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Nonlinear Relationship between the Number of Children and Late-Life Cognition[*]

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Abstract

Late-life cognition is a growing concern as populations age. This study investigates how the number of children affects late-life cognition in rural China by exploiting the exogenous variation in the rollout timing of Family Planning Policies. Theoretical analysis suggests a nonlinear effect along the fertility dimension. Using data from the China Health and Retirement Longitudinal Study, we find nonlinear causal effects of fertility. Having one more child when the mother has 4+ children leads to adverse effects on a range of late-life cognition measures, while positive effects exist for episodic memory and mental intactness at low parities, implying hump-shaped effect heterogeneity. Underlying this hump-shaped causal relationship is increased interaction with children but a greater risk of chronic conditions.

Keywords: Late-life cognition, dementia, mental intactness, aging, fertility, family planning
JEL classification: I12, I15, J13, J14

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1 Introduction

Population aging accelerates worldwide as people live longer and have fewer children. Associated with this demographic shift, the prevalence of old-age memory and cognition problems, such as dementia, has increased dramatically. In 2019, dementia cost 1.3 trillion US dollars globally, and approximately 50% of the estimated cost is attributable to care provided by informal carers such as family members (WHO, 2023). Particularly in developing countries, the lack of a developed social security system implies the critical role of children in providing care to the elderly.

Does this mean having fewer children accelerates old parents' cognitive decline? In empirical applications, there is no particular reason to assume that the underlying relationship is linear. Recent correlational studies suggest that while having a child plays an important role in maintaining late-life cognition, the impact varies substantially by the number of children (or parity). Read and Grundy (2017) find that having two children is associated with better cognition compared to any other number. Saenz et al. (2021) also find a hump-shaped relationship with a peak at 2-3 children. Other studies that focus on a specific parity also indicate hump-shaped relationships (Gemmill and Weiss, 2022; Yang et al., 2022). However, existing studies on this nonlinear relationship are all correlational, and whether the reported hump-shaped relationship is causal remains unknown. A careful causal investigation is essential because of omitted variable bias; that is, parents with fewer children and those with many children are likely to have different baseline characteristics.

Theoretically, there are two reasons to expect a nonlinear causal effect of fertility on late-life cognition. First, the marginal benefits of having children, such as physical and mental support, appear to decrease with the number of children, whereas its marginal costs, such as birth-related physical health burden and future financial burdens, are likely to be constant (or often even increasing), indicating that marginal benefits may dominate at low parities and marginal costs at high parities, resulting in a hump-shaped net effect of having an additional child. Second, less obviously but no less importantly, the production of late-life cognition requires different inputs, which may complement each other. Some of such inputs increase with the number of children, while others decrease. For example, consider social interaction and physical health. The former increases as one has more children, and the latter decreases. Standard technologies such as Cobb-Douglas and CES, which feature complementarity between inputs, imply that the production of late-life cognition may exhibit a hump-shaped relationship along parity. Whether such a hump-shaped relationship exists and, if it exists, what number of children maximizes cognition production have yet to be investigated.

This paper analyzes the nonlinear effect of the number of children (henceforth the effect of fertility) on the cognition of rural elderly women, exploiting the exogenous variation in the rollout timing of Family Planning Policies (FPPs). We focus on women firstly because women are more likely to develop dementia and have more severe symptoms due to biological differences and social gender roles (Mielke, 2018; WHO, 2023), and secondly because our identification strategy is more suitable for women. Our sample consists of four waves from the China Health and Retirement Longitudinal Study (CHARLS) data (2011, 2013, 2015, and 2018) of females aged 60 and above in rural China. We begin with estimating a linear model using measurements of exposure to FPPs as instrumental variables (IVs), then advance to nonparametric and quadratic IV approaches to explore the nonlinear causal effect. We also discuss potential mechanisms underlying the nonlinear causal relationship we find.

Our study contributes to the extensive literature on the causal effect of fertility. To our knowledge, no past studies have scrutinized nonlinearity primarily because they use IV strategies based on twins or the sex composition of the first two children (Angrist and Evans, 1998; Black et al., 2005; Rosenzweig and Zhang, 2009; Black et al., 2010; Oliveira, 2016), which do not allow for comparing causal effects by parity. Focusing on a particular fertility margin can mislead us with limited understanding. Moreover, assuming a linear underlying relationship restricts the marginal effects to be constant across all fertility margins, potentially yielding biased, misleading estimates and misguided policy implications. If the true relationship is U-shaped (or inverse U), the estimated slope of a linear model can be close to zero. To uncover potentially nonlinear causal effects, we build on the identification strategy of Chen and Fang (2021), which focuses on provincial heterogeneity in the implementation of "Later, Longer, Fewer" (LLF), the early phase of FPPs. Unlike Chen and Fang (2021), we construct measurements of exposure to not only LLF but also One-Child Policy (OCP), distinguishing these two inherently different FPPs. We thus have exogenous variations sufficiently richer to identify the causal effect of fertility at each parity.

Our study also contributes to the active research on the effect of fertility on health in old age by providing causal evidence on late-life cognition. Existing studies focus on physical and mental health outcomes such as BMI, health status, and depression (Cáceres-Delpiano and Simonsen, 2012; Joshi and Schultz, 2013; Kruk and Reinhold, 2014). Empirical evidence on the fertility effect on late-life cognition is still scant, with the majority being correlational. To our knowledge, Bonsang and Skirbekk (2022) is the only exception. They use the sex composition of the first two children as IV. Using data from the Survey of Health, Ageing, and Retirement in Europe, they find having 3 or more children leads to *worse* late-life cognition compared to 2 children. However, they focus on only this parity, and nonlinearity remains to be investigated.

Furthermore, there is a paucity of causal evidence in developing countries. We are the first to examine the causal link between fertility and late-life cognition in less developed countries, where family members are often the primary source of old-age support.

We find that having another child beyond 4 leads to robust adverse effects among rural elderly women on a variety of late-life cognition measures, including episodic memory (ability to recall words), mental intactness (ability to perform mathematical tasks and time orientation), and graphical cognition (ability to redraw a picture). Meanwhile, positive effects occur at low parities for episodic memory and mental intactness. The fertility effects on late-life cognition thus suggest a hump-shaped pattern. Specifically, mental intactness improves at lower parities, whereas it declines rapidly after four children. The hump shape may be due to cross-parity changes in intergenerational social interaction, upward financial transfers, and physical functioning. We investigate these channels and find that elderly parents with more children are more likely to have a child living nearby or together and receive weekly visits from children, while they are more likely to have chronic conditions that increase the risk of dementia.

The current world fertility rate is 2.3 (UNDESA, 2022), falling on the left side of the hump-shaped effect heterogeneity. This implies that, on average, declining fertility will accelerate the decline of late-life cognition. At the same time, our results of effect heterogeneity call for different social policies based on fertility levels: for low-fertility individuals, policies should concentrate on facilitating social interactions; while for high-fertility individuals, policies should emphasize improved healthcare access.

2 Why nonlinearity?

The number of children may affect late-life cognition through many channels. (1) Social interaction. With more children, upward social support increases, decreasing the risk of parents' social isolation, a widely reported risk factor for cognitive impairment (Vlachantoni et al., 2015; Ihle et al., 2018). (2) Upward transfers. With more children, financial transfers increase, and so does the knowledge of health management. These are protective against cognitive decline (Oliveira, 2016; Liu, 2021; Peng et al., 2023). (3) Financial stress. More children lead to greater childrearing costs and opportunity costs in the labor market, which could impair cognition (Rohwedder and Willis, 2010; Bonsang et al., 2012; Bradbury, 2014; Aaronson et al., 2021). (4) Physical and mental burden. Childrearing increases the risk of high blood pressure, smoking, and obesity (Cáceres-Delpiano and Simonsen, 2012; Wu and Li, 2012). Childrearing also increases mental stress due to reduced leisure activities, less time to relax, and reduced privacy. These health burdens may impair cognition (Aggarwal et al., 2014; Prenderville et al., 2015; WHO, 2023).

While such many channels can lead to any nonlinearity in general, conceptually, the number of children, n, and late-life cognition, LC, may exhibit a hump-shaped relationship for two particular reasons. First, an increase in n involves both marginal benefits and marginal costs. If marginal benefits outweigh at low parities and marginal costs at high parities, the net effect of having n-th child first increases then decreases as n gets larger. Second, the production of late-life cognition requires different inputs, which may complement each other. If social interaction and upward transfers increase with the number of children while physical health decreases, standard technologies with complementarity between inputs imply that the production of late-life cognition may exhibit a hump-shaped relationship (Mogstad and Wiswall, 2016). To illustrate this second mechanism, we present a stylized two-period model of utility-maximizing mothers.

The mother maximizes lifetime utility by choosing in Period 1 the level of consumption, savings, the number of children, n, and time allocation (among work, childrearing, and health-producing activities). In Period 2, physical health is produced, followed by the production of late-life cognition, which features complementarity between two inputs: physical health (which decreases with n) and social interaction (or any other services that increase with n).

Specifically, the mother maximizes lifetime utility subject to budget and time constraints and technologies to produce late-life physical health and cognition as follows:

$$\max_{c_1,s,n,t_l,t_k,t_h} U(c_1, c_2, n, LH, LC) = \ln c_1 + \delta \ln n + \beta[\ln c_2 + \eta \ln LH + \gamma \ln LC]$$

$$s.t.$$

$$c_1 + \theta n + s = wt_l,$$

$$c_2 = (1 + r)s + \tau n,$$

$$1 = t_l + t_k + t_h,$$

$$t_k = \kappa n,$$

$$LH = LH(n, t_h, c_1, c_2) = vt_h + ln(c_1 + c_2) - n,$$

$$LC = [\rho LH^\sigma + (1 - \rho)n^\sigma]^{1/\sigma},$$

where lifetime utility is drawn from goods consumption c_1 and c_2, in Periods 1 and 2, respectively, the number of children n, late-life physical health LH, and late-life cognition LC, with β being the time discount and δ, η, and γ being relative weights of other utility components. In Period 1, the mother optimally chooses c_1, savings s, n, and the time allocation to labor market activities t_l, childrearing activities t_k, and health maintenance t_h subject to the six restrictions. (1) the budget constraint in Period 1. The earnings, wage rate w times t_l, is allocated to c_1, childrearing cost, denoted as θn, and s. (2) the budget constraint in Period 2. The second-period consumption c_2 is determined by income from savings $(1 + r)s$ and transfers from children τn. (3) the time constraint in Period 1. The mother has an endowment of one unit of time and allocates it to t_l, t_k, and t_h. (4) time requirement for childrearing activities, κn. (5) late-life health production. The production of late-life physical health, LH, takes 3 types of inputs: LH increases in t_h and goods inputs c_1, c_2 (e.g., nutrition) and decreases in n (direct damage to health associated with childbearing). Lastly, (6) the technology to produce late-life cognition, which takes two inputs: physical health LH and the net benefit from other services, such as social interactions, proportional to n. A CES technology is assumed for the convenience of simulations. The parameter ρ determines the importance of LH relative to n, and σ determines the elasticity of substitution between the two inputs: $\lambda = 1/(1-\sigma)$. As λ becomes smaller, the two inputs exhibit stronger complementarity.

