confounding, we employed a two-stage least squares approach, using the sex of the first-born child as an instrumental variable, to estimate the effects on various physical health measures. On average, Indian women had 4.2 births, with those having a first-born daughter showing higher completed fertility compared to those with a first-born son (0.304 higher, 95% CI: 0.258 to 0.349). Each additional birth correlates with reduced grip strength (by 0.081 standard deviations, 95% CI: -0.149 to -0.014), lower body mass index (by 0.076 standard deviations, 95% CI: -0.145 to -0.007), and decreased likelihood of being overweight (by 0.044 standard deviations, 95% CI: -0.082 to -0.005) among mothers, particularly those without schooling. No association of fertility with blood pressure was observed. For fathers, completed fertility showed weaker associations with physical health, although there was a lower waist-hip

ratio associated with higher fertility. Findings of this study highlight the importance of managing birth-related physical health issues well beyond the postpartum period.

3.2 Introduction

Older women in India face multiple physical health challenges. Among older Indian adults, approximately 20% are underweight, while over 40% are overweight or obese (Pengpid and Peltzer 2021). Obesity is notably more prevalent among older Indian women (26.3%) compared to men (17.6%) (Muhammad et al. 2022), with no significant sex difference in underweight prevalence (Singh and Chattopadhyay 2023). Additionally, after the age of 60, about 51% of older Indian women experience hypertension, a rate 6% higher than that of their male counterparts (Mohammad and Bansod 2024).

Physical health, such as blood pressure, body mass index, are closely associated with older adults' well-being. High systolic blood pressure and high body mass index are leading risk factors of death and disability globally (Brauer et al. 2024). High blood pressure is highly predictive of cardiovascular disease (Fuchs and Whelton 2020; Francula-Zaninovic and Nola 2018), dementia (de Heus et al. 2021), and mortality (Li et al. 2022). Body mass index (BMI) has been consistently associated with mortality among older adults (Winter et al. 2014) and recent evidence indicates that waist-hip ratio may serve as a superior predictor of mortality compared to BMI (Khan et al. 2023). Significant gender differences exist in physical health measures, especially among older adults. After age 50, the incidence of hypertension increases more sharply in women than in men (Connelly, Currie, and Delles 2022). This trend is particularly evident in India, where older women have much higher rates of hypertension(Chauhan et al. 2022) and obesity (Muhammad et al. 2022) compared to older men. There is a lack of studies on

sex-specific factors, such as childbirth, that are associated with blood pressure, BMI, and other physical health measures, particularly in low- and middle-income countries, such as India.

Childbirth brings mothers significant physical health stress during pregnancy and postpartum period (Woolhouse et al. 2014). Current evidence from western countries revealed that completed fertility has been found to have a lasting impact on women's physical health well beyond the postpartum period. The indirect cost of reproduction, measured by the metabolic load of bearing the offspring, is much larger than the direct cost - the energy content of offspring (Ginther et al. 2024). There are both biological and psychosocial mechanisms linking births and parental physical health. Biologically, higher parity are associated with an elevated level of allostatic load in both fathers and mothers, which serves as a marker of systemic physical dysregulation stemming from chronic diseases, consequently elevating the risk of long-term illnesses (Grundy and Read 2015). On a psychosocial level, the experience of childbearing introduces both stress and potential health benefits. Parenthood can be stressful due to the financial and emotional demands of raising a child. However, it can also motivate parents to adapt healthier behaviors and provides a source of social interaction and support (Umberson et al. 2011). One study revealed that parents with a higher number of children exhibited lower mortality rates attributed to alcohol-related causes, although fathers with greater parity displayed elevated mortality rates due to accidents and violence (Grundy and Kravdal 2010). In comparison to men, women experience a disproportionate burden on their health due to childbirth. Previous research suggests that accounting for obesity and metabolic risk factors can mitigate the associations between higher birth rates and coronary heart disease risks among fathers, but not among mothers (Lawlor et al. 2003).

A previous study in India provided evidence that greater parity is associated with reduced systolic and diastolic blood pressure in mothers more than a decade after giving birth (Teufel et al. 2021), and even when mothers reached the age of 50 (Haug et al. 2018). Childbirths are also associated other physical measures for women in the long term. Weight gain during pregnancy is independently associated with mothers' greater BMI and overweight even more than two decades following pregnancy (Mamun et al. 2010). Mothers with increased births may also experience lower high-density lipoprotein cholesterol, higher triglyceride levels, increased diabetes prevalence, and reduced grip strength in their older adulthood (Lawlor et al. 2003; Zoet et al. 2019; Keenan and Grundy 2019). In addition to its effects on women, high fertility has been linked to elevated BMI, waist-hip ratio, obesity, and overall poorer physical health in both older men and women (Lawlor et al. 2003; Hardy et al. 2007; Sironi, Ploubidis, and Grundy 2020; O'Flaherty et al. 2016).

Most of the studies cited have been conducted in high-income countries, with limited evidence available from low- and middle-income countries (Weng and Yang 2023). Fertility levels are typically higher in LMICs, such as India, which provides an opportunity to explore a dose-response relationship between completed fertility and women's physical health. Compared to parents in high-income countries, parents in LMICs may have different desired fertility based on children's sex composition and number (Bonsang and Skirbekk 2022; Teufel et al. 2021), and they are more likely to face resource constraints in raising their children. These contextual differences raise questions about whether findings from high-income countries are applicable in LMICs.

In addition, the relationship between childbirth and women's physical health is susceptible for omitted confounders, which may make the findings biased. For example, the health status of

women in their early life, could potentially impacting both childbirth and subsequent physical health outcomes, is usually unmeasured in aging surveys that recruit participants at their older ages.

In this paper we use data from the Longitudinal Aging Study in India (LASI) to study complete fertility and women's physical health in later life. In addition to selecting blood pressure, BMI, and waist-hip ratio as measurement of physical health, we also include grip strength. Grip strength, a common measure of physical health in many aging surveys, exhibits a stronger correlation with markers of aging compared to chronological age (Syddall et al. 2003). Grip strength is associated with various concurrent health indicators and predictive for health outcomes in the future, including overall strength, fractures, falls, malnutrition, cognitive impairment, depression, diabetes, and multimorbidity (Bohannon 2019; Celis-Morales et al. 2018). Moreover, the association between grip strength and health outcomes tends to be more pronounced in women (Celis-Morales et al. 2018; Hong and Kim 2021). Particularly in India, grip strength is proved as an important indicator of frailty for both older men and women (Das and Prasad 2023). All these physical health indicators are modifiable or manageable.

To overcome the potential issue of omitted confounders, we use an instrumental variable approach (Greenland 2000). India is known for its strong preference for male children, which often leads couples with a daughter as their firstborn to continue having children until they have a son (Jayachandran and Kuziemko 2011). In this study, we employed the first-born being a daughter as an instrumental variable (IV) to explore the causal relationship between childbirth and women's physical health in the Indian context. This instrumental variable approach has been used in a number of related studies of the effects of fertility on health at older ages(Greenland 2000; van den Broek and Fleischmann 2021; Weng and Yang 2023).

3.3 Methods

Data and measurement

We used data from the Longitudinal Aging Study in India (LASI), which is a nationally representative panel survey for community-living older adults aged 45 and beyond in India (Perianayagam et al. 2022). LASI adopted a multistage stratified area probability cluster sampling design, with rural and urban areas as strata, sub-districts-tehsils as primary sampling units, and villages or urban wards as secondary sampling units (SSUs); Within each SSU, eligible individuals were those living in households who were 45 years or older and their spouses, regardless of age; LASI completed its baseline data collection of 72,262 individuals between 2017 and 2019 (Perianayagam et al. 2022) which made LASI the largest national health and retirement study in the world (Bloom, Sekher, and Lee 2021). We used harmonized LASI 2017-2019 data version A.2 developed by the Gateway to Global Aging Data (Chien et al. 2021) .

Our study sample is women and men who had completed their fertility and had at least one biological child. Among 72,262 individuals, we excluded 1) 6,597 women aged less than 45, and 5,027 men aged less than 49, to focus on respondents with a complete fertility history; 2) 648 respondents with missingness in total biological children; 3) 2,092 respondents with zero biological children; 4) 776 respondents with adopted children; 5) 571 respondents with their first-born not as a singleton; 6) 221 respondents with missingness in the sex of the first born and 2 respondents with missingness in covariates; and 7) 4,455 respondents did not participate in the physical health assessment. As a result, our study sample included 30,065 women and 21,808 men.

LASI has a set of physical health measures obtained from performance-based assessments, including systolic blood pressure, diastolic blood pressure, waist-hip ratio, body mass index (BMI), and grip strength. Based on those measures, we further created three binary health indicators, including high blood pressure, underweight, and overweight or obesity, with more clinical implications.

An Omron HEM-7121 Monitor was used to measure participants' blood pressure three times with a one-minute gap between each of the three measurements. We used the average values of the systolic reading and diastolic reading from the second and the third time of measurement. We further used the Indian guidelines on hypertension (Shah et al. 2020) to define high blood pressure for participants whose systolic blood pressure and/or diastolic blood pressure were 140 mm Hg or beyond, or 90 mm Hg or beyond, respectively.

A soft measuring tape was used to measure participants' waist circumference and hip circumference. Height, weight, waist, and hip circumference were each measured once. BMI was calculated by dividing the participant's weight (kg) by the squared value of their height (m). Based on the World Health Organization's definition, we further defined underweight as those whose BMI was less than 18.5 and used participants with a normal weight as the reference group. We defined overweight or obese as those whose BMI was 25 or more, and also used participants with a normal weight as the reference group (Chien et al. 2021).

A Smedley's hand dynamometer was used to conduct grip strength tests. Participants were asked to conduct the test four times, with each hand performing twice. We used the maximum hand strength measurement of the dominant hand as the grip strength measure.

Methodology

To explore the study relationship, we conducted separate statistical analyses on mothers and fathers' samples. We first utilized Ordinary Least Squares (OLS) regression analysis, regressing each health outcome against the number of children, assuming a linear relationship. Our OLS regression models also controlled basic demographic variables, including mothers' current age, years of schooling, residential status (rural or urban), religion, and residence states. Additionally, e accounted for clustering at the community level (villages or urban wards) for robust standard errors.

Subsequently, to address the endogeneity concern, we conducted an Instrumental Variable (IV) analysis using Two-Stage Least Squares (2SLS) regressions. In the first stage of the IV analysis, we regressed total number of births on the binary variable – first-born as a daughter, with the same controls used in the OLS regression. In the second stage of the IV analysis, we regressed each physical health measure on the predicted parity from the first stage, again employing the same controls. In both OLS regressions and IV analyses, we standardized health outcomes into values with a mean at zero and a standard deviation at one, except for three binary outcomes. This standardization ensures comparability of the effect sizes of parity across various outcomes. We replicated the above analysis using a sample of fathers; for fathers we may see the effect of raising children but not the effects of pregnancy and childbirth.

In India, social economic resources are closely related to the health of childbirth and uptake of maternal health care. Women with lower education are more likely to have a low birth weight birth (Kader and Perera 2014), and poor women are less likely to utilize maternal health care, such as prenatal care and skilled birth attendance (Pathak, Singh, and Subramanian 2010). The economic burden of raising the same number of children may vary significantly depending on a family's socioeconomic resources, which, in turn, may have different implications for mothers'

physical health in later life. To assess whether the study association varies among families with different economic resources, we conducted a subgroup analysis based on mothers' schooling levels (e.g., no schooling versus some schooling), which serves as an indicator of families' pre-birth economic resources. To examine whether the study association statistically different according to mothers' education level, we added an interaction term between the sex of the first-born and mothers' education level as an additional IV and added another interaction term between total births and mothers' education level as an additional endogenous variable. Finally, we conducted one sensitivity analysis that excluded women with a history of abortion. This will help mitigate the threat that the sex of the first child is not random due to sex selective abortions. We also conducted another sensitivity analysis by excluding women whose first-born dead under age 5. This will avoid the impact of the sex of the first-born on maternal physical health via replacement fertility rather than additional births.

Identification strategy

The IV approach requires four assumptions, relevance, exclusion, independence and monotonicity (Greenland 2000).

Relevance assumption: the instrumental variable (the first-born child being a daughter) is presumed to be closely associated with the total number of births. The first-stage IV analysis that explains total births using the sex of the first child will reveal the correlation. A substantial or statistically significant regression coefficient in this analysis would provide confidence that the chosen instrumental variable satisfies the relevance assumption.

Exclusion restriction: the instrumental variable (the first-born being a daughter) is expected to influence the outcome (physical health biomarkers) solely through total parity. This assumption

is not testable, and we must rely on intuition. We think that the biological effects of childbirth are similar for each sex. However, there are potential pathways that may link the sex of the first-born to mothers' physical health in later life. In India, daughters typically leave their parental home upon marriage, limiting ongoing support, while parents with sons may receive more assistance in later years, possibly leading to better health outcomes. Moreover, the tradition of providing dowries for daughters' marriages can strain parental resources, impacting their own health. Thus, having a first-born son in India may correlate with increased parental support and reduced dowry expenses, potentially improving parental health. We can address this, to some extent, by our parallel analysis of effects in fathers. Fathers will not be influenced by the pregnancy or childbirth itself. If this analysis shows no significant influence of births on fathers' health, it suggests a distinct biological mechanism, such as the cumulative effect of pregnancies, specifically linking childbirths, rather than child rearing, to mothers' long-term health outcomes.

Independence assumption: The relationship between the sex of the first-born child being a daughter and physical health measures is expected to be free from shared underlying causes. Typically, the sex of the first-born child is determined randomly. Nevertheless, the availability of fetal sex diagnosis methods may lead to an increased incidence of female fetal abortions, resulting in a higher proportion of male births. Simultaneously, the act of abortion itself may have adverse consequences for women's health and potentially contribute to reduced physical health. To mitigate this potential bias, we report a sensitivity analysis excluding women with a history of abortion.