Our purpose is to illustrate the nonlinearity of the *causal effect* of n on LC, not the correlational relationship between n and LC which can emerge as the result of individual heterogeneity. In our simulation, we assume a representative mother (without individual heterogeneity) and set n exogenously as in the spirit of Chinese FPPs. As we change n, different levels of LC emerge as a result of restricted optimization. We show how the causal effect of n on LC varies across parities depending on the substitution elasticity (λ) and the relative importance of LH (ρ).

In the following simulations, we choose parameter values that represent a preference for fertility such that the unconstrained fertility choice is about five children, which aligns with the high fertility level before the implementation of FPPs.[1] Figure 1 shows the simulated late-life cognition. In Row A, $\lambda = 10$, indicating a weak complementarity between physical health and

[1] We use the following parameter values: $\beta = 0.5,\ \gamma = 1,\ \delta = 10,\ \eta = 1,\ r = 0.1,\ \theta = 1,\ \kappa = 0.1,\ \tau = 1,\ w = 20,$ and $v = 30$.

social interactions; in Row B, $\lambda = 1$, a Cobb-Douglas production; in Row C, $\lambda = 0.5$, indicating a strong complementarity between the two inputs; in Row D, $\lambda = 0.2$, indicating an even stronger complementarity. Each Column represents a different value of ρ. When $\rho = 0.1$, social interactions play a dominating role in cognition production; as ρ increases, the relative importance of physical health increases.

Figure 1 demonstrates that hump-shaped effect heterogeneity arises from complementarity. Row A, where complementarity is weak ($\lambda = 10$), shows no hump-shaped relationship because physical health can well substitute for social interactions, yielding flat curves. As complementarity becomes stronger, more salient hump-shaped patterns arise. With a strong complementarity (Row D), physical health cannot substitute for social interactions, and hence, the cognition level is determined by the insufficient input, which is social interactions when *n* is small and physical health when *n* is large.

Complementarity induces a hump-shaped relationship regardless of ρ. ρ per se is not a source of nonlinearity, but in cases with mild complementarity (Row B), extreme values of ρ obscure the hump shape. It thus remains an empirical question whether such a hump-shaped relationship exists in reality and, if it exists, what number of children maximizes cognition production.

3 Family planning policies in rural China

FPPs in China date back to the Document No.[62]698 in 1962, though it was never enforced strictly before 1970. A voluntary “Later, Longer, Fewer” policy, or LLF, started in the early 1970s, advocating later marriage, longer spacing between births, and fewer children. Document No.[71]51 released in 1971 required provincial governments to set up a Family

Planning Leading Group, an important and high-level institution to help the enforcement of LLF by implementing family planning campaigns and technical support for birth control (Chen and Fang, 2021), but overall, LLF enforcement was lenient.

In 1979, to curb population growth further, LLF was replaced with the One-Child Policy (OCP), a one-size-fits-all family planning policy calling for one child per couple. OCP was enforced more strictly than LLF, where families in violation of the policy would face demotion or ineligibility for promotion in government sectors and also had to pay fines equivalent to 10%-20% of both parents' wages for the next 3-14 years (Liao, 2013). While OCP was effective in urban areas until the 2010s, rural OCP encountered strong local resistance, which led to the relaxation of rural OCP in 1984.[2] By the end of the 1980s, fertility regulations could be classified into three types: one-child (one child allowed), one-and-half-child (a second child is allowed if the first is a girl), and two-child (two children allowed) policies.[3] The stabilized provincial birth regulations were not changed until the 2010s.

A woman's completed fertility level depends on the timing and length of exposure to FPPs, which varies by both geographical location and birth cohort. Geographical variation stems from the province-specific implementation of the FPPs. Figure 2 illustrates the geographic variation in FPPs across provinces. Panel A depicts the years of establishment of the LLF leading group. In Panel B, we present the number of children allowed in rural areas across provinces in 1990 after the relaxation of OCP. Comparing these two graphs reveals that the correlation of the cross-

[2] On April 13th, 1984, central government distributed Document No.7.

[3] By 1990 in rural areas, five provinces and major cities were regulated with a One-Child Policy; in 18 provinces, a second child was allowed if the firstborn was a girl; and in another five provinces, two children were generally allowed (Feng and Hao, 1992). In particular, One-Child Policy: Beijing, Tianjin, Shanghai, Jiangsu, and Sichuan; One-and-Half-Child Policy: Hebei, Inner Mongolia, Shanxi, Liaoning, Jilin, Heilongjiang, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangxi, Guizhou, Shaanxi, and Gansu; Two-Child Policy: Ningxia, Yunnan, Qinghai, Guangdong, and Hainan.

province variations of the two FPPs' intensity is not high. An early establishment of an LLF leading group is not associated with a stricter or less strict enforcement of OCP later. For example, Guangdong is the province with the earliest year of establishing the LLF leading group, but it allows for two children in the rural areas after the relaxation of OCP. Hence, using both LLF and OCP benefits us as they offer different sources of exogenous variations to strengthen our identification.

Additionally, a women's birth year determines the particular phase and duration of FPPs she experiences. Early cohorts are exposed to LLF only, middle cohorts to both LLF and OCP, and late cohorts to OCP only. Different cohorts also have different levels of realized fertility before the implementation of FPPs, indicating that FPPs also serve to restrain the further births of early cohorts who already had many children. [4] Taken together, regional variations in FPP implementation and differences in the birth year allow us to uncover the fertility effect, not only at lower parities but also at higher parities, despite FPPs' intention to limit the second child.

4 Data

4.1 Main data and sample restrictions

Our sample is obtained from CHARLS, a nationally representative longitudinal survey of individuals aged 45 years or older in China, led by Peking University. Designed based on the US Health and Retirement Study (HRS), CHARLS is comparable to several international aging surveys, such as the English Longitudinal Study of Ageing (ELSA) and the Indonesia Family Life

[4] For example, if she is born in a high-fertility province in an early cohort (with a longer period of unrestricted birth), she could have had multiple children prior to LLF or OCP. Exposure to OCP will forbid additional childbearing, resulting in an exogenous variation in fertility at a high parity of birth (from the desired number to the pre-OCP level).

Panel (IFLS). CHARLS contains detailed information on the demographic and socioeconomic characteristics and health measures of elderly Chinese. CHARLS is an ongoing survey project with its first round conducted in 2011, covering 10,257 households and 17,708 individuals from 28 provinces. It uses a stratified multistage probability-proportionate-to-size random sampling strategy to ensure a representative sample. The respondents were followed in 2013, 2015, and 2018. The response rate was over 80% across all waves (Zhao et al., 2020), exceeding 90% in rural areas, as is common with surveys in developing countries (Zhao et al., 2013).

We use four waves of CHARLS: 2011, 2013, 2015, and 2018. We first drop households with either spouse listed in a minority ethnic group because these households are exempt from FPPs (Peng, 1997; Chen and Fang, 2021). Then we restrict our sample to woman-year observations which: (1) have rural hukou and are older than 60 at the time of survey;[5] (2) have at least one living child;[6] (3) have no missing information of cognition tests and covariates; and (4) have a birth province that can be mapped with the particular province-level LLF/OCP policy. Since over 95% of families have six or fewer children, we cap the maximum number of children to six.[7] Our final sample consists of 2688 unique women and 5342 woman-year observations. The sample cohort ranges from 1921 to 1958, with an average of 1948.[8]

4.2 Main variables and summary statistics

We construct three measures of cognition following the existing literature (see, e.g., Lei et al., 2012; Ma, 2019; Wang et al., 2023). The first is episodic memory, which measures the

[5] Individuals aged 49 or older in 1969 are also excluded because they were unaffected by the family planning policy, making it impossible to predict their fertility based on the policy instrument. Their share in our data is less than 0.1%.
[6] We use the number of living children instead of live births, following Chen and Fang (2021).
[7] In the Appendix A.3, we check the estimates without capping the number of living children in a household.
[8] Our sample is not dominated by any specific cohort, and we report the sample distribution of cohorts in Appendix Figure A1.

cognitive ability to recall. Respondents were given 10 words and asked to recall them immediately after reading all the words and later after a few questions. Episodic memory is then measured by taking an average of two counts, with a higher value indicating better memory capacity. The second cognition measure is mental intactness, which is obtained by the sum of correct answers to 9 questions, including subtraction 7 from 100 for five times and recognition of current date (day of week, month, day, and year). These questions are taken from the Telephone Interview of Cognitive Status (TICS) test. This screening tool has demonstrated exceptional sensitivity and specificity in accurately distinguishing individuals with Alzheimer's disease (AD) from the general population. The third measure is graphical cognition, which is defined as an indicator variable that equals one if the respondent can redraw a picture shown by the interviewer.[9] These three scores are standardized in the regression analysis below.

The number of children in each wave is calculated by adding the total number of living children of the respondent and/or spouse, including both co-resident and non-co-resident children. In particular, the list of children is obtained from both the household roster and the respondent's childbearing information in CHARLS. Although children in our analysis include adopted, foster, and step-children, the focus of this paper is still the effect of the number of biological children because that is what our instruments influence. Figure 3 plots the average scores of three cognition outcomes by the number of children, along with linear and quadratic fitted lines, illustrating concave relationships, in particular for mental intactness, for which the quadratic fit indicates its peak at two children.

Finally, we obtain individual- and household-level control variables from CHARLS: age, age gap, education, spousal education, marital status, childhood health status, and health insurance.

[9] Graphical cognition is sometimes counted in mental intactness. We have confirmed the robustness of our results regarding this inclusion (Appendix A.3).

Following Chen and Fang (2021), we exclude controls such as household expenditures and children's education that might be determined after the household's fertility decision in order to avoid potential bad-control problems. Age is measured in years; age gap equals the husband's age minus the wife's age; education is measured by levels (illiterate, some elementary school, middle school, and high school or above); marital status is a dummy variable (1=married, and 0=otherwise); childhood health status is the retrospective self-evaluation of health before 16, measured by a categorical variable (1=excellent, 2=very good, 3=good, 4=fair, and 5= poor); health insurance status is a dummy variable (1=covered by public health insurance, and 0=otherwise). We further control province-level GDP per capita (measured in constant 2000 prices) and the number of hospital beds per 10,000 people constructed from the China Statistical Yearbook of corresponding years.

Table 1 shows the summary statistics of the main variables. The average number of children for a mother is 3.27. The sample is relatively uneducated; both the sampled women and their spouses have not completed elementary school on average. Most of them have a good retrospective self-evaluation of health at age 16 and are covered by public health insurance.[10]

5 Empirical strategy

We start with the following linear OLS model to study the effect of fertility:

Linear OLS:

$$cognition_{ipcw} = \beta_0 + \beta_1^{OLS} n\_kids_{ipcw} + \boldsymbol{\gamma Controls1}_{ipcw} + \boldsymbol{\delta Controls2}_{pw}$$

[10] Launched in 2003, New Cooperative Medical Insurance is the main public health insurance in rural China. The program was voluntary, but the participation rate has been high due to substantial subsidies from the government. It served 83% of rural residents in 2007 and 98.8% in 2015 (Bai and Wu, 2014; Chen et al, 2019).

$$+\lambda_p + \theta_p \times c + \eta_w + \varepsilon_{ipcw} \,,$$

where $cognition_{ipcw}$ is the late-life cognition (measured by episodic memory, mental intactness, or graphical cognition) of individual i born in province p in cohort c surveyed in wave w. n_kids_{ipcw} denotes the number of children; $\boldsymbol{Controls1}_{ipcw}$, individual-level controls, including age, gender, coverage of public health insurance, and own and spousal educational attainment; $\boldsymbol{Controls2}_{pw}$, province-level controls for survey wave w, including real GDP per capita (constant 2000 price) and the number of hospital beds per 10,000 population; $\lambda_p$and η_w, province and wave fixed effects, respectively; $\theta_p \times c$ is the province-specific linear cohort trends; and ε_{ipcw} the error term. β_1^{OLS} captures the linear association between the number of children and late-life cognition after controlling everything else in the equation.

β_1^{OLS}, however, is likely biased due to confounders such as unobserved preferences and family circumstances. To obtain reliable causal estimates, we exploit the exogenous variation in the fertility constraints created by FPPs. Specifically, unlike Chen and Fang (2021), which uses only LLF, we exploit LLF and OCP, two main phases of FPPs, for two reasons. First, this approach allows us to cover one's entire fertility period and hence construct a more complete and accurate history of policy exposure, enhancing the power of our instruments. Second, by having both policies in the same regression separately, we can contrast the effectiveness of each policy measure.

Our exposure measurements are constructed as follows. First, we measure exposure to LLF by following Chen and Fang (2021) with some modifications:

$$LLF_{p,c} = \sum_{a=15}^{a=49} \left[AFR_{p,1969}(a) \cdot I\left(c + a > T_p\right) \cdot I(c + a \leq 1979) \right].$$

$LLF_{p,c}$ measures exposure to LLF for mothers born in province p in cohort c. $AFR_{p,1969}(a)$ is the province-level rural fertility rate specific to age a in 1969 (Coale and Li, 1987). T_p denotes the establishment year of the Family Planning Leading Group in province p, and $I(c + a > T_p)$ is an indicator of whether the provincial leading group has been established by the time when a woman in cohort c reaches age a. $I(c + a \leq 1979)$ is an indicator of whether a woman in cohort c reaches age a no later than 1979. The use of $I(c + a \leq 1979)$ is the difference from Chen and Fang (2021). We assume LLF exposure ends when LLF is replaced by OCP.[11]

We measure exposure to OCP for rural women born in province p in cohort c as:[12]

$$OCP_{p,c} = \sum_{a=15}^{a=49} \left[AFR_{p,1978}(a) \cdot I(c + a > 1979) \cdot I(c + a \leq 2015)\right].$$

Each fertility year exposed to rural OCP in 1979-2015 is weighted by the province-level rural fertility rate specific to age a in 1978 (Coale and Li, 1987).

Taken together, $LLF_{p,c}$ and $OCP_{p,c}$ capture the FPP exposure more precisely as they account for age-specific fertility rate weighted years exposed to LLF and OCP separately, compared to a single-variable measure of total FPP exposure as in Chen and Fang (2021). Thus, the combination of $LLF_{p,c}$ and $OCP_{p,c}$ could produce more accurate estimates by allowing for differences in the intensity of exposure to different phases of FPP. Figure 4 illustrates these differences by showing the average number of children (left axis) and average exposure to LLF

[11] Chen and Fang (2021) define the exposure to LLF as $\text{CF\_LLF}_{p,c} = \sum_{a=15}^{a=49}\left[AFR_p(a) \cdot I(c + a > T_p)\right]$. For a detailed comparison of $\text{CF\_LLF}_{p,c}$ and $\text{LLF}_{p,c}$, see Appendix A.2.

[12] We use the term OCP to represent the FPPs during 1979-2015. Rural OCP started in 1979 in its strict form, and its enforcement was relaxed to various degrees after 1984, but we make no special treatment to the 5-year strict enforcement period, assuming that it makes no major difference on completed fertility because a 35-year-long fertility life allows a woman to adjust her fertility intertemporally.

and OCP across provinces (right axis) by cohorts 1920-1958.[13] For cohorts 1930 or older, the exposure to any FPP is negligible and the number of children fluctuates around 4.5. For cohorts 1930-1940, the exposure to LLF is increasing while exposure to OCP stays negligible and the number of children starts to decline at a slow rate. For cohorts 1941-1950, exposure to LLF continues to grow and exposure to OCP begins to pick up, while the number of children falls from above 4 to below 3 on average. For cohorts 1951 or younger, exposure to LLF declines quickly but exposure to OCP rises sharply, and the number of children decreases further to around 2.

The extent of local relaxations of the rural OCP may have a differential impact on completed fertility. To consider this, we classify our sample into three groups by three policy-group indicators: $Onechild$, $Twochild$, and $Oneandhalf$. $Onechild$ indicates whether the mother is born in provinces that enforced a one-child rule during the rural OCP. $Twochild$ and $Oneandhalf$ are defined similarly. In the IV regressions below, we interact $OCP_{p,c}$ with the three indicators to allow for policy-group specific effects of rural OCP. Thus, LLF and OCP measure exposure during the entire fertility period of women in our sample, who are at least 60 at each survey year (2011, 2013, 2015, or 2018). Hence, the youngest woman in our sample was born in 1958 and completed her fertility life by the time when OCP was abolished in 2015.

Our Linear IV estimation is based on the following first-stage and structural equations:

First-stage equation, Linear IV:

$$n\_kids_{ipcw} = \alpha_0 + \boldsymbol{\alpha_1 Z_{ipc}} + \boldsymbol{\gamma_1 Controls1}_{ipcw} + \boldsymbol{\delta_1 Controls2}_{pw}$$

$$+\lambda_p + \theta_p \times c + \eta_w + \varepsilon_{ipcw} .$$

[13] Specifically, we obtain the average exposure to LLF and OCP across provinces by taking the means of $LLF_{p,c}$ and $OCP_{p,c}$ across provinces for each cohort, respectively.

Structural equation, Linear IV:

$$cognition_{ipcw} = \beta_0 + \beta_1^{LinearIV} \widehat{n\_kids}_{ipcw} + \boldsymbol{\gamma_2 Controls1}_{ipcw} + \boldsymbol{\delta_2 Controls2}_{pw}$$

$$+\lambda_p + \theta_p \times c + \eta_w + \varepsilon_{ipcw} ,$$

where $\boldsymbol{Z}_{ipc}$ is a vector of four instruments: $LLF_{p,c}$, $OCP_{p,c} \times Onechild_p$, $OCP_{p,c} \times Twochild_p$, and $OCP_{p,c} \times Oneandhalf_p$; $\widehat{n\_kids}_{ipcw}$ is the predicted number of children from the first stage. Other variables are similarly defined as in the Linear OLS.

We relax the linearity assumption and explore nonlinearity in two ways. Our first approach is nonparametric, which imposes no functional-form restrictions. Specifically, we define a set of indicators at each fertility level: $atleast\_2$, $atleast\_3$, $atleast\_4$, $atleast\_5$, and $atleast\_6$. For example, $atleast\_2$ takes on 1 if a female has at least two living children and 0 if one child or none. For $atleast\_x, x \in \{2,3,4,5,6\}$, we estimate:

First-stage equation, Nonparametric approach:

$$atleast\_x_{ipcw} = \alpha_0 + \boldsymbol{\alpha}_{1,X} \boldsymbol{Z}_{ipc} + \boldsymbol{\gamma_1 Controls1}_{ipcw} + \boldsymbol{\delta_1 Controls2}_{pw}$$

$$+\lambda_p + \theta_p \times c + \eta_w + \varepsilon_{ipcw} .$$

Structural equation, Nonparametric approach:

$$cognition_{ipcw} = \beta_0 + \beta_{1,x}^{NonparametricIV} \widehat{atleast_x}_{ipcw} + \boldsymbol{\gamma_2 Controls1}_{ipcw} + \boldsymbol{\delta_2 Controls2}_{pw}$$

$$+\lambda_p + \theta_p \times c + \eta_w + \varepsilon_{ipcw} ,$$

where $\widehat{atleast\_x}_{ipcw}$ is the predicted value of the probability of having at least x children from the first stage. Other variables are defined similarly to the Linear IV. In each IV regression, the coefficient of interest is $\beta_{1,x}^{NonparametricIV}$, the causal effect of having at least x children on late-life cognition.