Monotonicity assumption: the instrumental variable affects treatment status for all individuals in the same direction. The societal norms favoring sons in India suggest that individuals are more

likely to continue having children if the first-born is a daughter, aligning with the direction of the instrument.

3.4 Results

Table 3.1 outlines the characteristics of mothers categorized by their first child's sex. The majority had a son as their first-born. The average age of women in our sample is 59.3 years. Mothers with a first-born daughter generally have more years of schooling. Most mothers are Hindu and live in rural areas, with few having had abortions. The proportion of first-born children who died before the age of 5 is higher among mothers whose first-born is a daughter (7.5%) compared to those whose first-born is a son (6.4%). On average, mothers had 4.2 births, with those having a daughter as the first-born tending to have more. Despite sex differences in births, mothers show similar physical health distributions, although those with a daughter as the first-born exhibit slightly weaker grip strength and lower rates of high blood pressure, being underweight, or overweight. Appendix Table 3.1 presents similar characteristics for fathers.

Table 3.1 Descriptive characteristics of mothers by the sex of the first-born

	Son (N=17,723)	Daughter (N=12,342)	Total (N=30,065)
Age in years	59.5 (10.5)	59.0 (10.4)	59.3 (10.5)
Years of education	2.7 (4.1)	3.0 (4.3)	2.8 (4.2)
Religion			
Hindu	13,155 (74.2%)	8,962 (72.6%)	22,117 (73.6%)
Muslim	2,123 (12.0%)	1,556 (12.6%)	3,679 (12.2%)
Christian	1,625 (9.2%)	1,298 (10.5%)	2,923 (9.7%)
Other	820 (4.6%)	526 (4.3%)	1,346 (4.5%)
Place of residence			
Urban	6,062 (34.2%)	4,418 (35.8%)	10,480 (34.9%)
Rural	11,661 (65.8%)	7,924 (64.2%)	19,585 (65.1%)
Ever had an abortion			
No	17,325 (97.8%)	12,042 (97.6%)	29,367 (97.7%)
Yes	398 (2.2%)	300 (2.4%)	698 (2.3%)
The first-born dead under age 5			
No	16,586 (93.6%)	11,412 (92.5%)	27,998 (93.1%)
Yes	1,137 (6.4%)	930 (7.5%)	2,067 (6.9%)
Total number of births	4.1 (2.2)	4.3 (2.2)	4.2 (2.2)

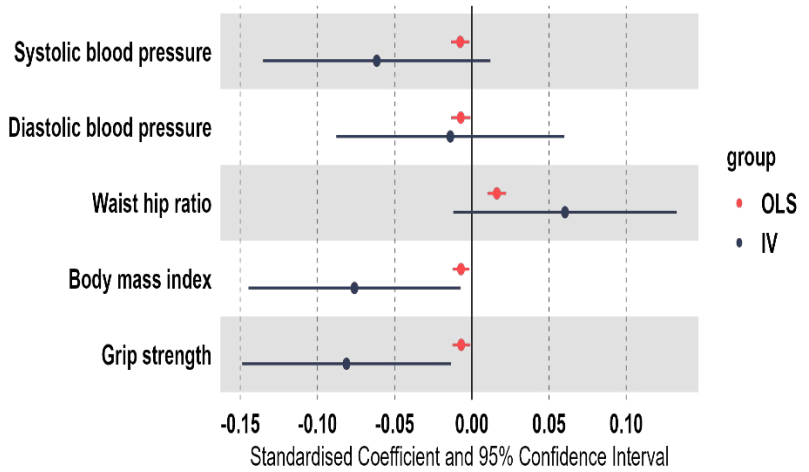
Systolic blood pressure (mm Hg)	129.2 (19.6)	128.8 (19.6)	129.0 (19.6)
Diastolic blood pressure (mm Hg)	81.0 (10.3)	81.2 (10.3)	81.1 (10.3)
Waist hip ratio	0.9 (0.1)	0.9 (0.1)	0.9 (0.1)
Body mass index	23.3 (5.2)	23.3 (5.1)	23.3 (5.1)
Grip strength (kilograms)	18.8 (5.6)	18.7 (5.6)	18.8 (5.6)
High blood pressure			
No	11,875 (67.1%)	8,306 (67.4%)	20,181 (67.2%)
Yes	5,824 (32.9%)	4,020 (32.6%)	9,844 (32.8%)
Underweight			
No	8,410 (72.5%)	5,950 (73.6%)	14,360 (72.9%)
Yes	3,193 (27.5%)	2,137 (26.4%)	5,330 (27.1%)
Overweight			
No	8,410 (58.6%)	5,950 (59.1%)	14,360 (58.8%)
Yes	5,943 (41.4%)	4,120 (40.9%)	10,063 (41.2%)

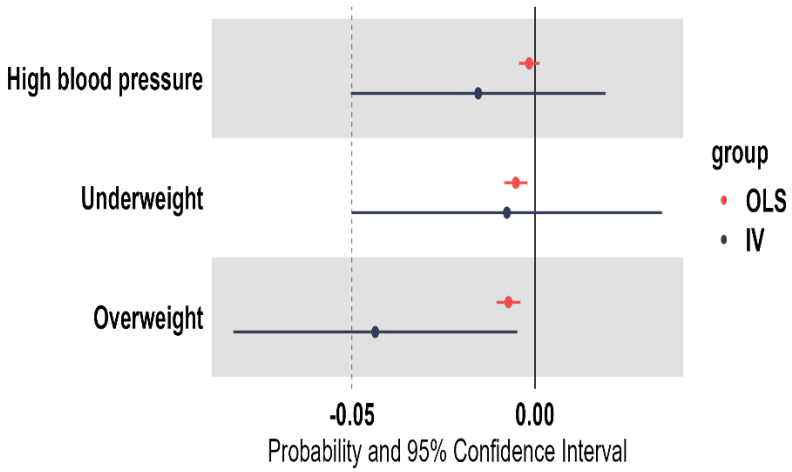
Note: standard deviations for continuous variables are in parentheses.

OLS regression analysis reveals a statistically significant relationship between the number of births and almost all measures of mothers' physical health, except high blood pressure (Figure 3.1 and Table 3.2). Greater parity is associated with reduced systolic and diastolic blood pressure. Every one birth increase is associated with 0.008 (95% CI: -0.014, -0.002) standard deviation decrease in systolic blood pressure, and 0.007 (95% CI: -0.013, -0.001) standard deviation decrease in diastolic blood pressure; while increased number of births is not associated with risks of high blood pressure. Per birth increase is associated with 0.016 (95% CI: 0.01, 0.022) standard deviation increase in waist hip ratio, and 0.007 (95% CI; -0.012, -0.002) standard deviation decrease in body mass index. Additionally, mothers with a higher number of births exhibit a decreased likelihood of being either underweight (-0.005, 95% CI: -0.008, -0.002) or overweight (-0.007, 95% CI: -0.01, -0.004). One birth increase is also associated with a reduction in grip strength by 0.007 standard deviation (95% CI: -0.013, -0.001).

In the first stage of the IV analysis, findings revealed a notable difference: mothers whose first-born child was a daughter tended to have, on average, 0.304 more subsequent births (95% CI: 0.258, 0.349) compared to those whose first-born child was a son (Table 3.2). As depicted in

Figure 3.1, results of the subsequent stage of the IV analysis show similar direction as the OLS results, though with less precision and many uncertainty intervals crossing the null association. Notably, greater parity corresponded to a decrease in mothers' grip strength by 0.08 standard deviation (95% CI: -0.149, -0.014) and a reduction in mothers' BMI by 0.076 standard deviation (95% CI: -0.145, -0.007). Moreover, mothers with greater fertility exhibited a 5% lower probability of being overweight (95% CI: -0.082, -0.005).





Panel a Panel b

Figure 3.1 Regression results of parity and mothers' physical health using OLS and IV analysis

Notes: For both OLS and IV analysis, we used standardized outcomes to make the effect size comparable across health outcomes. We controlled basic demographic information, including mothers' current age, education attainment, rural or urban residency, religion, and state residency fixed effects. We also adjusted community level clusters for robust standard errors.

Table 3.2 OLS and IV analysis results on parity and mothers' physical health

Outcome	Estimates (95% Confidence Intervals) of completed fertility effects on physical health		Estimates (95% Confidence Intervals) of first-born daughter on completed fertility	
	OLS results	Second-stage IV results	First-stage IV results	Kleibergen-Paap Wald rk F statistic
Systolic blood pressure	-0.008* (-0.014, -0.002)	-0.062 (-0.135, 0.012)	0.304*** (0.258, 0.349)	172.346
Diastolic blood pressure	-0.007* (-0.013, -0.001)	-0.014 (-0.088, 0.06)	0.304*** (0.258, 0.349)	172.346
Waist hip ratio	0.016*** (0.01, 0.022)	0.06 (-0.012, 0.133)	0.305*** (0.259, 0.35)	173.171
Body Mass Index	-0.007* (-0.012, -0.002)	-0.076* (-0.145, -0.007)	0.306*** (0.26, 0.351)	174.289
Grip strength	-0.007* (-0.013, -0.001)	-0.081* (-0.149, -0.014)	0.304*** (0.259, 0.35)	169.759
High blood pressure	-0.002 (-0.004, 0.001)	-0.016 (-0.05, 0.019)	0.304*** (0.258, 0.349)	172.346
Under weight	-0.005** (-0.008, -0.002)	-0.008 (-0.05, 0.035)	0.293*** (0.233, 0.352)	92.462
Overweight	-0.007*** (-0.01, -0.004)	-0.044* (-0.082, -0.005)	0.305*** (0.257, 0.354)	153.571

Notes: For physical health outcomes in both OLS and IV analysis, we used standardized outcomes to make the effect size comparable across health outcomes. We controlled basic demographic information, including mothers' current age, education attainment, rural or urban residency, and religion, as well as state residency fixed effects to address any unmeasured, time-constant confounding factors. We also adjusted community level clusters for robust standard errors. ***p<0.001; **p<0.01, *p<0.05. Stock-Yogo weak ID test critical values: 10% maximal IV size is 16.38 for Kleibergen-Paap Wald rk F statistic.

In contrast, within the fathers' sample, OLS regression results illustrated that the association between parity and each physical health outcome is minimal and close to zero, except for BMI and overweight status. IV regression results show a similar trend to OLS results, except for the waist hip ratio. Each additional birth among fathers is associated with a 0.087 (95% CI: -0.168, -0.006) standard deviation decrease in waist hip ratio, based on IV regression results, compared to a near-zero association from OLS regression. Moreover, per birth increase is also associated with fathers' decreased likelihood of being overweight by 0.036 (95% CI: -0.079, 0.006) (Figure 3.2 and Appendix Table 3.2).

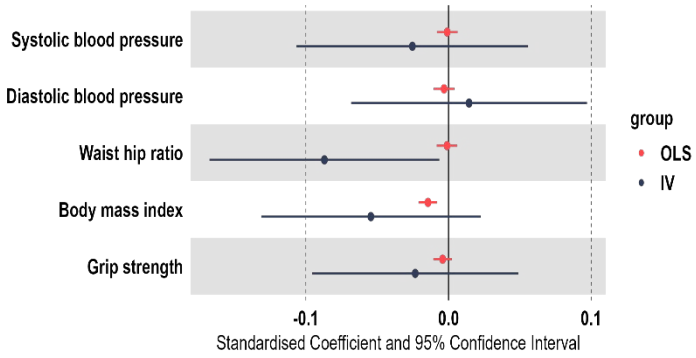


Figure 3.2 Regression results of parity and fathers' physical health using OLS and IV analysis

Notes: For both OLS and IV analysis, we used standardized outcomes (systolic blood pressure, diastolic blood pressure, waist hip ratio, body mass index, and grip strength) to make the effect size comparable across health outcomes. We controlled basic demographic information, including mothers' current age, education attainment, rural or urban residency, religion, and state residency fixed effects. We also adjusted community level clusters for robust standard errors.

Further analysis (Table 3.3 and Figure 3.3), which separated the study sample into mothers with no formal schooling and those with any schooling, revealed that the association between parity and mothers' BMI or being overweight remained statistically significant only among mothers with no schooling. While there is no difference between mothers of different schooling levels in the relationship between parity and mothers' grip strength. Finally, findings persisted in the sensitivity analysis (Figure 3.4, Appendix Table 3.3).

Table 3.3 Subgroup analysis on parity and mothers' Body Mass Index, being overweight, and grip strength

	Standardized coefficient	*P* value	95% Confidence Interval	*P* value for interaction
Body Mass Index				<0.001
No schooling	-0.096**	0.007	(-0.166, -0.027)	
Any schooling	-0.043	0.21	(-0.111, 0.024)	
Overweight				<0.001
No schooling	-0.051*	0.012	(-0.09, -0.011)	
Any schooling	-0.034	0.083	(-0.072, 0.004)	
Grip strength				<0.001
No schooling	-0.09*	0.01	(-0.159, -0.022)	
Any schooling	-0.069*	0.043	(-0.135, -0.002)	

Notes: Results are based on IV analysis. We used standardized outcomes to make the effect size comparable across health outcomes. We controlled basic demographic information, including mothers' current age, education attainment, rural or urban residency, and religion, as well as state residency fixed effects to address any unmeasured, time-constant confounding factors. We also adjusted community level clusters for robust standard errors. ***p<0.001; **p<0.01, *p<0.05.