We also conduct a conventional quadratic IV estimation as a convenient way to summarize nonlinear relationships and calculate the turning point. We follow Løken et al. (2012) to use the predicted number of children, pn_kids_{ipcw}, and the predicted number of children squared ${pn\_kids_{ipcw}}^2$ as the instruments in the 2SLS estimation to obtain estimates of our coefficients of interest $\beta_1^{QuadraticIV}$ and $\beta_2^{QuadraticIV}$.[14] We refer to this model as Quadratic IV below:

First-stage equation I, Quadratic IV:

$$n\_kids_{ipcw} = \alpha_0 + \boldsymbol{\alpha_1 Q}_{ipc} + \boldsymbol{\gamma_{11} Controls1}_{ipcw} + \boldsymbol{\delta_{11} Controls2}_{pw}$$
$$+\lambda_p + \theta_p \times c + \eta_w + \varepsilon_{ipcw}.$$

First-stage equation II, Quadratic IV:

$${n\_kids_{ipcw}}^2 = \varphi_0 + \boldsymbol{\varphi}_1 \boldsymbol{Q}_{ipc} + \boldsymbol{\gamma_{12} Controls1}_{ipcw} + \boldsymbol{\delta_{12} Controls2}_{pw}$$
$$+\lambda_p + \theta_p \times c + \eta_w + \varepsilon_{ipcw}\ .$$

Structural equation, Quadratic IV:

$$cognition_{ipcw} = \beta_0 + \beta_1^{QuadraticIV} n\_\widehat{kids}_{ipcw} + \beta_2^{QuadraticIV} n\_\widehat{kids^2_{ipcw}}$$
$$+\boldsymbol{\gamma_2 Controls1}_{ipcw} + \boldsymbol{\delta_2 Controls2}_{pw} + \lambda_p + \theta_p \times c + \eta_w + \varepsilon_{ipcw}\ ,$$

where $\boldsymbol{Q}_{ipc}$ is the vector of instruments, pn_kids_{ipcw} and ${pn\_kids_{ipcw}}^2$.

[14] First, predicted-number-of-children instruments, pn_kids_{ipcw} and ${pn\_kids_{ipcw}}^2$ are constructed by regressing the number of children on the controls, the four instruments, and the fixed effects. From these regression coefficients, we predict number of children pn_kids_{ipcw} for each individual, and compute the squared value ${pn\_kids_{ipcw}}^2$. Second, we apply the standard 2SLS procedure using pn_kids_{ipcw} and ${pn\_kids_{ipcw}}^2$ as instruments. According to Løken et al. (2012), under the assumption that the included covariates and the instruments are mean-independent of the regression error, we can use any function of the controls and instruments $\boldsymbol{Z}_{ijt}$ variables to form instruments. Using predicted treatment generates efficiency gains because these predicted number of children are more highly correlated with the endogenous level of number of children.

6 Results

6.1 Baseline results

Table 2 presents the full first-stage results for all linear and quadratic IV regressions. Consistent with previous studies (Liu, 2014; Wang and Zhang, 2018; Chen and Fang, 2021), all instruments significantly lower the number of children a woman has (Column (1)), meaning that family planning policies effectively reduce fertility. The KP F-statistics is 12.47, supporting the relevance of our instruments. Columns (2)-(6) show the estimates of these instruments' effects on having at least 2, 3, 4, 5, and 6 children, respectively. The overall KP F-statistics support the relevance of our family planning policy instruments, although the evidence is weaker for having at least 5 and 6 children. Column (7) reports the first-stage results from quadratic IV estimations. Using the predicted number of children and its squared term as instrument variables, the KP F-statistics is 15.47, again supporting the relevance of our instruments.

Table 3 reports the estimated effect of fertility on episodic memory, mental intactness, and graphical cognition in Panels A, B, and C, respectively. In all regression models, we control for socio-demographic characteristics variables, year fixed effects, province fixed effects, and province-specific linear cohort trends.

Column (1) presents the linear OLS estimates. We do not find any statistically significant correlation between fertility and late-life cognition. The linear IV results are reported in Column (2), indicating that having more children has a significant impact only on mental intactness – an additional child increases late-life mental intactness score by 0.32 standard deviations. The KP F-statistics is 12.47, indicating the relevance of our instruments. The Hansen J tests of over-identification are not rejected, supporting the validity of our instruments.

Columns (3)-(7) show the results of the nonparametric IV approach, more specifically, the effects of having at least two, three, four, five, and six children, respectively. The KP F-statistics and the Hansen J tests support the relevance and validity of our instruments even at higher parities. In general, the results of the nonparametric approach offer robust evidence of an adverse causal effect of having many children. Having 6+ children led to a reduction of 1.08, 1.81, and 1.51 standard deviations in episodic memory, mental intactness, and graphical cognition, respectively. At low parities, having an additional child has a beneficial effect on mental intactness, leading to a hump-shaped effect pattern, though this positive effect is weaker for episodic memory and insignificant for graphical cognition.

In particular, we find modest evidence of the nonlinear effect of having more children on memory. Compared to having one or two children, having at least three children has a statistically significant positive effect on memory. Having at least four children (as opposed to having three or fewer) shows a similar effect size but is not statistically significant. Having at least five children diminishes memory capacity, albeit statistically insignificantly, and having at least six worsens memory significantly. These results together indicate a hump-shaped fertility effect with a peak between 4 and 5.

This hump-shaped pattern is more salient in the case of mental intactness. Having at least two or three children improves maternal mental intactness. Mothers with 5+ children, however, experience statistically significantly worse mental intactness compared to mothers with four or fewer children, and having 6+ children accelerates the decline of mental intactness. We do not find a similar pattern for graphical cognition; insignificant and small estimates in Columns (3)-(5)

indicate no benefit of having more children. However, the significant negative estimates in Columns (6) and (7) show that having 5+ children significantly reduces graphical cognition.[15]

In Column (8), we report the Quadratic IV estimates. While the quadratic relationship is statistically insignificant for episodic memory and graphical cognition, the fertility effect on mental intactness has a significant hump-shaped pattern, with a turning point around four.[16] For mothers with fewer than four children, their mental intactness improves when one additional child is born, but the effect size declines rapidly when the number of children exceeds four. The turning point of four aligns with the results from the nonparametric approach and is larger than inferred from the raw data (Figure 2), probably reflecting the systematic baseline difference between mothers who tend to have few children and mothers who tend to have many children. Our estimated turning point contrasts with Bonsang and Skirbekk (2022), who show having 3+ children as opposed to 2 children affects late-life cognition negatively in Europe. This contrast may be due to the more critical roles children play in providing old-age support in rural China (Chen and Fang, 2021).

Our results are robust to various specification checks, including alternative instrument choices, adding childless families, and using the total number of children without capping it to six. See Appendix A.3 for further details.

6.2 Potential mechanisms

Investigating the fertility effect on some mediator variables allows us to understand the fertility effect on late-life cognition better. In this section, we report the effect of fertility on

[15] In Appendix Figure A3, we plot the nonparametric approach estimates of fertility for each late-life cognition outcome.

[16] In the Appendix Table A1, we break down the score of mental intactness into scores for orientation and serial-seven tests. We find fertility has significant nonlinear impacts on both scores.

intergenerational social interaction, upward financial transfers, and the physical functioning of elderly mothers.

Table 4 reports the results of the linear OLS, linear IV, and quadratic IV regressions. Columns (1) and (2) show that the likelihood of children living nearby or together and paying weekly visits to parents increases with the number of children. The quadratic IV estimates suggest evidence of a weak nonlinear effect on the probability of living nearby or together, implying that this marginal benefit diminishes fairly quickly with the number of children.[17]

Columns (3) and (4) report the fertility effect on financial support. Although OLS estimates show significant and positive relationships, the IV estimates are non-significant, indicating that financial support is unlikely to be the primary mechanism behind the effect of fertility on late-life cognition among rural women.

Lastly, we examine physical health outcomes. Among many chronic conditions an elderly parent may live with, hypertension, diabetes, and being overweight or obese are the major risk factors for dementia (WHO, 2023). In Column (5), the linear IV estimate shows that mothers with more children are more likely to have chronic conditions that increase the risk of dementia, though this effect is not significant in the quadratic IV model. This at least suggests that the marginal adverse effect of fertility on chronic conditions does not diminish with the number of children. We do not find significant fertility effects on the number of functional limitations (Column (6)).[18] In summary, an additional child increases interaction with children and increases the risk of chronic

[17] Intergenerational coresidence is a common living arrangement that provides old-age security (Johar and Maruyama, 2014) and increases social interactions. A possible explanation to this decline in marginal benefit is the free-rider problem when multiple children consider provision of social support for elderly parents (Maruyama and Johar, 2017).

[18] Functional limitations in CHARLS include having some difficulty in running or jogging 1km, walking 1km, waking 100m, getting up after sitting for a long period, climbing several stairs, stooping/kneeling/crouching, reaching/extending the arms above shoulder, lifting or carrying weights over 10 jin, and picking up a small coin from a table.

conditions. While the former effect diminishes with the number of children, the latter doesn't. These are likely behind the hump-shaped effects of fertility on late-life cognition. Complementarity between interaction with children and the risk of chronic conditions in the production of late-life cognition may be another source of the hamp-shaped fertility effect.

7 Conclusion

Cognition is a critical determinant of late-life social well-being. This paper explores the potentially nonlinear, causal effect of fertility on old-age cognition. Theoretical analysis suggests a nonlinear effect along the fertility dimension. We use data from the CHARLS to investigate nonlinear causal effects of fertility by taking advantage of the exogenous variation in the timing of the implementation of Family Planning Policies in rural China. We find nonlinear causal effects of fertility: robust negative effects of having 5+ children on different measures of late-life cognition, including episodic memory, mental intactness, and graphical cognition, while positive effects exist for episodic memory and mental intactness when the number of children is small, implying a hump-shaped effect. We further check two major mechanisms: social interaction with children and physical functioning associated with higher fertility levels. Our results show that older women with more children are more likely to live near their children and get weekly visits from their children. However, they have a higher risk of dementia-related chronic diseases.

Our study adds value to the growing literature on the relationship between fertility and late-life health outcomes. A few correlational studies suggest that the impact of fertility on late-life cognition may vary along the fertility level, but their estimates are subject to bias due to confounders. Incorporating all living children in a household, we investigate the causal effect of fertility on late-life cognition and compare these effects by parity. In addition, we provide evidence of fertility impact on late-life cognition in less developed countries. Compared to the findings from Europe that having 3+ children (versus 2) results in lower old-age cognition (Bonsang and Skirbekk, 2022), rural Chinese mothers do not experience a decline in cognition until they have 4+ children, suggesting that children play a critical role in supporting elderly mothers in rural China.