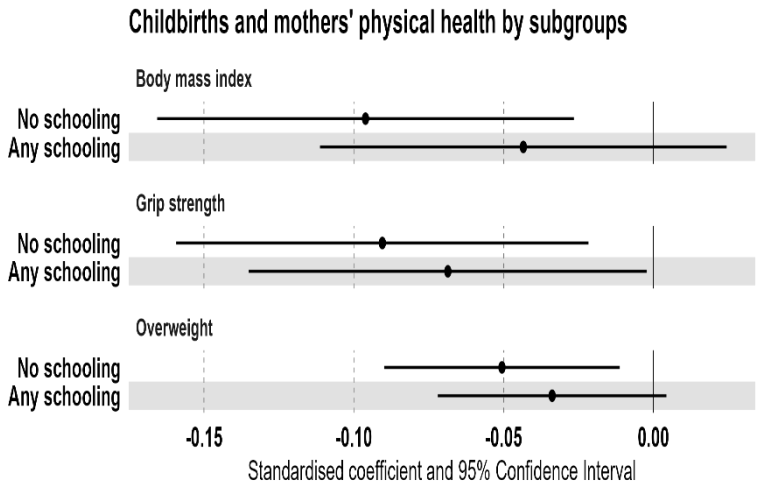
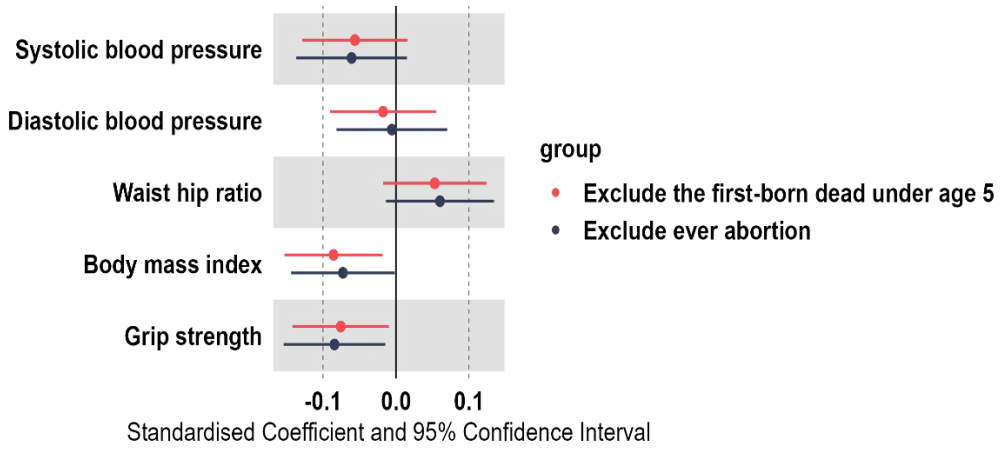
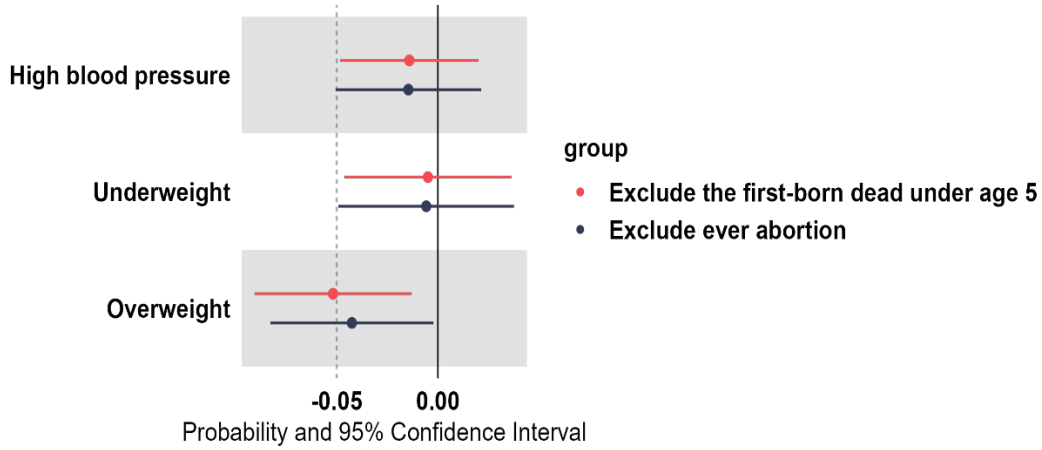


Figure 3.3 Parity and mothers' physical health by subgroups based on IV analysis results

Notes: We used standardized outcomes (body mass index and grip strength) to make the effect size comparable across health outcomes. For overweight outcome, the coefficient can be interpreted as probability. We controlled basic demographic information, including mothers' current age, education attainment, rural or urban residency, religion, and state residency fixed effects. We also adjusted community level clusters for robust standard errors.



Panel a



Panel b

Figure 3.4 Sensitivity analysis for parity and mothers' physical health based on IV analysis

Notes: For the first sensitivity analysis, we excluded 2067 women whose first-born dead under age 5 and for the second sensitivity analysis, we excluded 698 women ever with abortions. For both sensitivity analysis, we used standardized outcomes (systolic blood pressure, diastolic blood pressure, waist hip ratio, body mass index, and grip strength) to make the effect size comparable across health outcomes. We controlled basic demographic information, including mothers' current age, education attainment, rural or urban residency, religion, and state residency fixed effects. We also adjusted community level clusters for robust standard errors.

3.5 Discussion

Our study revealed higher completed fertility is associated with reduced grip strength, BMI, and being overweight in mothers' physical health after age 45. We also found greater parity is associated with fathers' reduced waist-hip ratio and overweight. This suggests that the link from childbirth to some of mothers' physical health measures is not solely biological (e.g. being pregnant) but may also be influenced by social factors (e.g., raising a child).

Our study's findings align with and contribute to existing research in several key areas. Consistent with a previous study (Keenan and Grundy 2019), our study also found that increased births were linked to reduced grip strength in mothers. Unlike that study (Keenan and Grundy 2019), we did not find an increased number of births associated with fathers' declining grip strength in neither OLS results nor IV regression results. Grip strength is an important biomarker of older adults' health status, predictive of malnutrition, fractures, falls, sleep problems, and various other health indicators (Bohannon 2019). Particularly in India, grip strength is quite predictive of frailty for both older men and women (Das and Prasad 2023). Childbearing and childrearing can consume parents' energy, potentially leading to sleep problems, malnutrition, and other long-term health issues, which are reflected in poor grip strength. Compared to Indian fathers, Indian mothers often bear more responsibilities in caring for children and may therefore be more susceptible to grip strength decline associated with an increased number of births. Future analysis should investigate mechanisms linking childbirth and grip strength.

Previous findings in high-income countries (Hardy et al. 2007; Mamun et al. 2010; Sironi, Ploubidis, and Grundy 2020) found that an increased number of births is associated with higher body mass index, waist-hip ratio, and overall obesity; and weight gain during pregnancy is associated with long-term increase in body mass index(Mamun et al. 2010). In contrary to

previous findings, we found that greater fertility was associated with decreased BMI and lowered likelihood of being overweight among both Indian mothers and fathers. Particularly, the study relationship is stronger among mothers without any schooling. We suspected that greater fertility may lead to limited food availability for parents and thus reduced their likelihood of being overweight. In addition, parents with more children are more likely to adopt healthier behaviors (Umberson et al. 2011), contributing to a normalization of weight status in older ages.

The finding that mothers with greater fertility had higher waist-hip ratio is consistent with previous findings (Sironi, Ploubidis, and Grundy 2020; Mamun et al. 2010). Our study did not find significant effects on mothers' systolic blood pressure and diastolic blood pressure, which is unlike previous findings (Haug et al. 2018; Teufel et al. 2021)which found reductions. In particular a study in India found effects of completed fertility on blood pressure in women up to age 49 but with smaller effects in women with long intervals since their last childbirth. Our study also observes an increased number of births associated with reduced systolic blood pressure. Our analysis is in a sample of older women, all are over 45, and this may explain our lack of significant result.

By elucidating the adverse impact of increased parity on mothers' physical health later in life, our study contributes significantly to the expanding body of evidence in this domain. This finding underscores the importance of considering fertility rates as a potential risk factor for long-term health outcomes among women. Consequently, future health interventions may benefit from targeting women with higher fertility rates.

Our study has several limitations. Firstly, 4,834 respondents opted out of voluntary physical health assessments. Appendix Tables 3.4 and 3.5 demonstrate that abstaining from these exams among mothers and fathers showed no clear correlation with the sex of the first-born child.

Instead, it was associated with demographic factors such as age and schooling, which were already controlled for in both OLS and IV regressions. Therefore, we do not expect this sample selection to significantly affect the validity or generalizability of our study results. Secondly, the LASI study had a recruitment criterion of respondents aged 45 or older, leaving out women who have died before reaching this age. Previous research indicates that women with higher parity tend to face earlier mortality (Barclay and Kolk 2019; Keenan and Grundy 2019) and we may be missing this important group creating survival bias.

We assume the sex of the first birth is random. Challenges to this come from sex selective abortion and factors that may influence selective conception and fetal loss. We have a robustness check omitting women with abortions, but the biological pathways may be present and we assumed the impact is minimal. A recent study found that increased level of air and water pollution are modestly associated with a lower sex ratio at birth (males versus females), but not with seasons, temperature, or many other factors (Long et al. 2021). Another study showed in populations with a higher proportion of malnourished women, the sex ratio at birth tends to be biased towards daughters; this is thought to serve as a protective mechanism for mothers, as the physiological demands of bearing sons are higher, making it more challenging under conditions of nutritional stress (Mace, Jordan, and Holden 2003). There might be potential violations of the exclusion assumption. The sex of the first-born may impact mothers' health directly. Previous evidence suggests that bearing sons is more physiologically demanding than bearing daughters; this is due to factors such as faster fetal growth rates, greater maternal energy intake requirements, and higher birth weights associated with male pregnancies (Hurt, Ronsmans, and Quigley 2006). The sex of the first-born may impact parental health via other pathways beyond total number of births, including the cultural practice of providing dowries for daughters upon

marriage and the replacement fertility due to premature death of the first born. We used fathers as a comparison group as fathers do not directly bear the fetus. When comparing fathers, we observed fewer associations between parity and physical health, supporting the assumption of exclusion restrictions. To further exclude other threats of the exclusion restriction assumption, we conducted a sensitivity analysis by excluding mothers whose firstborn child died before the age of five. The regression results remained consistent with those of the main analysis, suggesting that the potential influence of replacement fertility, if present, does not significantly affect the validity of the exclusion restriction assumption. However, it's crucial to acknowledge that mothers and fathers may bear different burdens in raising children. While a mediation analysis could potentially provide evidence of additional pathways, it falls beyond the scope of this current analysis. Finally, our findings only apply to Indian parents with at least one birth as we did not include participants without a birth. Previous studies found nulliparity is associated with worse parental physical health in later life (Harville et al. 2018; Guralnik et al. 2009). Future studies should investigate this issue.

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4 Contraceptive use and fertility as risk factors for early natural menopause among Indian women: a synthetic panel analysis

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4.1 Abstract

Research Question: Are contraceptive use and fertility patterns of young Indian women (aged 20-29) associated with risks of early natural menopause (before age 45)? **Method:** We utilized data from two waves of the National Family Health Survey (NFHS) in India. This survey collected cross-sectional data on a nationally representative sample of 724,115 women aged 15-49 years in the period 2005-6 and again in 2019-21. We constructed a synthetic panel of women and look at measures from 2005-6 as risk factors for early menopause in 2019-21. Our analysis data set includes 156,050 women aged 35 to 44 years surveyed in NFHS 2019-21 without a history of hysterectomy. To minimize reverse causality, we measured exposures in 2005-2006 when the women are aged 20-29. The exposures include early marriage and childbirth (before age 20), number of births, sterilization, and the use of oral contraceptives and intrauterine devices (IUDs) and we adjusted for age, religion, caste, state of residence, rural residence, education, smoking, alcohol intake, body mass index, anemia, and poverty. Data on early marriage and childbirth, fertility, religion, caste, state of residence, and education in 2005-6 were calculated from women's life histories. Data on oral contraceptive and IUD use in 2005-6 were imputed using Bayesian methods based on ever use in 2019-21. For data on smoking, alcohol

intake, body mass index, anemia, poverty, and rural residence in 2005-6 we used multivariate imputation by chained equations (MICE). Logistic regressions were then conducted to analyze the association between contraceptive use and fertility patterns at young ages and early natural menopause. **Results**: Early marriage (OR: 1.54, 95% CI: 1.42-1.66) and early childbirth (OR: 1.50, 95% CI: 1.40-1.60) are associated with higher risks of early natural menopause. Using two births as a reference, the risks are also higher for zero births (OR: 1.24, 95% CI: 1.12-1.37), three births (OR: 1.09, 95% CI: 1.02-1.17), and four or more births (OR: 1.34, 95% CI: 1.24-1.45). Conversely, use of oral contraceptives (OR: 0.70, 95% CI: 0.64-0.77), IUDs (OR: 0.66, 95% CI: 0.56-0.78), and sterilization (OR: 0.68, 95% CI: 0.63-0.72), are associated with lower risks of early natural menopause. **Discussion**: The study adds to the health arguments for women in India to delay marriage and childbirth to at least age 20. Nulliparity is rare in India and may be due to health conditions that also lead to early menopause. India has a high rate of early menopause; however, women are moving to a pattern of smaller family sizes and the use of effective contraceptive methods, and our results suggest this will lead to a decline in the rate of early menopause in the future.

4.2 Introduction

Early natural menopause, occurring under age 45 (Mishra et al. 2017), is associated with heightened risks of premature mortality and various chronic diseases, including cardiovascular disease, neurological diseases, psychiatric diseases, osteoporosis, and Type 2 diabetes (Faubion et al., 2015; Muka et al., 2016; Shuster et al., 2010). In India, 20.4% of women experience early natural menopause (Kundu and Acharya 2023), a number significantly higher than that in high-income countries, which ranges from 2.5% to 9.6% (Mishra et al. 2017; Zhu et al. 2018). It is

crucial to understand the risk factors contributing to the high prevalence of early natural menopause in India.

From a biological perspective, the onset of menopause is primarily influenced by the quantity of oocytes women being born with and the pace at which oocytes are depleted over time (Hansen et al. 2008). Reproductive events such as pregnancy, breastfeeding, and contraceptive use, can interrupt regular ovulation and alter the rate of oocytes loss, potentially affecting the timing of menopause (Cramer, Xu, and Harlow 1995). Emerging studies are examining women's reproductive experiences as potential risk factors of early natural menopause, but the results are mixed and such topics remain understudied in India.

The relationship between fertility and early natural menopause is complicated by potential reverse causality. Women's fecundability may decrease significantly five to ten years before menopause (American Society for Reproductive Medicine 2012), potentially leading to fewer total births. Many studies that used lifetime nulliparity have found that nulliparous women are more likely to experience early menopause (Mishra et al. 2017; Langton et al. 2020) or reach menopause at younger ages (Gottschalk et al. 2021; Roman Lay et al. 2020), while a recent study measuring nulliparity by age 38 found no apparent association (Peycheva et al. 2022). Compared to nulliparity, having more births is generally associated with a reduced risk of early menopause (Langton et al. 2020) although this relationship is not strictly linear (Gottschalk et al. 2021). On the other hand, other studies have found no apparent association between the number of childbirths and the timing of menopause (Gold et al. 2013; Pokoradi, Iversen, and Hannaford 2011). Those studies are different in sample size, study design, and amount of early life confounders adjusted, with the number of covariates typically increasing from cross sectional studies (Gottschalk et al. 2021; Mishra et al. 2017) to prospective longitudinal studies (Gold et

al. 2013; Langton et al. 2020; Pokoradi, Iversen, and Hannaford 2011), and even more so in birth cohort longitudinal studies (Peycheva et al. 2022).

Oral contraceptives, which contain both estrogen and progesterone, can interrupt ovulation by altering estrogen level, and this may potentially impact the timing of menopause. Studies suggest that the use of oral contraception is associated with a delayed onset of menopause (Gold et al. 2013; Lujan-Barroso et al. 2018; Roman Lay et al. 2020; Stepaniak et al. 2013). Similar to fertility, the relationship between oral contraceptive use and menopause is also vulnerable to reverse causality. For instance, perimenopausal women may use oral contraceptives to treat menstrual irregularities or alleviate menopausal symptoms(Cho 2018). If measuring the use of oral contraception at each age, the use of oral contraception after age 35 is associated with lower risks of early natural menopause, while overall use and duration of use do not seem to be linked with early menopause (Langton et al. 2021). Another study examining oral contraceptive use at younger ages (by ages 30 or 42) also reported no associations with early natural menopause (Peycheva et al. 2022). To address the concerns of reverse causality, several studies excluded participants using oral contraceptives or hormone replacement therapy within four years prior to their last menstrual period (de Vries et al. 2001), or those who used oral contraceptives beyond age 40 (Lujan-Barroso et al. 2018). However, the findings remain mixed. The earlier study found no associations of oral contraceptive use and the timing of menopause (de Vries et al. 2001), whereas the later study found ever use of oral contraceptives is associated with a later menopause (Lujan-Barroso et al. 2018).

Sterilization is generally not expected to impact menopause, as it involves blocking or removing the fallopian tubes without affecting ovaries, which continue to release eggs. However, previous studies show mixed findings: some found no associations (Ainsworth et al. 2019; Nichols et al.

2013) while others suggested an increased risks of early natural menopause (Langton et al. 2021) or menopause at younger ages (Pokoradi, Iversen, and Hannaford 2011).

Current studies are mainly from European countries or high-income countries. In contrast, research of this topic in India is limited. There is one study examining risk factors of premature menopause in India (Meher and Sahoo 2021). Reproductive events are unique and challenging in India, with high fertility level and high prevalence of sterilization (Bansal, Dwivedi, and Ali 2022) as well as prevalent practice of child marriage and early birth (Raj et al. 2009). This study will examine the roles of those reproductive behaviors on risks of early natural menopause among Indian women. The earlier study (Meher and Sahoo 2021) used cross-sectional data from the fourth round of the National Family Health Survey (NFHS) of India collected between 2015 and 2016. This study will use data from the fifth round of NFHS, collected between 2019 and 2021. To mitigate the potential risks of reverse causality and unmeasured early-life confounders, this study will construct a synthetic panel data and measure reproductive events of study women as of 2005, when they aged 20 to 29 years, a period with infrequent occurrences of menopause.

4.3 Methods

Data

Our primary data source is the fifth of National Family Health Survey (NFHS-5), conducted in India, which provides current population and health information. The survey was carried out in two phases – Phase I covered 17 states and 5 union territories (UTs) from June 2019 to January 2020, and Phase II covered 11 states and 3 UTs from January 2020 to April 2021. NFHS-5 adopted a stratified two-stage sampling design, which is representative at the national, state/UT, and district level. Each district was stratified into urban and rural areas. Probability proportional to population size (PPS) was used to select villages in rural areas and Census Enumeration

Blocks in urban areas as primary sampling units (PSUs) in the first stage. Subsequently, a random sampling was used to select a fixed number of households within each PSU in the second stage.

NFHS-5 features a nationally representative sample of women encompassing all females aged 15-49 residing in the selected households, irrespective of their marital status. The survey achieved high response rates, with an average exceeding 96% for both households and individual women (International Institute for Population Sciences 2022). As a result, a total of 724,115 women from 636,699 households participated in NFHS-5.

NFHSs are cross-sectional, capturing women's reproductive characteristics and menopausal status simultaneously. This approach does not provide clear information on the timing of certain events, such as the initiation of oral contraceptive use and the onset of menopause, leading to potential issues with reverse causality. To address this challenge, we measure the values of our exposure variables as of 2005. Some of these exposures can be captured using retrospective questions in NFHS-5. For other measures we use data from NFHS-3, collected data between November 2005 and August 2006. Although NFHS-3 and NFHS-5 sampled different women, both surveys are nationally representative. We use data from NFHS 2005 to impute missing values for variables in 2005 for women in the NFHS-5 survey. Further details on our methodology are provided below.

NFHS-3 employed the same sampling strategy, with similar survey questions as NFHS-5 with high response rates for both household and women surveys, exceeding 94% (International Institute for Population Sciences 2007). In total, NFHS-3 gathered data from 124,385 women across 109,041 households. Since we would use NFHS-3 data for imputation, we also excluded 26,394 NFHS-5 women living in union territories not sampled in NFHS-3 survey (Figure 4.1).

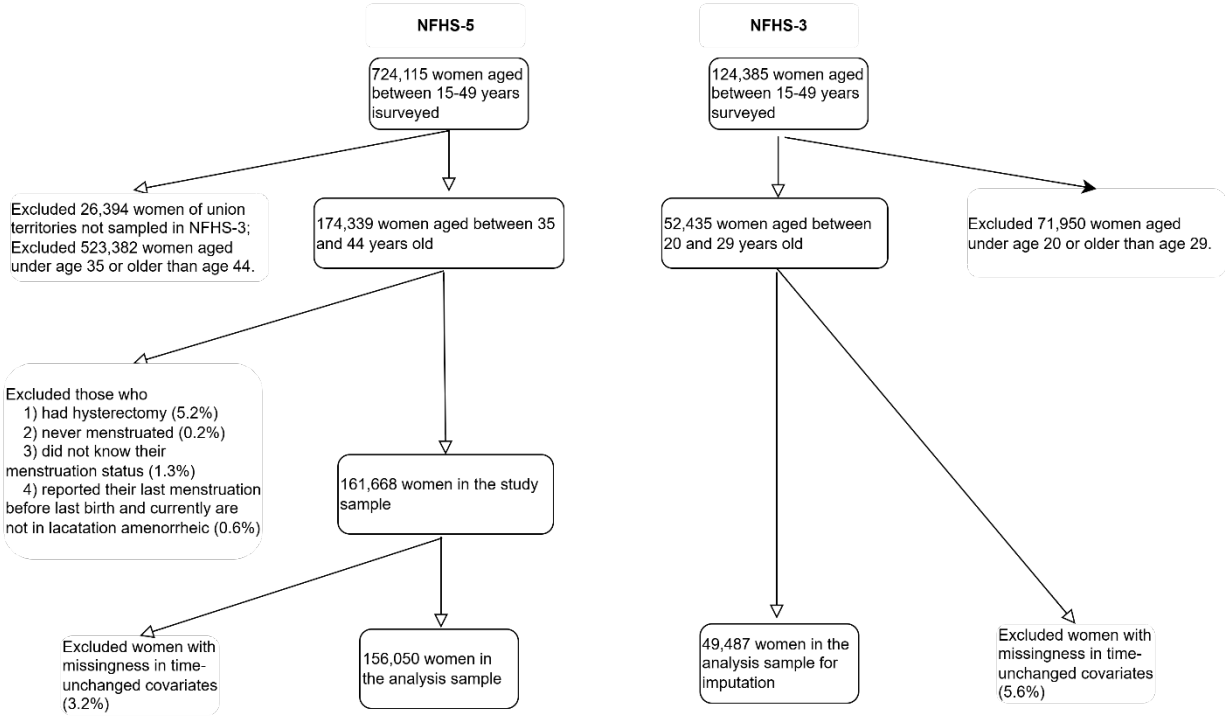

Figure 4.1 flow chart of study sample

Outcome measurement and study population

The outcome of interest is early natural menopause. Natural menopause is defined as the cessation of menstruation for a minimum of 12 consecutive months, excluding causes such as surgical removal of the uterus, pregnancy, breastfeeding, oral contraceptive use, cancers, radiation, or chemotherapy (Mishra et al. 2017; Langton et al. 2020). Early natural menopause is the occurrence of menopause before age 45 (Mishra et al. 2017). The NFHS-5 survey includes only one question related to menopause: "Time since last period (months)". The response options for this question are: the number of months, had a hysterectomy, in menopause, before last birth, never menstruated, inconsistent answers compared to other relevant questions (as identified by interviewers), and don't know. For women who report being "in menopause", there is no follow-

up question to determine the exact timing of menopause. We identified women as menopausal if they either reported currently being in menopause or had not menstruated in the past 12 months. Among these menopausal women, only 24.6% of them reporting number of months since their last period. Consequently, for the remaining large proportion of menopausal women, we lack precise information regarding the timing of their menopause.

Therefore, we restricted our analysis to women under the age of 45. If they were being in menopause based on our definition, the timing of their menopause must be under age 45, which is early natural menopause. Additionally, we excluded women under the age of 35 due to low incidence of natural menopause in this age group.

Among a total of 174,339 women aged 35 and 44 in NFHS-5 (Figure 4.1), we excluded women with hysterectomy (5.2% of study population) since we are interested in natural menopause, and we do not have data on the timing of hysterectomy relative to menopause. We also excluded those who reported never menstruating (0.2%), had inconsistent answers with other questions or those who responded 'don't know' to the menopause question (1.0%). We further excluded women who reported having their last period before their last birth but currently were not breastfeeding (0.6%), as it remains unclear whether they will resume menstruation or not. Lastly, we excluded women who had missingness on covariates (3.2%) we treat as time invariant, such as birth year or religion, that we use for imputation. The final analysis sample consists of 156,050 women aged 35 to 44.

In the NFHS-3 survey, there are 52,435 women born in the same years (between 1975 and 1986) as our analysis sample from NFHS-5. Similarly, we excluded those who had missingness on time-invariant covariates (5.5%). Consequently, 49,487 women from NFHS-3 were included in the imputation model.

Exposures: Marriage, Fertility, and Contraceptive use

We explore the role of early marriage (before age 20), giving birth at an early age (before age 20), number of births, sterilization, ever use of oral contraceptive pills, and ever use of IUDs on early menopause. To mitigate the possibility of reverse causality, we measure these characteristics as they would have been reported had the women been interviewed in 2005, when they aged 20 to 30 years. The NFHS-5 provides comprehensive measures of women's marriage and birth history and the timing of sterilization, enabling us to create variables for early marriage, early childbirth, total number of births, and sterilization as of 2005.

However, the NFHS-5 survey only measured whether women had ever used oral contraceptive pills or IUDs by the time of interview, without providing information on the timing of their use. Our exposures are ever use of oral contraceptive pills or IUDs up to 2005. For women who reported never using oral contraceptive pills or IUDs in NFHS-5, we can infer that they also did not use these methods as of 2005. However, for women who reported ever using oral contraceptive pills or IUDs in NFHS-5, the timing of their use is unknown, resulting in missing data for their contraceptive use status as of 2005. The NFHS-3 survey collected data on women's contraceptive use up to the data collection years, between 2005 and 2006. We will utilize NFHS-3 data and an imputation method to address the missing information on contraceptive use up to 2005 for women surveyed in NFHS-5. Details of the imputation method are given below.

Covariates

We controlled a set of covariates that correlated with both women's reproductive characteristics and early natural menopause. These covariates include smoking, alcohol intake, Body Mass Index (BMI), hemoglobin level, wealth, rural residence, age, religion, caste, education level (less

than secondary, secondary, degree), and state of residence. Some of these covariates, such as smoking, alcohol intake, BMI, hemoglobin level, wealth, and rural residence, may change over time. The NFHS-5 survey only measured the current status of those time-changing covariates, which might be mediators between women's earlier reproductive risk factors and their menopausal status. To address this, we use NFHS-3 data to impute the status of these time-varying covariates as of 2005.

Statistical methods

We first address the missing data issue. There are two types of missing data in our study population. Firstly, there is partial missingness regarding women's ever use of oral contraceptive pills or IUDs as of 2005. For women who reported never using oral pills or IUDs in 2019, we know they did not use these methods by 2005. However, for those who reported using oral pills or IUDs in 2019, their timing of initiation is missing. Secondly, there is missingness for certain covariates at earlier time points, such as smoking status in 2005, because we cannot infer smoking status in 2005 based on their smoking status in 2019.

For variables where a woman reports ever use in 2019 we can make some inferences about ever use in 2005. Let X_0 denote ever use of X in 2005 and X_1 denote ever use of X in 2019. Clearly we have $P(X_0 = 1|X_1 = 0) = 0.$ If a women is a never user in 2019 she must have been a never user in 2005.