Our findings underscore the importance of government policies in effective prevention of late-life cognitive decline. With a global fertility rate of 2.3 (UNDESA, 2022), our results imply that declining fertility will not slow down but accelerate the decline of late-life cognition. Hence, there is a pressing need to mitigate the deterioration of cognition among the elderly. In the meantime, our results of effect heterogeneity call for tailored social policies based on fertility levels. For low-fertility individuals, insufficient social support leads to poor cognition, so policies should concentrate on enhancing social interactions. In contrast, for high-fertility individuals, poor physical functioning is predictive of impaired cognition, so policies should emphasize improved healthcare access. While our findings are based on data from a developing country, our findings of the relative importance of social interactions over financial support in determining late-life cognition indicate the relevance of policies promoting social interactions for developed countries as well.

Three questions deserve further research. First, can community-based social support offset reduced social support from children in determining late-life cognition? Second, are improved pension and financial social-welfare support effective policies to prevent cognitive decline? Third, our analysis excludes childless women due to the nature of our instruments. The impacts and mechanisms, however, may differ substantially between intensive and extensive margins (Baudin et al., 2015). We leave these to future research.

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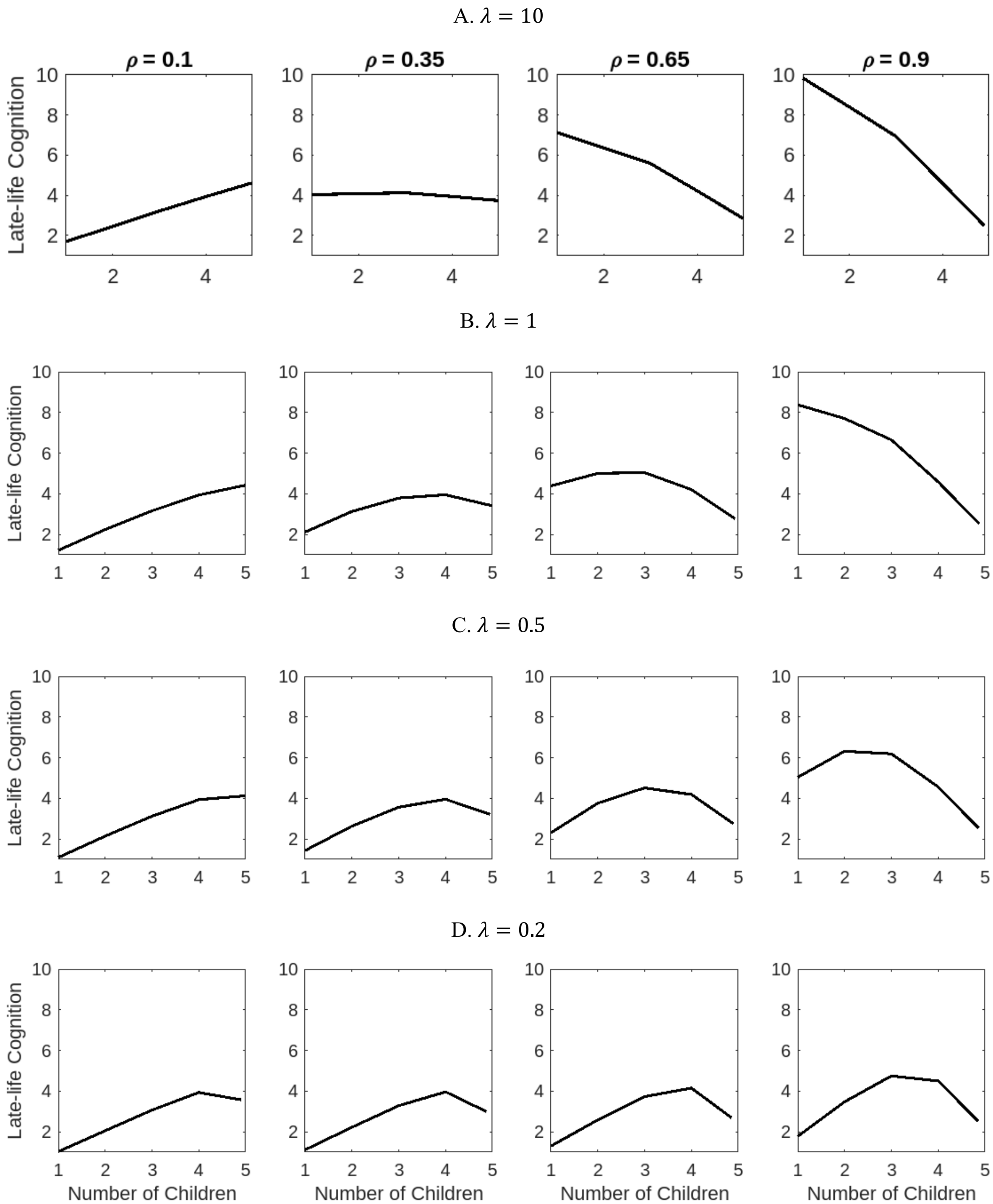
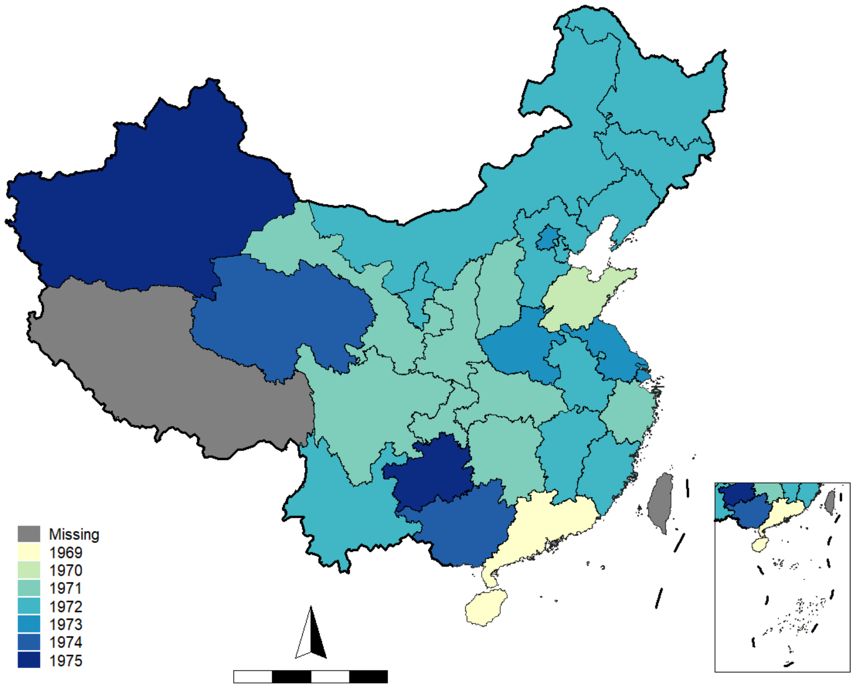
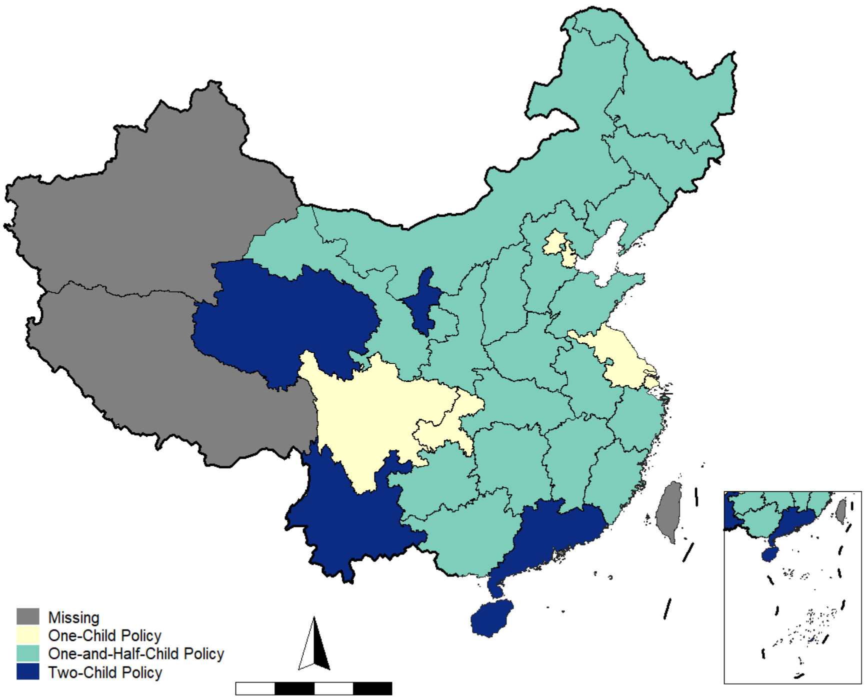


Figure 1. Late-life cognition, *LC*, and the number of children, *n*, with different substitution elasticities, λ, and relative importance of inputs, ρ.

Notes: Two inputs considered are: physical health LH and social interactions (and other general benefits) captured by the number of children n. ρ is the relative importance of LH. The other model parameters are set at $\beta = 0.5, \gamma = 1, \delta = 10, \eta = 1, r = 0.1, \theta = 1, \kappa = 0.1, \tau = 1, w = 20,$ and $v = 30$.