For ever users in 2019 calculating the probability of ever use in 2005 is more complex. By Bayes' theorem, we have

$$P(X_1 = 1, X_0 = 1) = P(X_1 = 1|X_0 = 1)P(X_0 = 1) = P(X_0 = 1|X_1 = 1)P(X_1 = 1)$$

Hence

$P(X_0 = 1|X_1 = 1) = \frac{P(X_1=1|X_0=1)P(X_0=1)}{P(X_1=1)} = \frac{P(X_0=1)}{P(X_1=1)}$, since $P(X_1 = 1|X_0 = 1) = 1$.

We can therefore calculate the probability that a women who is an ever user in 2019 was an ever user in 2005 as the ratio of the probability of her ever use in 2005 divided by the probability of her ever use in 2019 (Hammon and Zinn 2020). The intuition of this result is that inference about ever use in 2005 based on ever use in 2019 depends on the incidence of new use between 2005 and 2019. If the probability (and hence prevalence) of ever use in 2005 and 2019 is the same there are no new users between 2005 and 2019 and the probability an ever user in 2019 was an ever user in 2005 is one. Similarly, if the probability of being an ever user in 2005 is half that of being an ever user in 2019, half the ever users in 2019 would have been ever users in 2005. As shown in Table 4.1, 16% of women in our sample report ever use of oral contraceptives in 2019, while for women with matching birth years surveyed in 2005 11.4% report ever use. This suggests that around 71% of women who report ever use in 2019 were already users by 2005 while 29% initiated use after 2005.

To calculate the probability of ever use of contraceptives in 2005 more accurately we perform separate logistic regressions of ever use of oral contraceptives using NFHS-3 and NFHS-5 data based on a set of time-invariant predictors that are available in both data sets: year of birth, first marriage before age 20, first birth before age 20, number of births by 2005, sterilization by 2005, religion, caste, education level (less than secondary degree), height, and state of residence. This allows to calculate $P(X_0 = 1)$ and $P(X_1 = 1)$ for each woman based on her individual characteristics, and hence to calculate a conditional probability of ever use in 2005 for each ever user in 2019. We then impute that never users in 2019 were never users in 2005 and for ever users in 2019 we undertake multiple imputation (10 imputations) in 2005 by using a random

draw and imputing ever use in 2005 with the calculated conditional probability. We undertake a similar procedure for ever use of IUD.

For time varying covariates we used multivariate imputation by chained equations (MICE) to impute values for 2005 for women surveyed in 2019. Both surveys include time invariant characteristics for the women that we use to predict the missing values. We applied logistic regression models for binary variables and linear regression models for continuous variables. We undertake 10 imputations for each variable prespecifying the 10 imputed values for ever use of oral contraceptives and IUDs in 2005 from the Bayesian approach above.

We then use the calculated and imputed values of the explanatory variables in 2005 to predict early menopause by 2019, using logistic regression models. We first regressed early natural menopause on early marriage and early childbirth, only controlling time-invariant variables - age, caste, religion, less than secondary education, and residence states. This excludes contraceptive use, fertility, and other covariates measured as of 2005, which are potentially mediators between early marriage/childbirth and early natural menopause. Secondly, based on the first logistic regression model, we additionally added total births, sterilization, oral contraceptive use, and IUD use as of 2005, as well as adjusting covariates by 2005, including current smoking, current drinking, body mass index, anemia, poverty, and rural residence. In the second model, we focused on assessing the roles of total births and contraceptive use on risks of early natural menopause.

To account for correlations within primary sampling units (PSUs)—villages in rural areas and Census Enumeration Blocks in urban areas—we treated PSUs as clusters to obtain robust standard errors. We also adjusted the standard errors to account for within- and between-

imputation variance across the multiple imputed datasets by applying Rubin's rule (Heymans and Eekhout 2019). We used a two-sided test with a significant level of 5%.

In addition to our main analysis, we provide results based only on the NFHS-5 cross-sectional data, to allow comparisons between our synthetic panel approach and the more common cross section approach.

4.4 Results

Table 4.1 presents the descriptive characteristics of women from the NFHS-5 and NFHS-3 surveys, along with some characteristics imputed for NFHS-5 women as of 2005. All three columns include only data on women from the same birth cohort born between 1975 and 1986. These women are aged 35 to 44 in NFHS-5, and 4.6% had experienced early natural menopause (Table 4.1). Specifically, 10% of women aged 44 had experienced early natural menopause, while the prevalence was 5% among those aged 40 (see Appendix Figure 4.1).

Table 4.1 Descriptive characteristics of study women survey in NFHS-5 and their counterparts surveyed in NFHS-3

	Observed data for NFHS-5 women in 2019 (N=156,050)	Imputed or assigned data for NFHS-5 women in 2005 (N=156,050)	Observed data for NFHS-3 women in 2005[2] (N=49,487)
Early natural menopause	4.6%	Not Apply[3]	0.5%
Reproductive characteristics			
Married before age 20	56.7%	56.7%	51.8%
Giving birth before age 20	38.2%	38.2%	37.5%
Number of births			
0	4.3%	27.1%	33.5%
1	9.4%	22.3%	19.5%
2	35.4%	27.6%	23.4%
3	25.8%	15.1%	13.2%
>=4	25.1%	7.8%	10.4%
Sterilization	46.6%	16.6%	17.2%
Ever use oral pills[1]	16.0%	9.5%	11.4%
Ever use IUDs[1]	6.0%	3.4%	5.2%
Lifestyle characteristics			
Current smoking[1]	9.7%	10.9%	10.6%
Current drinking[1]	2.9%	3.7%	2.6%
Body Mass Index[1]			
Underweight	10.2%	32.5%	30.6%
Normal	57.6%	59.2%	59.2%
Overweight	32.2%	8.3%	10.2%
Other demographic characteristics			
Year of birth (s.d.)	1980.7 (3.0)	1980.7 (3.0)	1980.7 (3.5)
Religion			

Hindu	76.1%	76.1%	72.1%
Muslim	11.2%	11.2%	13.6%
Christian	7.5%	7.5%	9.1%
Other	5.2%	5.2%	5.2%
Caste			
Schedule caste	18.7%	18.7%	16.8%
Schedule tribe	19.0%	19.0%	14.1%
Other backward caste	38.6%	38.6%	31.6%
None of them	23.7%	23.7%	37.5%
Anemia[1]	32.0%	39.3%	33.0%
Poor[1]	42.6%	29.9%	25.9%
Rural residence[1]	74.1%	75.0%	55.1%

Notes: Results are unweighted. [1] Characteristics of NFHS-5 women in 2005 were based on imputation. [2] Only included NFHS-3 women of the same years of birth as NFHS-5 study women. [3]NFHS does not have data on the timing of menopause and we do not impute it since we do not use it in the regression models.

Among NFHS-5 women in our sample, 56.7% married before age 20, and 38.2% gave birth before age 20 (Table 4.1). Women in NFHS-3, with the same birth years as those in NFHS-5, exhibited similar trends in total number of births and sterilization as of 2005. In 2019, 16% of NFHS-5 women had ever used oral contraceptive pills, and 6% had ever used IUDs. In 2005, these figures were 9.5% and 3.4% for oral pills and IUDs, respectively, among NFHS-5 women, based on imputation. Women in the NFHS-3 survey in 2005 exhibited similar trends in the use of oral pills and IUDs as the NFHS-5 women did in 2005.

In 2005, the demographic characteristics of NFHS-5 women based on imputation and NFHS-3 women based on observation were similar (Table 4.1) and more balanced after being weighted for national representativeness (Appendix Table 4.1). From 2005 to 2019, the prevalence of smoking and drinking among NFHS-5 women remained stable, while the prevalence of being overweight increased from 8.3% to 32.2%. Additionally, compared to women in NFHS-3, a higher proportion of women in NFHS-5 residing in rural areas.

Model 1 in Table 4.2 presents the associations between early marriage or early childbirth and early natural menopause. Women who married before age 20 have 1.43 times the odds of experiencing early natural menopause (95% CI: 1.33–1.54), compared to women who married at age 20 or later. Similarly, women who gave birth before age 20 versus those who gave a birth later have 1.44 times the odds (95% CI: 1.35–1.54). In Model 2 of Table 4.2, when total births, contraceptive use, and covariates measured by 2005 are included, the associations are not changed significantly. In addition, compared to women with two births by 2005, there is no significant difference in the odds of early natural menopause for women with one birth or two births; however, women with zero births, three births, or four or more births are associated with

higher odds of early natural menopause. Using any type of contraception is associated with lower odds of early natural menopause.

Table 4.2 The associations of reproductive characteristics with early natural menopause among Indian women

Reproductive characteristics	Model 1 Odds Ratio (95% Confidence Interval)	Model 2 Odds Ratio (95% Confidence Interval)
Ever married before age 20	1.43*** (1.33-1.54)	1.54*** (1.42-1.66)
First birth before age 20	1.44*** (1.35-1.54)	1.50*** (1.40-1.60)
Number of births by 2005		
0 birth (ref=2)		1.24*** (1.12-1.37)
1 birth		1.04 (0.96-1.13)
3 births		1.09* (1.02-1.17)
4 or more births		1.34*** (1.24-1.45)
Sterilization by 2005		0.68*** (0.63-0.72)
Ever use IUD by 2005		0.66*** (0.56-0.78)
Ever use oral pills by 2005		0.70*** (0.64-0.77)

Notes: We used a logistic regression controlling age, caste, religion, less than secondary education, residence states, and covariates by 2005, including current smoking, current drinking, body mass index, anemia, poverty, and rural residence. Standard errors were adjusted by clustering primary sampling units - villages in rural areas and Census Enumeration Blocks in urban areas, and by within and between imputation variance in the multiple imputed datasets.

Table 4.3 shows results using only the NFHS-5 data, which measured menopause status, reproductive characteristics, and covariates at the time of the interview. There are differences between Table 4.2 and Table 4.3 regarding the role of the number of births in early natural menopause. Based on 2005 values in Table 4.2, zero births or more than two births are associated with increased odds of early natural menopause. Based on cross-sectional data in Table 4.3, zero

births remain associated with increased odds, and one birth also shows a significant positive association with early natural menopause. Contrary to Table 4.2, the associations of three or more births with early natural menopause are not significant in Table 4.3. Compared to Table 4.2, the associations of early marriage/childbirth or using any type of contraception with early natural menopause are stronger in Table 4.3.

Table 4.3 The associations of reproductive characteristics with early natural menopause among Indian women using NFHS-5 data only

Reproductive characteristics	Odds Ratio	95% Confidence Interval
Ever married before age 20	1.55***	1.44-1.68
First birth before age 20	1.72***	1.61-1.84
Number of births		
0 birth (ref=2)	2.20***	1.96-2.48
1 birth	1.41***	1.28-1.55
3 births	1.02	0.95-1.09
4 or more births	1.00	0.92-1.07
Sterilization	0.50***	0.47-0.53
Ever use IUD	0.61***	0.52-0.70
Ever use oral pills	0.61***	0.56-0.66

Notes: Using NFHS-5 data, we used a logistic regression controlling age, caste, religion, less than secondary education, residence states, current smoking, current drinking, body mass index, anemia, poverty, and rural residence. Standard errors were adjusted by clustering primary sampling units - villages in rural areas and Census Enumeration Blocks in urban areas.

4.5 Discussion

Our results suggest risk factors for early natural menopause in India include early marriage, early childbirth, before age 20 and nulliparity, and having more than two births measured at ages 20-29. Conversely, a lower risk of early natural menopause is associated with the use of oral contraceptives, IUDs, and sterilization between ages 20 and 29.

The findings regarding the association between nulliparity and higher risks of early natural menopause are consistent with previous findings (Gottschalk et al. 2021; Langton et al. 2020; Mishra et al. 2017; Roman Lay et al. 2020). However, a difference from Gottschalk and

colleagues' study (Gottschalk et al. 2021), is that we find having three or more births, compared to two births, is associated with a higher likelihood of early natural menopause. This differs from their findings, which indicated that three births are associated with a lower risk compared to two births, and four or more births do not increase the risk of early natural menopause. The relationship between fertility and early natural menopause is susceptible to reverse causality as discussed before. To mitigate such potential threats, our study measured the number of births occurring 15 years prior to the measurement of menopause status, while the aforementioned study used a complete fertility history. Their result is similar to our result in Table 4.3, also using complete fertility. The association between nulliparity and early natural menopause appears to be less susceptible to reverse causality, as we consistently found nulliparity measured at ages 20-29 or older is associated with higher likelihood of early natural menopause. This is in agreement with previous research indicating that nulliparity is associated with an elevated risk of early natural menopause, regardless of whether the number of births was measured at ages 25, 30, 35, or across a lifetime (Langton et al. 2020).

The "oocyte sparing' hypothesis is popular in interpretating the relationship between fertility and early natural menopause; the experience of pregnancy suppresses the atresia of ovarian follicles and thus delay the menopause (Cramer, Xu, and Harlow 1995). In addition, Langton and colleagues' study (Langton et al. 2020) found breastfeeding attenuated the association of parity with early natural menopause; as breastfeeding, especially exclusive breastfeeding suppresses the secretion of follicle-stimulating hormone and luteinizing hormone, though neither fertility nor the duration of breastfeeding has a dose-response relationship with early natural menopause (Gottschalk et al. 2021; Langton et al. 2020). Our findings partially support the hypothesis that, compared to women with two births, nulliparous women – those who experience incessant

ovulation – are more likely to undergo early natural menopause. Additionally, our study revealed that higher fertility (more than two births) among Indian women is associated with an increased risk of early natural menopause. In India and many other low- and middle-income countries, women with higher fertility are more likely to experience pregnancy complications, such as miscarriage, abortion, or stillbirths, and have limited access to healthcare (Leone, Brown, and Gemmill 2023). These complications may be linked to early natural menopause, particularly for Asian women (Liang et al. 2024), or a younger age at menopause (Langton et al. 2023). Moreover, Indian women who engage in high-risk fertility behaviors (e.g. early marriage/birth, high fertility, short birth interval) are more likely to suffer from chronic undernutrition (Pal and Shekhar 2021). Better nutrition, on the other hand, is associated with delay ovarian senescence (Pearce and Tremellen 2016). Future research in India should explore the mechanisms that connect high fertility with an elevated risk of early natural menopause.