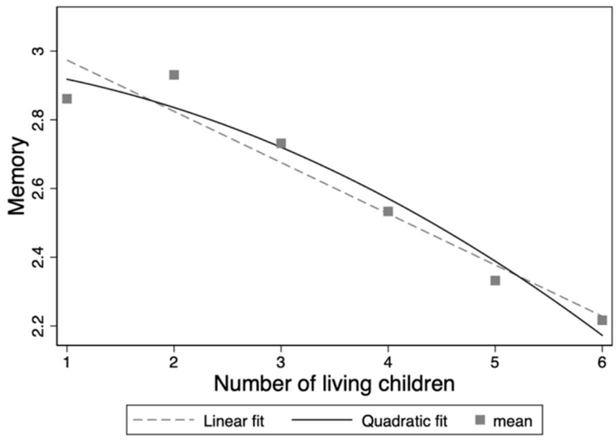
(a) The establishment years of the family planning leading group



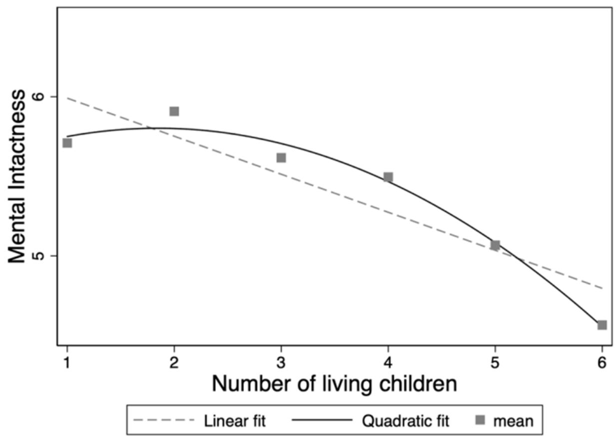
(b) The number of children allowed by a relaxation of OCP in rural China by 1990

Figure 2. Family planning policies (LLF and OCP) across provinces

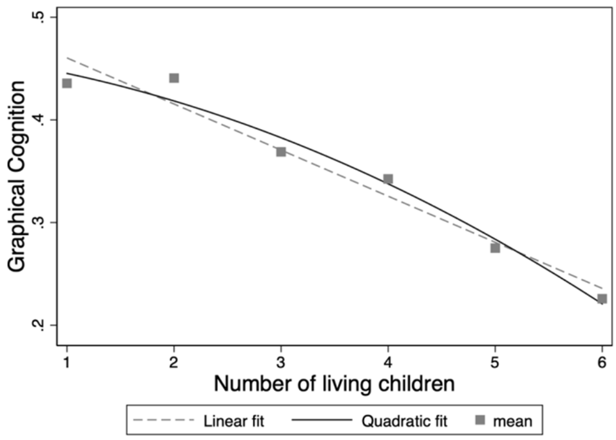
Notes: The data of LLF and OCP are obtained from Chen and Fang (2021) and Feng and Hao (1992), respectively.



Panel A



Panel B



Panel C

Figure 3. Late-life cognition and the number of children

Notes: This figure shows the average of memory (Panel A), mental intactness (Panel B), and graphical cognition (Panel C) scores of elderly female respondents (age>=60) at each fertility level in rural China using CHARLS 2011-2018. Sampling weight is applied.

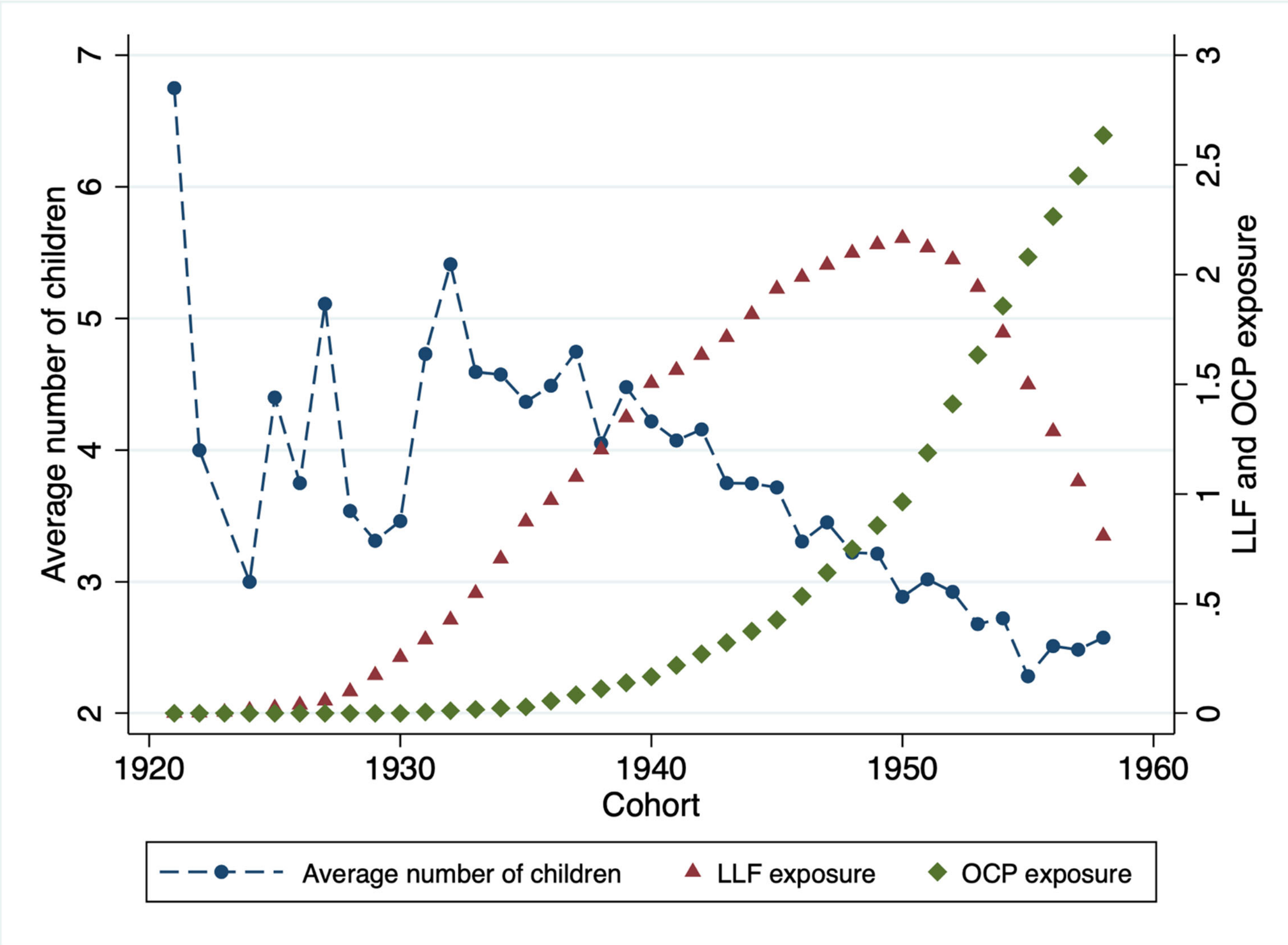


Figure 4. Average number of children and exposure score across birth cohorts

Notes: This figure shows the cohort-specific average of the number of children (left axis) and the cohort-specific average of LLF and OCP exposure (right axis) for 1920-1958 birth cohorts in the sample. The averages of LLF and OCP exposure are the means of $LLF_{p,c}$ and $OCP_{p,c}$ across provinces for each cohort, respectively.

Table 1. Summary Statistics

Variables	Description	Mean	S.D.
Outcome Variables			
Episodic memory	Standardized score of word recall	0.00	1.00
Mental intactness	Standardized score of serial sevens and orientation	0.00	1.00
Graphical cognition	Standardized score of redrawing a picture showed by the interviewer (0-1), 0 otherwise	0.00	1.00
Independent Variable			
Number of children	The number of living children in the household	3.27	1.29
Instrumental Variables			
LLF	Exposure to LLF policy	1.94	0.60
OCP× Onechild	Exposure to OCP × An indicator that a mother is born in a province with one-child rural OCP	0.09	0.27
OCP× Twochild	Exposure to OCP× An indicator that a mother is born in a province with two-child rural OCP	0.20	0.65
OCP× Oneandhalf	Exposure to OCP× An indicator that a mother is born in a province with one-and-half-child rural OCP	0.61	0.74
Control Variables			
Married	1 for married, 0 otherwise	0.80	0.40
Age	Age in years	66.34	5.68
Age gap	Age of husband - age of wife	2.24	4.05
Health insurance	1 if covered by public health insurance, 0 otherwise	0.95	0.22
Health during childhood	Retrospective self-evaluation of health before 16: 1 excellent, 2 very good, 3 good, 4 fair, 5 poor	2.84	1.12
Education	Education of the respondent: 1illiterate, 2 some elementary school, 3 elementary school, 4 middle school, 5 high school or above	1.98	1.04
Spouse education	Education of the respondent's spouse: 1illiterate, 2 some elementary school, 3 elementary school, 4 middle school, 5 high school or above	2.79	1.18
Province characteristics			
GDP per capita	GDP per capita (constant 2000 price)	32575.98	13531.98
# of hospital beds	Number of hospital beds per 10,000 population	48.64	9.90

Notes: N=5,342. The unit of observation is an individual-year. Episodic memory is the average score of immediate word recall and delayed word recall. Mental intactness is the sum of the orientation (recognition of current date and day) test score and serial-7 (subtraction 7 from 100 for five times) test score. Graphical cognition is an indicator for whether the respondent can correctly redraw a picture shown by the interviewer.

Table 2. First-stage estimates of LLF and OCP policies on the number of living children

	Number of children	2+ children	3+ children	4+ children	5+ children	6+ children	Number of children	Squared number of children
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
LLF	-0.2504***	-0.0166	-0.0143	-0.0851***	-0.0789**	-0.0553		
	(0.0954)	(0.0214)	(0.0324)	(0.0316)	(0.0368)	(0.0337)		
OCP×Onechild	-1.2468***	-0.4416***	-0.3972***	-0.2442**	-0.1302	-0.0336		
	(0.3960)	(0.0577)	(0.1494)	(0.1191)	(0.0805)	(0.0735)		
OCP×Twochild	-0.8578***	0.0095	-0.1732***	-0.2904***	-0.2623***	-0.1414***		
	(0.1488)	(0.0316)	(0.0439)	(0.0422)	(0.0595)	(0.0450)		
OCP×Oneandhalf	-0.5569***	-0.0883***	-0.2483***	-0.2037***	-0.0349	0.0183		
	(0.1708)	(0.0285)	(0.0687)	(0.0559)	(0.0722)	(0.0584)		
Predicted number of children							0.5845	-1.7596
							(0.4127)	(2.8304)
Predicted number of children squared							0.0793	1.3577***
							(0.0536)	(0.3941)
KP *F*-statistics	12.47	23.92	45.77	58.44	7.534	23.74	15.47	
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Province FE × Cohort Trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	

Notes: N= 5,342. The dependent variables are the number of children in Column (1), having at least two, three, four, five, and six children, in Columns (2)-(6), respectively. In Columns (7)-(8), the dependent variables are the number of children and the squared number of children. Other controls include age, marital status, health insurance, childhood health, education, spousal education, two province-level characteristics (GDP per capita and number of hospital beds per 10,000 population), and a set of fixed effects listed at the end of the table. In parentheses are standard errors clustered at the province level. *** p<0.01, ** p<0.05, * p<0.1