This study also found early marriage and early childbirths (before age 20) are associated with a higher likelihood of early natural menopause, a topic that has received limited attention in existing literature. One study in India reported similar findings regarding the association of early childbirths with premature menopause, but did not specifically examine the impact of early marriage on menopause timing (Meher and Sahoo 2021). The potential mechanisms underlying the connection between early marriage, early childbirth, and early natural menopause may be similar to those associated with high fertility rates. We suspect early marriage and early childbirths expose women to a higher number of total births or higher risks of pregnancy complications. Both of which have been associated with a higher likelihood of early natural menopause. One study in the U.S. found that age at first birth was not independently associated with early natural menopause after accounting for factors like parity and breastfeeding (Langton

et al. 2020). However, our study revealed an independent association even after adjusting parity. It may be that there are counteracting mediation effects. Early marriage and childbirth may be associated with more total births by 2005 which tends to raise the risk of early menopause but may also be associated with sterilization, oral contraceptive use, or IUD use by 2005 which tend to lower the risk. This indicates early childbirth may have more health implications for early natural menopause in India compared to the U.S. Moreover, early marriage is associated with more adverse pregnancy outcomes (Paul 2018), which may further increase the likelihood of early natural menopause (Langton et al. 2023; Liang et al. 2024). In addition, early marriage is also associated with various health risks for women, including undernutrition (Prakash et al. 2011), domestic violence, and stress (Fan and Koski 2022), all of which may contribute to early natural menopause later in life.

Our finding that oral contraceptive use is associated with lower risks of early natural menopause is consistent with previous findings (Gold et al. 2013; Lujan-Barroso et al. 2018; Roman Lay et al. 2020; Stepaniak et al. 2013). A recent study found only the use of oral contraception after age 35 is associated with lower risks of early natural menopause, suggesting potential reverse causality (Langton et al. 2021). To mitigate the threats of reverse causality, our study measured ever using oral contraceptives at ages 20 to 29 and have similar findings as another study that found women who started using oral contraception between ages 25-30 are less likely to experience early menopause compared to those who began at ages 31 or older (Lujan-Barroso et al. 2018). Oral contraceptive use has been shown to decrease levels of ovulation-related follicle-stimulating hormone (FSH) and luteinizing hormone (LH), as well as anti-Müllerian hormone (AMH), which is an indicator of ovarian aging (D'Arpe et al. 2016). These hormonal changes driven by oral contraceptive use may contribute to delaying the onset of menopause.

Our study also found sterilization is associated with reduced risks of early natural menopause, which contrasts with previous studies, that either finding a positive association (Langton et al. 2021; Pokoradi, Iversen, and Hannaford 2011), or no association at all (Ainsworth et al. 2019; Nichols et al. 2013). The primary mechanism of sterilization on preventing pregnancies involves the obstruction of the fallopian tubes, thereby preventing the union of oocytes and sperm, and subsequent fertilization. This procedure theoretically does not interfere with hormonal changes associated with menopause. Additionally, this study found IUD use is also associated with reduced risks of early natural menopause, an area that has received less attention in current research. We hypothesize that sterilization may reduce the likelihood of additional births, thereby lowering the risk of adverse pregnancy outcomes, which are associated with a higher risk of early natural menopause. Similarly, the association between IUD use and a reduced risk of early natural menopause may be due to fewer subsequent births, a decrease in adverse pregnancy outcomes, or improved birth spacing. Further studies should investigate the mechanisms underlying how sterilization or IUDs may influence the timing of early natural menopause.

In summary, results for risk factors for early menopause in India may be different from those found in other countries, particularly high-income countries where many studies have been conducted. The high prevalence of nutritional deficiencies in India (e.g., the proportion of women underweight in 2005 in Table 4.1) may increases the stress on women from pregnancy and childbirth. The high proportion of women in India being sterilized before age 30 as a method of family planning (Tabel 4.1) may mean it has a different association with menopause than in setting where sterilization at young ages is rare.

Given the lack of long-term panel data in India, our study uses a synthetic panel approach to study how early life contraceptive use and fertility affects the risk of early menopause in women

in India. Many of these early life variables can be calculated directly from fertility histories for women, while we use imputation methods for other variables.

This study has several limitations. Firstly, there is a potential for misclassification of our outcome, menopause status. For a small proportion of study women this is calculated based on the reported timing of their last menstruation. Women in pre-menopausal status may have poorer recall accuracy regarding their last menstruation (Monteleone et al. 2018). For same variables such as fertility and sterilization in 2005 we use histories as reported in 2019. This may suffer from recall bias and may be less accurate that if we had contemporaneous measures, though in aggregate calculated births and sterilization rates in 2005 based on 2019 data are similar to those reported by women from the same birth cohort in 2005 (Table 4.1).

A major issue with interpreting our results is the potential for confounding due to omitted variable bias. Firstly, we cannot control for age of menarche, which is known to correlate with early sexual initiation and pregnancy (Ibitoye et al. 2017) and early natural menopause (Mishra et al. 2017). Adverse pregnancy outcomes, miscarriages, stillbirths, and the onset of infertility may also be factors that are associated with early menopause (Langton et al. 2023; Liang et al. 2024). There might be other unmeasured predictors such as male involvement in family planning decisions (Dey et al. 2022).

While we identify risk factors based on available data it is difficult to interpret our risk ratios as causal given the possibility of confounding. For example, while we find no births as a risk factor for early natural menopause, we do not distinguish between women who have no birth due to infertility and those who are fertile but choose to have no births. Ift may be the underlying unobserved infertility that is linked to early natural menopause with no births simply being a marker for this.

Despite challenges posed by limited data availability and associated methodological constraints, this study contributes significant evidence linking reproductive characteristics in early life to early natural menopause among Indian women. Our synthetic panel approach has advantages over the pure cross section approach usually employed using NFHS data but it is still open to issue of interpretation given the possibility of confounding.

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5 Conclusion

This dissertation demonstrates the long-term impact of women's early life reproductive experiences on their well-being in later life through three papers focused on the contexts of China and India.

The first paper reveals that exposure to stringent family planning policies during reproductive years has a negative impact on Chinese women's mental health in post-reproductive years. This association is primarily driven by the 'Later-Longer-Fewer' Policy (LLFP) and the 'One-and-a-Half-Child' Policy (OHCP). Exposure to LLFP is associated with increased depressive symptoms and worse self-reported memory problems. Exposure to OHCP is linked to increased depressive symptoms and more cognitive impairments, including recall impairment, orientation impairment, and self-reported memory problems.

The second paper finds that an increased number of births is associated with reduced grip strength, body mass index (BMI), and the likelihood of being overweight among mothers after age 45. These associations are stronger among mothers without schooling. Additionally, an increased number of births is also associated with a reduced waist-hip ratio among fathers.

The third paper identifies that early natural menopause is prevalent in India. The risks of early natural menopause are higher among women who marry early, give birth before age 20, are nulliparous, or have three or more births. Conversely, Indian women who have used oral contraceptives, IUDs, or have been sterilized are less likely to experience early natural menopause.

5.1 Contribution

This dissertation contributes to the field of women's health across the life course by identifying new exposures, offering a global comparison, and introducing innovative methodologies to address limited data availability.

The first paper examines the impact of exposure to stringent family planning policies on the mental health of older Chinese women. Previous studies on early life experiences and mental health in China typically focus on in utero or early postnatal famine exposure and lack assessments of experiences during young and mid-adulthood. The findings of this paper contribute to a better understanding of how women's mental health in later life is shaped by their life histories and historical events. These findings have significant policy implications not only for China but also for other countries with birth control policies. The paper reveals that family planning policies have a long-term negative impact on women's mental health, with effects primarily being direct rather than mediated through changes in education, marriage, or birth trajectories. This suggests that stringent family planning policies conflict with women's reproductive rights. Currently, China still enforces birth limits, and women in many other countries experience unwanted family planning measures, which could potentially contribute to future mental health burdens. The findings of this study underscore the importance of comprehensively evaluating the implications of family planning policies on population health.

A growing body of literature investigates the long-term impact of early life reproductive experiences, such as fertility history and contraceptive use, on women's health across the life course. However, these studies often require longitudinal data spanning from young adulthood to older adulthood, which are typically scarce in low- and middle-income countries (LMICs). Current findings predominantly stem from research conducted in high-income countries. Leveraging recent data availability, this dissertation explores the effects of fertility and

contraceptive use on Indian women's physical health in later life and their risk of early onset menopause. The study identifies new findings that diverge from those observed in high-income countries. In India, an increased number of childbirths is associated with a reduction in mothers' body mass index (BMI) and a decreased likelihood of being overweight, contrasting with findings from high-income countries. This association is particularly pronounced among mothers without schooling, indicating lower socioeconomic status and limited access to resources, which may contribute to nutritional constraints. Additionally, the research reveals that Indian women who have three or more births are more likely to experience early natural menopause, whereas in high-income countries, the likelihood of early menopause tends to decrease up to three births. These findings contribute to global comparisons and offer new insights into reproductive health and women's well-being throughout the life course.

This dissertation also introduces methodological innovations that could inspire future study designs. Assessing the impact of early life reproductive experiences on early natural menopause typically necessitates panel data that captures women's reproductive histories and menopausal status at various points in time. In India, however, only cross-sectional surveys are available, which measure reproductive experiences and menopause status at the time of the interview without chronological sequence. To address this challenge, where early life reproductive experiences are missing for current survey participants, I utilized an imputation method. This involved using socio-demographic information shared by participants and women from an earlier survey, which asked about their current reproductive experiences. Despite being based on different study populations, this earlier survey data served as a proxy for the early life experiences of the current study participants. An alternative method for addressing missing data in this context is the synthetic cohort method (Karra and Fink 2019), which categorizes

individuals into groups defined by socio-demographic characteristics and uses mean values from earlier surveys within the same groups to fill in missing data. However, the imputation method employed in this dissertation improves upon the synthetic cohort method by considering both mean values and variability in the available data, thereby enhancing the precision of missingness estimates. This methodological approach holds promise for numerous studies aiming to assess the impact of early life conditions when only cross-sectional data are available at different time points. It proves particularly valuable for research into reproductive health across the life course, where understanding early life reproductive experiences is crucial.

5.2 Future research

This dissertation adopts a life course approach to study early life reproductive experiences and women's well-being in later life. Life course studies typically span decades and require extensive follow-up across a person's lifetime or even intergenerationally. However, such longitudinal data are currently lacking in China and India.

In Paper 1, the study measured the differential start years of family planning policies across provinces but acknowledged the potential for greater variation at lower administrative levels such as counties or villages/urban communities, and among individuals. The China Health and Retirement Longitudinal Study (CHARLS) collected data related to the One-Child Policy (OCP) at each surveyed village/urban community but lacked comprehensive measures of the 'Later-Longer-Fewer' Policy (LLFP) and individual-level exposures. Future studies could benefit from life history surveys collecting data on policy start years, penalties for violations, compliance awards at lower administrative levels, and individuals' personal experiences with family planning policies. While retrospective data collection may introduce recall bias, it would yield valuable insights into policy exposures, enhancing assessments of individual exposure.

In Paper 2, the study found that the association between childbirth and mothers' physical health was stronger among those without any formal schooling, suggesting a potential pathway through limited food access or adoption of healthier diets. While the Longitudinal Aging Study in India (LASI) included questions on current food security status, historical measures of food security or diet were absent. Enhanced data collection on these topics would illuminate mechanisms linking early life experiences to later life health outcomes. In addition, in Paper 2, to address the potential impact of abortion on the sex distribution of first births and to satisfy the independence assumption for IV analysis, I conducted a sensitivity analysis among women with no history of abortion. This approach was necessary due to the lack of data specifying whether abortions occurred before or after the first birth. While this method may have inadvertently excluded some women who had abortions after their first birth, I believe the effect on the overall results is minimal. This is because the reported rate of abortions in the sample is low (2.3% of the total women sampled), leading to only a small number of exclusions from the study population. It is important to note that collecting data on the timing of abortions in future research would be beneficial. Such data could help answer significant research questions, such as whether abortion influences the sex distribution of the first birth, and whether the number of abortions differs based on the sex of the first birth. Addressing these questions could provide deeper insights into the relationship between fertility and women's physical health.

In Paper 3, the study was constrained by the Demographic and Health Survey's (DHS) measurement of women's current menopausal status without timing of menopause occurrence. Consequently, the study focused on women under age 45 to examine early natural menopause, excluding older women who had reached menopause earlier. This limitation reduced the generalizability of findings and restricted the ability to detect differences due to fewer

menopause cases in the study sample. Future research should prioritize comprehensive data collection on menopause, including timing and symptoms, to enrich analyses of this critical period in women's life courses.

Moreover, in Paper 3, the study utilized an imputation method to estimate study women's early contraceptive use, enabling assessment of its role in early natural menopause. However, this approach may introduce bias or uncertainty due to assumptions in modeling early contraceptive use. Future studies would benefit from enhanced data collection on early contraceptive practices, including timing, to improve accuracy in assessing their impact.

To address the challenges of limited data availability and obtain high-quality evidence, I applied advanced study designs and econometric and statistical methods. Future research, with increased data availability, should focus on enhancing causal inference. In Paper 1, to mitigate the impact of confounding factors related to family planning policy exposures and later-life mental health outcomes, I adopted the analysis strategy from a previous study (Chen and Fang 2021). This strategy utilizes province-level variations in the initiation year of these policies, which are independent of provincial social, political, and economic conditions. I expanded this approach by including exposures to the OCP and the OHCP. Future research could further utilize the variations in OHCP implementation. The OHCP was implemented in only 19 out of 31 provinces with significant variations in policy initiation years and exclusively in rural areas. These variations allow for more nuanced comparisons, such as between rural and urban areas within OHCP-implemented provinces, and between rural/urban areas in provinces that did and did not implement OHCP. In Paper 1, I only used a summary measure of OHCP exposure and compared individuals' difference in OHCP exposure. Future analysis of the impact of family planning policies would greatly benefit from those external variations. In Paper 2, to address the

unmeasured confounding factors between fertility and women's later-life physical health outcomes, I employed an instrumental variable (IV) method by leveraging India's son-preference culture, which has been strongly associated with higher fertility rates among mothers whose first-born child is a daughter. However, the sex of the first-born is quite imbalanced in our data. To ensure the validity of the IV analysis, I controlled for a set of socio-demographic variables to satisfy the independent assumption. In future research, with access to genetic variants associated with both fertility and physical health outcomes, Mendelian randomization analysis could provide more robust evidence by better fulfilling the IV assumptions. This approach could strengthen the causal inference between fertility and physical health outcomes. In Paper 3, to address potential threats of reverse causality, I measured women's fertility and contraceptive use behavior at least 15 years prior to the measure of menopause status. To control more early life confounding factors, I employed multiple imputation methods to obtain imputed early life conditions. Despite these efforts, there may still be unmeasured confounders and reverse causality issues. Future research could benefit from utilizing data from older family planning intervention programs to study longer-term outcomes. For instance, the Matlab maternal and child health/family planning program (Barham et al. 2021) provides rich data on fertility and contraceptive use and includes treatment and comparison groups with similar socioeconomic characteristics, differing only in intervention status. This setup would minimize the impact of unmeasured confounders and clearly delineate the timing of exposure and outcomes, offering a more robust analysis.

In addition to improving data collection efforts and making efforts in getting causal inference, several potential studies could build upon the findings of this dissertation.

The first paper revealed a long-term association between family planning policies and women's mental health in later life. While the study identified high-school education, early marriage, and total births as potential mediators linking family planning policies to later mental health, it did not conduct a formal mediation analysis. Future research could explore these mechanisms in greater depth, quantifying the specific roles of each mediator in connecting family planning policies with women's mental health outcomes over time. Such analysis could provide valuable insights into how policy interventions impact individual health through intermediate factors.

Moreover, the implementation of the 'One-and-a-Half-Child' Policy (OHCP) exhibited considerable variations across urban and rural areas, with some regions never implementing OHCP and others experiencing policy changes over multiple time periods. These disparities may have exacerbated urban-rural differences in total birth limits, potentially influencing women's education, marriage patterns, and long-term mental health outcomes. Given that women born after the mid-1960s were primarily exposed to OHCP during their reproductive years, it is crucial to revisit these cohorts in future studies as they age and become more representative within datasets like CHARLS. This would enable researchers to assess how urban-rural disparities in family planning policy implementation have shaped lifetime births, educational attainment, marriage trends, and mental health outcomes among women over time.

The second paper revealed that an increased number of childbirths is associated with lower grip strength, BMI, and a decreased likelihood of being overweight among mothers. This association was particularly pronounced among mothers without formal schooling, suggesting a potential pathway involving nutrition. Future research could explore this further by conducting a mediation analysis once data on food security and dietary patterns become available. Such an

analysis would help quantify the role of nutrition in connecting childbirths to women's later physical health outcomes.

Additionally, the study employed an instrumental variable method, assuming that the sex of the first-born child influences women's physical health primarily through its impact on the total number of births. However, this exclusion assumption may be challenged in the context of India's dowry culture, where daughters' marriages entail significant household costs. Future research could investigate this by examining data on children-related household expenditures. Conducting a mediation analysis in this regard would assess whether children's costs mediate the relationship between the sex of the first-born and women's physical health in later life. This approach would also help evaluate the validity of using the instrumental variable method in this context.

The third paper investigates the associations between early life reproductive characteristics and early natural menopause among Indian women. Due to the lack of data on the timing of menopause occurrence, the study utilized logistic regression to assess the odds of experiencing natural menopause. However, understanding the timing of natural menopause carries significant clinical and health implications. Future research could benefit greatly from conducting survival analysis using data that includes precise timing of natural menopause. Survival analysis would allow for a more nuanced examination of how early life reproductive experiences impact the timing of natural menopause. By incorporating data on the age at which menopause occurs, researchers could explore whether factors such as early marriage, childbirth before age 20, parity, and contraceptive use influence the timing of menopause onset. This approach would provide deeper insights into the longitudinal effects of reproductive health experiences on women's health trajectories across the life course.

5.3 References

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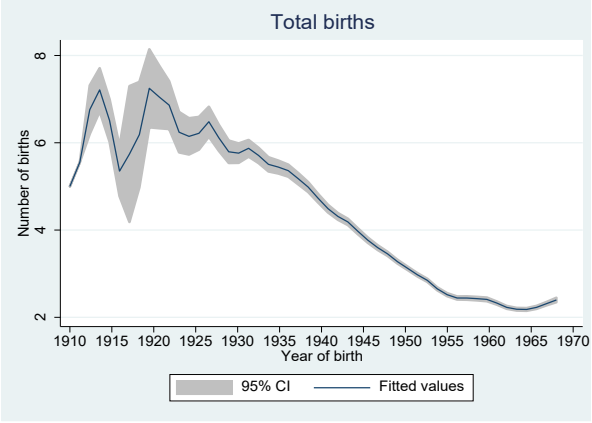
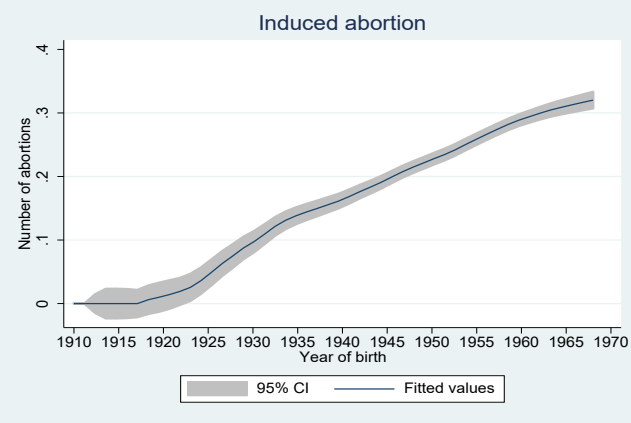
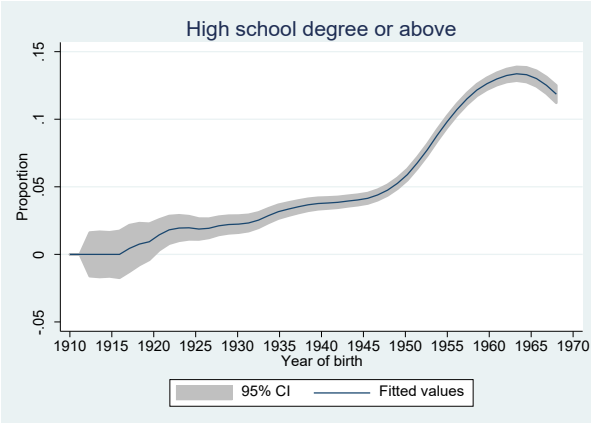
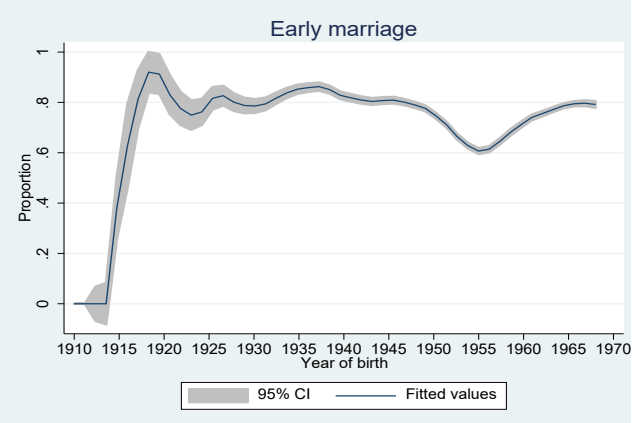
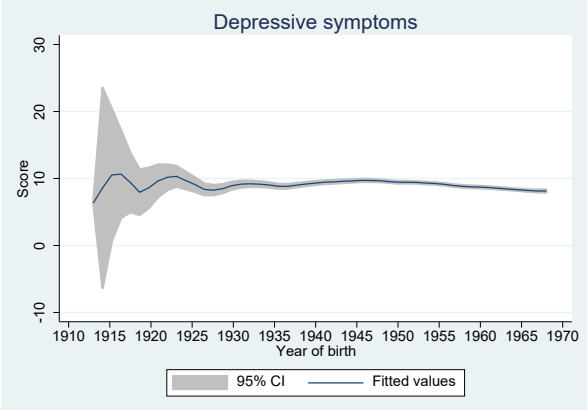
Supplemental materials for Chapter 2

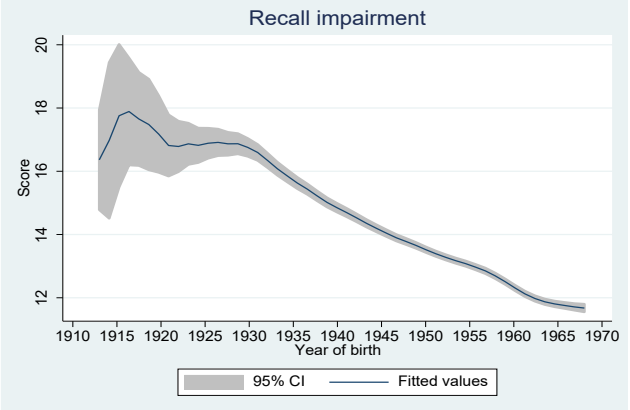


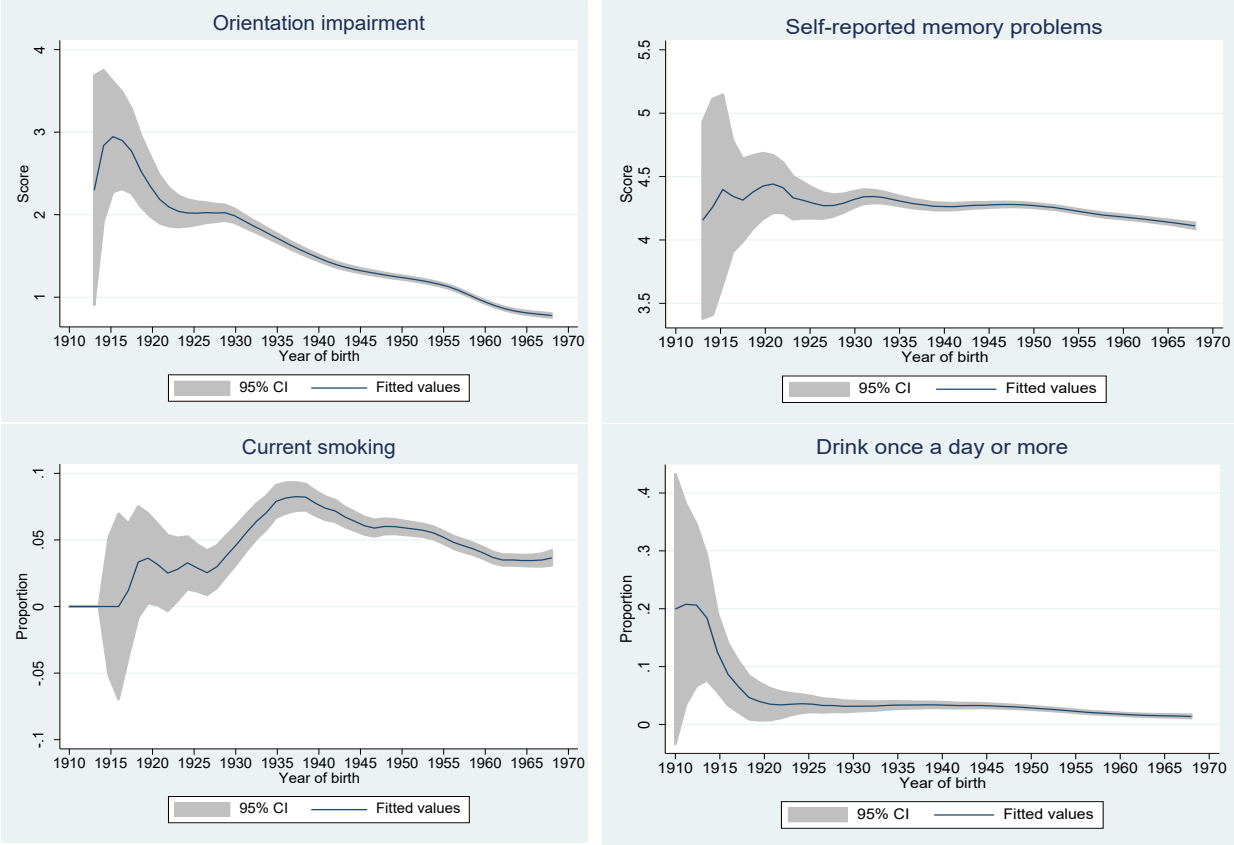












Appendix Figure 2.1 Demographic and mental health outcomes across birth cohorts

Supplemental materials for Chapter 3

Appendix Table 3.1 Descriptive characteristics of fathers

	Son (N=12,802)	Daughter (N=9,006)	Total (N=21,808)
Age in years	63.0 (9.6)	62.4 (9.5)	62.7 (9.6)
Years of education	5.3 (5.0)	5.6 (5.0)	5.5 (5.0)
Religion			
Hindu	9,616 (75.1%)	6,557 (72.8%)	16,173 (74.2%)
Muslim	1,481 (11.6%)	1,089 (12.1%)	2,570 (11.8%)
Christian	1,107 (8.6%)	955 (10.6%)	2,062 (9.5%)
Other	598 (4.7%)	405 (4.5%)	1,003 (4.6%)
Place of residence			
Urban	4,171 (32.6%)	3,091 (34.3%)	7,262 (33.3%)
Rural	8,631 (67.4%)	5,915 (65.7%)	14,546 (66.7%)
Ever had an abortion			
No	12,552 (98.0%)	8,804 (97.8%)	21,356 (97.9%)
Yes	250 (2.0%)	202 (2.2%)	452 (2.1%)
Total number of births	4.0 (2.2)	4.2 (2.1)	4.1 (2.1)
Systolic blood pressure (mm Hg)	129.9 (19.0)	130.1 (18.5)	130.0 (18.8)
Diastolic blood pressure (mm Hg)	82.3 (10.7)	82.6 (10.5)	82.4 (10.6)
Waist hip ratio	1.0 (0.1)	1.0 (0.1)	1.0 (0.1)
Body mass index	22.0 (4.1)	22.1 (4.1)	22.1 (4.1)
Grip strength (kilograms)	27.6 (7.8)	27.7 (7.9)	27.7 (7.9)
High blood pressure			
No	8,269 (64.7%)	5,785 (64.3%)	14,054 (64.5%)
Yes	4,520 (35.3%)	3,207 (35.7%)	7,727 (35.5%)
Underweight			
No	7,114 (72.7%)	5,121 (74.4%)	12,235 (73.4%)
Yes	2,670 (27.3%)	1,763 (25.6%)	4,433 (26.6%)
Overweight			
No	7,114 (71.3%)	5,121 (71.6%)	12,235 (71.4%)
Yes	2,861 (28.7%)	2,031 (28.4%)	4,892 (28.6%)

Note: standard deviations for continuous variables are in parentheses.