Table 3. Effect of fertility on late-life cognition: OLS, linear IV, and non-linear IV estimates

	Linear OLS	Linear IV	Nonparametric IV					Quadratic IV
			2+ children	3+ children	4+ children	5+ children	6+ children	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
***Panel A. Episodic memory* (*N*=5,342)**								
Number of children	0.0043	0.1166						0.1792
	(0.0102)	(0.1029)						(0.1630)
At least *x* children			0.4102	0.4287**	0.4078	-0.5714	-1.0816**	
			(0.3215)	(0.1745)	(0.3585)	(0.5074)	(0.5048)	
Quadratic number of children								-0.0117
								(0.0247)
KP *F*-statistics		12.47	23.92	45.77	58.44	7.534	23.74	15.47
Hansen *J* test (*p*-value)		0.255	0.158	0.690	0.300	0.216	0.642	
***Panel B. Mental intactness* (*N*=5,342)**								
Number of children	-0.0201	0.3215**						1.0332***
	(0.0166)	(0.1595)						(0.2374)
At least *x* children			1.3708***	0.8594***	0.8021	-0.8837*	-1.8144**	
			(0.2215)	(0.2667)	(0.5209)	(0.4562)	(0.7272)	
Quadratic number of children								-0.1330***
								(0.0357)
KP *F*-statistics		12.47	23.92	45.77	58.44	7.534	23.74	15.47
Hansen *J* test (*p*-value)		0.104	0.217	0.382	0.101	0.0959	0.291	
***Panel C. Graphical cognition* (*N*=5,342)**								
Number of children	-0.0150	-0.0964						0.2198
	(0.0124)	(0.1516)						(0.2432)
At least *x* children			0.3249	0.1701	-0.3905	-1.3895***	-1.5123**	
			(0.3735)	(0.2307)	(0.4826)	(0.4301)	(0.7260)	
Quadratic number of children								-0.0591
								(0.0373)
KP *F*-statistics		12.47	23.92	45.77	58.44	7.534	23.74	15.47
Hansen *J* test (*p*-value)		0.192	0.378	0.538	0.163	0.980	0.706	

Notes: Columns (3)-(7) report the estimated effects of having at least two, three, four, five, and six children. All regressions include controls for age, marital status, health insurance, childhood health, education, spousal education, and province-level characteristics (GDP per capita and the number of hospital beds per 10,000 population). We also control for year fixed effects, province fixed effects, and province-specific cohort trends. Standard errors are clustered at the province level. *** p<0.01, ** p<0.05, * p<0.1.

Table 4. Mechanism: The effect of fertility on interaction with children, financial support, and physical functioning

	Interaction with children		Financial support		Physical functioning	
	Living nearby or together (0/1)	Any weekly contact in person (0/1)	Amount of transfers	Any transfers (0/1)	Any chronic condition predictive of dementia (0/1)	# of functional limitations
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. OLS						
Number of children	0.0239***	0.0324***	0.6651***	0.0635***	0.0202*	0.0827**
	(0.0058)	(0.0068)	(0.0496)	(0.0063)	(0.0112)	(0.0345)
Panel B. Linear IV						
Number of children	0.0895**	0.1041**	0.7309	0.0575	0.1780**	0.0653
	(0.0386)	(0.0418)	(0.7123)	(0.0653)	(0.0782)	(0.3460)
KP F-statistics	12.60	12.36	43.86	39.08	8.477	12.47
Hansen J test (p-value)	0.167	0.514	0.416	0.433	0.218	0.147
Panel C. Quadratic IV						
Number of children	0.2553**	0.1771	1.7414	0.1623	0.1304	0.9041
	(0.1126)	(0.1205)	(1.2907)	(0.1387)	(0.1952)	(0.9038)
Quadratic number of children	-0.0311*	-0.0137	-0.1839	-0.0192	0.0089	-0.1567
	(0.0167)	(0.0219)	(0.1663)	(0.0200)	(0.0273)	(0.1458)
KP F-statistics	15.53	15.49	16.57	16.77	9.016	15.47
$\bar{Y}$	0.84	0.78	6.27	0.81	0.626	2.820
N	5,324	5,334	5,164	5,168	3,607	5,342

Notes: The dependent variables in Columns (1)-(6) are: (1) having a child living nearby or together, (2) receiving any weekly visits from children, (3) the amount of upward transfers, (4) receiving upward transfers, (5) living with a predictive chronic disease for dementia, and (6) the total number of functional limitations. All models include the same controls and fixed effects as shown in Table 2. In parentheses are standard errors clustered at the province level. *** p<0.01, ** p<0.05, * p<0.1.

Online Appendix (Not for publication)

A.1 Distribution of cohorts in the sample

Our sample consists of 2688 unique women born between 1921 and 1958. Figure A1 illustrates the number of unique women in each cohort. On average, a mother is born in 1948 and the standard deviation is 6.82. The sample is left-skewed due to the higher likelihood of survival for younger cohorts. However, the sample is not over dominated by any specific cohort.

A2. Difference between $\mathrm{CF\_LLF}_{p,c}$ and $LLF_{p,c}$

Chen and Fang (2021) define the exposure to LLF as $\mathrm{CF\_LLF}_{\mathrm{p,c}} = \sum_{\mathrm{a}=15}^{\mathrm{a}=49}\left[\mathrm{AFR}_{\mathrm{p}}(\mathrm{a}) \cdot \mathrm{I}\left(\mathrm{c}+\mathrm{a} > \mathrm{T}_{\mathrm{p}}\right)\right]$. Conceptually, while our $\mathrm{LLF}_{\mathrm{p,c}}$ measures policy exposure specific to LLF, $\mathrm{CF\_LLF}_{\mathrm{p,c}}$ is a proxy measure for exposure to the entire FPPs. Here we give a simple example to illustrate the differences between the two measures. For a female born in 1945 in Shandong where Family Planning Leading Group was established in 1970, she started exposure to LLF when she was 26 years old in 1971 (counting 1 year of potential pregnancy). While Chen and Fang (2021) assume her exposure to LLF ends when she passes age 49 at the end of her fertility life, we assume her exposure to LLF ends when she passes age 34 in 1979 when OCP came into effect. Note that $\mathrm{LLF}_{p,c}$ is not a linear transformation of $\mathrm{CF\_LLF}_{p,c}$. For more recent cohorts, say a female born in 1965, $\mathrm{CF\_LLF}_{p,c}$ assigns her a full-fertility-life exposure to LLF, but $\mathrm{LLF}_{p,c}$ assigns zero exposure to LLF because when she reached the first year of fertility life (age 15, year 1980), OCP had replaced LLF. For a graphical comparison of the two measures, please see Figure A2.

We make three changes to Chen and Fang (2021)'s exposure measurement to improve the IV estimation. First, we separate the total policy exposure to FPP into two measures, $\mathrm{LLF}_{p,c}$ and $\mathrm{OCP}_{p,c}$. Second, we apply age-specific fertility rates to LLF exposure and OCP exposure specific to the year before implementation. We use 1969 AFR to construct $\mathrm{LLF}_{p,c}$ and 1978 AFR to construct $\mathrm{OCP}_{p,c}$. Third, we define exposure as during the years of implementation and fertility years of a woman. Specifically, a woman is not exposed if she is under or over fertility age or if the implementation of a certain FPP has ended.

A.3 Additional Results

Figure A3 plots the impacts of the number of children on late-life cognition using the nonparametric approach. Panels A, B, and C illustrate the effects on episodic memory, mental intactness, and graphical cognition, respectively. We find that having 6+ children impairs cognition, whereas having another child at low parities (e.g., 2 or 3) has a positive effect on mental intactness, though the evidence is less salient for memory and graphical cognition. The relationship between fertility and cognition thus shows a hump-shaped pattern.

As noted in Section A.3, the score of mental intactness is the sum of scores of orientation (recognition of current date and day) and serial-7 (subtraction 7 from 100 for five times) tests. Table A1 reports the additional results of fertility impacts on these distinct mental intactness outcomes. Specifically, Panel A reports the results of the orientation test, and Panel B reports the results of the serial-7 test. The linear IV results presented in Column (1) indicate that having more children has a significant impact on the serial-7 score – an additional child increases this score by 0.36 standard deviations. The fertility effect on orientation score, however, is not significant. Columns (2)-(6) report the results from the nonparametric approach. We find that the pattern is similar to our main results: having 6+ children leads to a reduction of 0.64 and 2.05 standard deviations in orientation and serial-7 test scores, respectively. At low parities, having an additional child has beneficial effects. These results thus suggest a hump-shaped relationship between fertility and these cognitive functions in old age, and the pattern is more salient in the serial-7 test. The results from quadratic IV in Column (7) attest to this hump-shape relationship, with a turning point at 4 children.

Table A2 reports the results of various robustness checks for episodic memory, mental intactness, and graphical cognition. Column (1) presents baseline results, in which we use the predicted number of children instruments with all four family planning policies as noted in Section 4.2, that is, $LLF, OCP \times Onechild, OCP \times Twochild,$ and$OCP \times Oneandhalf$. We replace the LLF exposure with the alternative measurement used in Chen and Fang (2021) in Column (2), in which we relax the indicator function that equals 1 if a mother is no older than 49 in 1979. Using the newly predicted number of children instruments, we find our estimates are robust. The number of children has no significant impact on memory and graphical cognition but has significant nonlinear impacts on mental intactness. The turning point is slightly smaller than our baseline results, but the cognition measured by mental intactness remains declining when the number of children is over four. The KP F-statistics are significant but smaller than our baseline estimates, suggesting that one can make an improvement on the instrument by separating the exact exposure of LLF and OCP family policies.

In Column (3), we drop OCP policy and directly use LLF exposure in Chen and Fang (2021) and its squared term as IVs for quadratics of the number of children. We find the number of children remain to have a significant inverse U-shape impact on mental intactness, but not on memory and graphical cognition. However, we find the standard errors are larger and KP F-statistics are much lower when OCP exposure is not considered, suggesting that missing OCP exposure might provide us with less variation in estimating the quadratic effects.

We then check if our estimates are robust if childless families are added in Column (4). Although the family planning policies always allow for at least one child born in a household and thus do not serve as a good instrument for fertility decisions in childless families, we add childless mothers to check how our estimates are impacted. As expected, the KP *F*-statistics are smaller, but our main estimates remain robust. The number of children has a nonlinear effect on mental intactness for rural women but not on the other two cognition outcomes.