Appendix Table 3.2 OLS and IV analysis results on parity and fathers' physical health

Outcome	Standardized coefficient	*P* value	95% Confidence Interval
Systolic blood pressure			
OLS	-0.001	0.807	(-0.008, 0.006)
IV			
First stage	0.315***	<0.001	(0.262, 0.367)
Second stage	-0.025	0.541	(-0.106, 0.056)
Kleibergen-Paap Wald rk F statistic	139.12		
Diastolic blood pressure			
OLS	-0.003	0.403	(-0.01, 0.004)
IV			
First stage	0.315***	<0.001	(0.262, 0.367)
Second stage	0.014	0.733	(-0.068, 0.097)
Kleibergen-Paap Wald rk F statistic	139.12		
Waist hip ratio			
OLS	-0.001	0.777	(-0.008, 0.006)
IV			
First stage	0.319***	<0.001	(0.267, 0.372)
Second stage	-0.087*	0.034	(-0.168, -0.006)
Kleibergen-Paap Wald rk F statistic	141.66		
Body Mass Index			
OLS	-0.014***	<0.001	(-0.021, -0.008)
IV			
First stage	0.32***	<0.001	(0.267, 0.372)
Second stage	-0.054	0.165	(-0.131, 0.022)
Kleibergen-Paap Wald rk F statistic	142.45		
Grip strength			
OLS	-0.004	0.221	(-0.011, 0.002)
IV			
First stage	0.321***	<0.001	(0.268, 0.373)
Second stage	-0.023	0.527	(-0.096, 0.049)
Kleibergen-Paap Wald rk F statistic	143.43		
High blood pressure			
OLS	0.001	0.491	(-0.002, 0.005)
IV			
First stage	0.315***	<0.001	(0.262, 0.367)
Second stage	-0.011	0.608	(-0.051, 0.03)
Kleibergen-Paap Wald rk F statistic	139.12		

Under weight			
OLS	0.002	0.378	(-0.002, 0.005)
IV			
First stage	0.317***	<0.001	(0.256, 0.378)
Second stage	0.005	0.82	(-0.036, 0.046)
Kleibergen-Paap Wald rk F statistic	102.19		
Overweight			
OLS	-0.005**	0.002	(-0.009, -0.002)
IV			
First stage	0.31***	<0.001	(0.255, 0.366)
Second stage	-0.036	0.093	(-0.079, 0.006)
Kleibergen-Paap Wald rk F statistic	118.92		

Notes: For both OLS and IV analysis, we used standardized outcomes to make the effect size comparable across health outcomes. We controlled basic demographic information, including mothers' current age, education attainment, rural or urban residency, and religion, as well as state residency fixed effects to address any unmeasured, time-constant confounding factors. We also adjusted community level clusters for robust standard errors. ***p<0.001; **p<0.01, *p<0.05.

Appendix Table 3.3 Sensitivity analysis results of parity and mothers' physical health

	Standardized coefficient	*P* value	95% Confidence Interval
Systolic blood pressure	-0.061	0.116	(-0.137, 0.015)
Diastolic blood pressure	-0.006	0.882	(-0.082, 0.07)
Waist hip ratio	0.06	0.111	(-0.014, 0.134)
Body mass index	-0.073*	0.045	(-0.144, -0.002)
Grip strength	-0.084*	0.018	(-0.154, -0.015)
High blood pressure	-0.015	0.426	(-0.05, 0.021)
Underweight	-0.006	0.795	(-0.049, 0.038)
Overweight	-0.042*	0.039	(-0.083, -0.002)

Notes: Results are based on IV analysis after we excluded 698 women ever with an abortion. We used standardized outcomes to make the effect size comparable across health outcomes. We controlled basic demographic information, including mothers' current age, education attainment, rural or urban residency, and religion, as well as state residency fixed effects to address any unmeasured, time-constant confounding factors. We also adjusted community level clusters for robust standard errors. ***$p<0.001$; **$p<0.01$, *$p<0.05$.

Appendix Table 3.4 Descriptive characteristics of mothers by participation in physical measures status

	In (N=30,065)	Not in (N=2,526)	Total (N=32,591)
Sex of the first born			
Son	17,723 (58.9%)	1,490 (59.0%)	19,213 (59.0%)
Daughter	12,342 (41.1%)	1,036 (41.0%)	13,378 (41.0%)
Ever had an abortion			
No	29,367 (97.7%)	2,466 (97.6%)	31,833 (97.7%)
Yes	698 (2.3%)	60 (2.4%)	758 (2.3%)
Total number of births	4.2 (2.2)	4.0 (2.2)	4.2 (2.2)
Age in years	59.3 (10.5)	61.7 (12.4)	59.5 (10.6)
Years of education	2.8 (4.2)	3.2 (4.8)	2.8 (4.2)
Religion			
Hindu	22,117 (73.6%)	1,864 (73.8%)	23,981 (73.6%)
Muslim	3,679 (12.2%)	300 (11.9%)	3,979 (12.2%)
Christian	2,923 (9.7%)	244 (9.7%)	3,167 (9.7%)
Other	1,346 (4.5%)	118 (4.7%)	1,464 (4.5%)
Place of residence			
Urban	10,480 (34.9%)	1,058 (41.9%)	11,538 (35.4%)
Rural	19,585 (65.1%)	1,468 (58.1%)	21,053 (64.6%)

Note: standard deviations for continuous variables are in parentheses.

Appendix Table 3.5 Descriptive characteristics of fathers by participation in physical measures status

	In (N=21,808)	Not in (N=1,929)	Total (N=23,737)
Sex of the first born			
Son	12,802 (58.7%)	1,155 (59.9%)	13,957 (58.8%)
Daughter	9,006 (41.3%)	774 (40.1%)	9,780 (41.2%)
Ever had an abortion			
No	21,356 (97.9%)	1,898 (98.4%)	23,254 (98.0%)
Yes	452 (2.1%)	31 (1.6%)	483 (2.0%)
Total number of births	4.1 (2.1)	3.8 (2.1)	4.1 (2.1)
Age in years	62.7 (9.6)	63.3 (10.6)	62.8 (9.6)
Years of education	5.5 (5.0)	6.0 (5.5)	5.5 (5.1)
Religion			
Hindu	16,173 (74.2%)	1,459 (75.6%)	17,632 (74.3%)
Muslim	2,570 (11.8%)	216 (11.2%)	2,786 (11.7%)
Christian	2,062 (9.5%)	162 (8.4%)	2,224 (9.4%)
Other	1,003 (4.6%)	92 (4.8%)	1,095 (4.6%)
Place of residence			
Urban	7,262 (33.3%)	791 (41.0%)	8,053 (33.9%)
Rural	14,546 (66.7%)	1,138 (59.0%)	15,684 (66.1%)

Note: standard deviations for continuous variables are in parentheses.

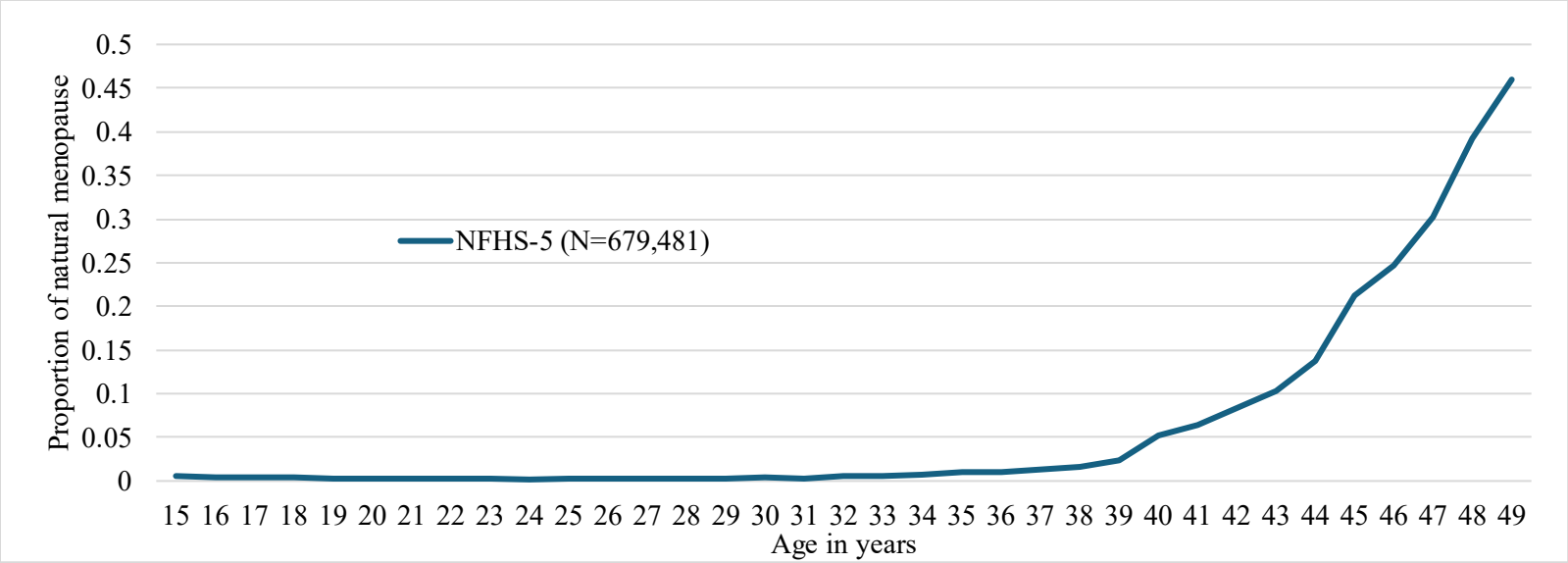
Supplemental materials for Chapter 4

Appendix Table 4.1 Descriptive characteristics of study women survey in NFHS-5 and their counterparts surveyed in NFHS-3 (weighted)

	Observed data for NFHS-5 women in 2019	Imputed or assigned data for NFHS-5 women in 2005	Observed data for NFHS-3 women in 2005[2]
Early natural menopause	4.7%	Not Apply[3]	0.7%
Reproductive characteristics			
Married before age 20	59.7%	59.7%	63.5%
Giving birth before age 20	40.1%	40.1%	46.2%
Number of births			
0	4.0%	25.6%	26.6%
1	10.2%	22.7%	19.5%
2	38.1%	28.9%	25.7%
3	24.3%	15.0%	15.4%
>=4	23.3%	7.8%	12.9%
Sterilization	51.6%	20.1%	21.7%
Ever use oral pills[1]	14.2%	9.3%	10.7%
Ever use IUDs[1]	5.2%	3.3%	4.4%
Life style characteristics			
Current smoking[1]	6.4%	7.3%	7.8%
Current drinking[1]	1.2%	1.7%	1.9%
Body Mass Index[1]			
Underweight	9.9%	32.1%	36.2%
Normal	55.1%	59.5%	55.4%
Overweight	35.0%	8.4%	8.4%
Other demographic characteristics			

Mean year of birth	1980.7	1980.7	1980.7
Religion			
Hindu	82.3%	82.3%	81.0%
Muslim	12.1%	12.1%	13.5%
Christian	2.6%	2.6%	2.3%
Other	3.0%	3.0%	3.2%
Caste			
Schedule caste	21.1%	21.1%	19.1%
Schedule tribe	9.3%	9.3%	8.5%
Other backward caste	43.5%	43.5%	39.4%
None of them	26.2%	26.2%	33.0%
Less than a secondary education	50.0%	50.0%	50.0%
Anemia[1]	32.7%	39.1%	36.2%
Poor[1]	37.1%	28.2%	36.9%
Rural residence[1]	65.2%	68.3%	68.1%

Notes: Results are weighted. [1] Characteristics of NFHS-5 women in 2005 were based on imputation. [2] Only included NFHS-3 women of the same years of birth as NFHS-5 study women. [3]NFHS does not have data on the timing of menopause and we do not impute it since we do not use it in the regression models.



Appendix Figure 4.1 Prevalence of natural menopause in NFHS-5 women

Note: NFHS - The National Family Health Survey. The results were unweighted. Totally, there are 724,115 women. We exclude those had hysterectomy (2.9%), who never had menstruation or don't know their menstruation status (2.8%), and those who reported their last menstruation before last birth and currently are not in lactation amenorrheic (0.4%).