We further check how our results are sensible to the measurements. In Column (5), we use the total number of children instead of capping it to six. In Columns (6) and (7), we measure mental intactness by adding the scores for season check and graphical cognition (Lei et al., 2012; Ma, 2019). Our baseline results remain consistent, suggesting that the non-linear effect of fertility on mental intactness is not driven by peculiarities in measurement choices.

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Ma, Mingming. "Does children's education matter for parents' health and cognition? Evidence from China." *Journal of Health Economics* 66 (2019): 222-240.

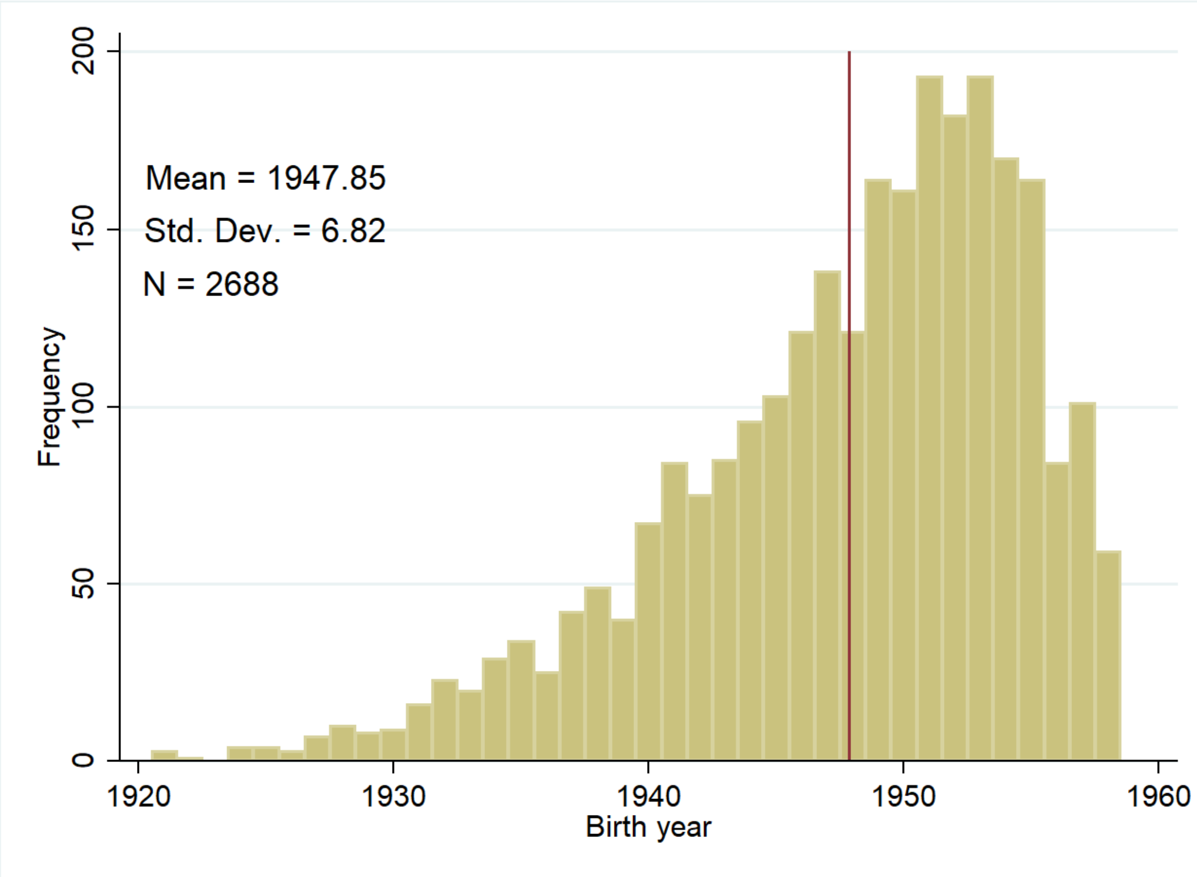


Figure A1. The distribution of birth year

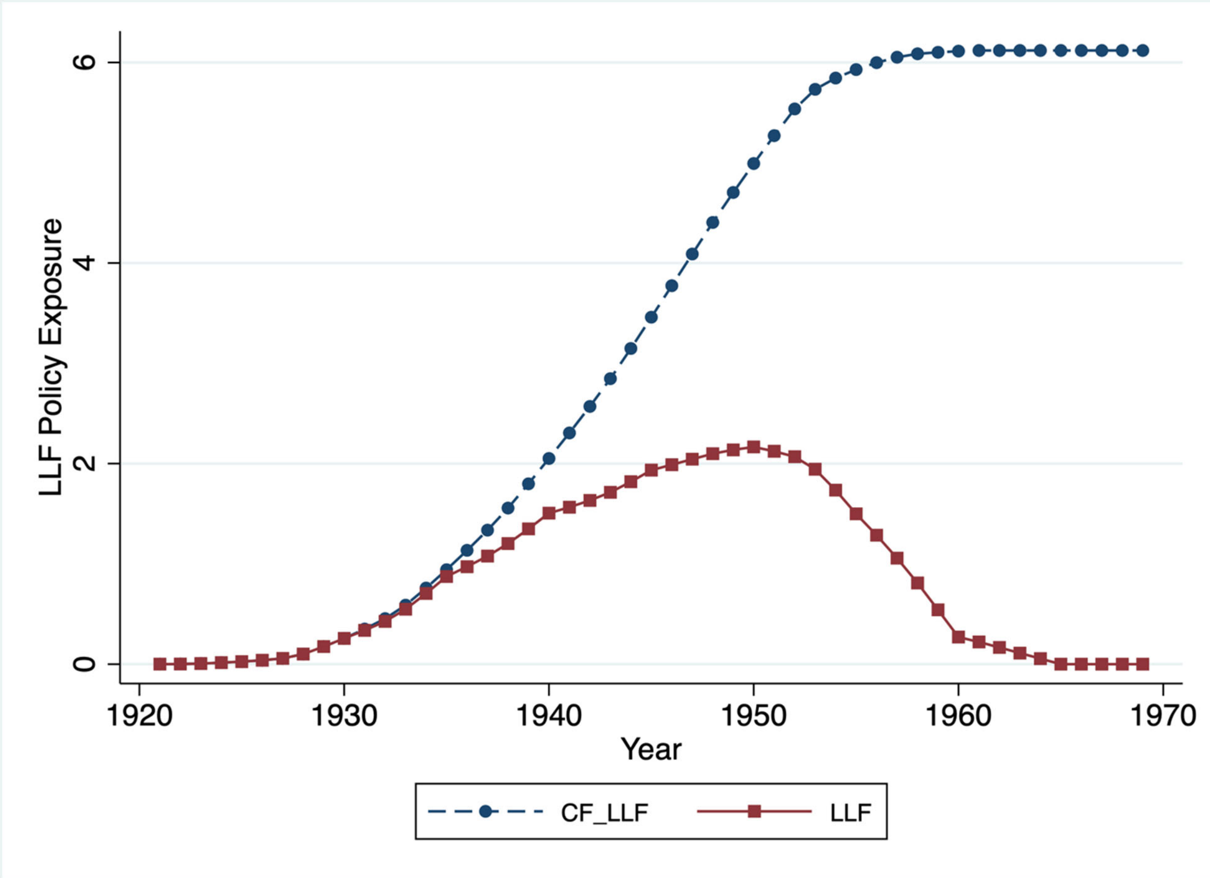
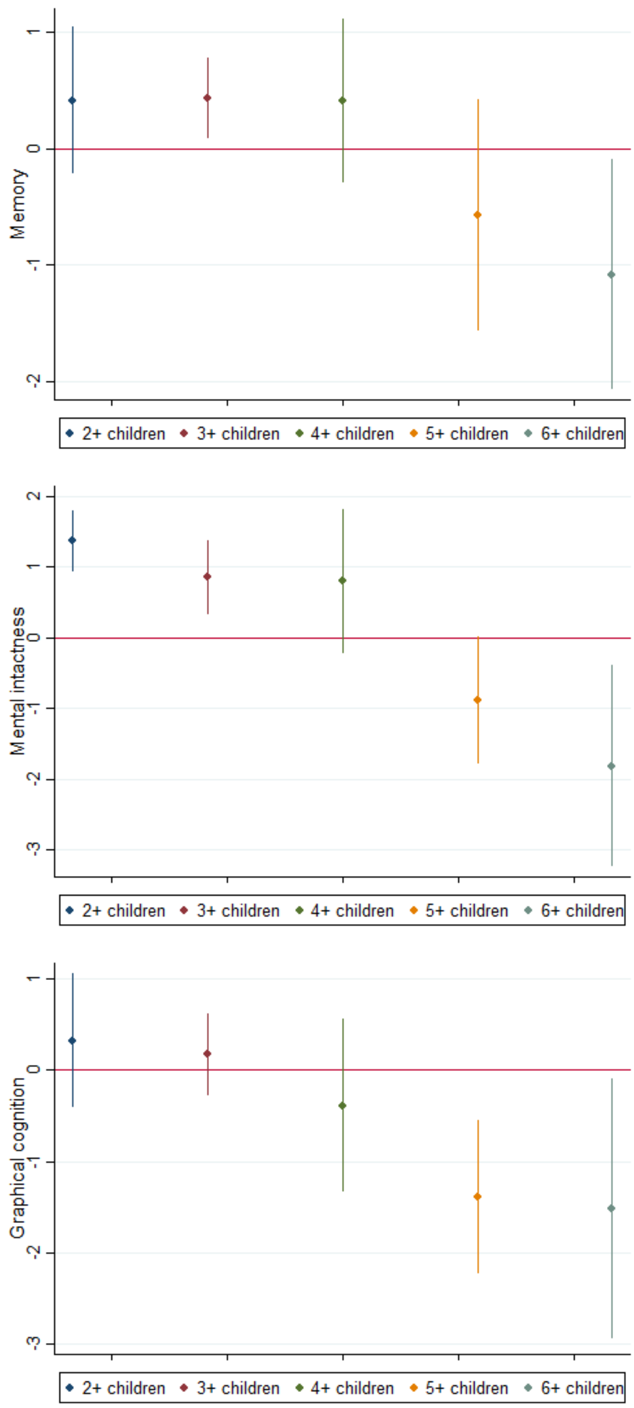


Figure A2. The two measures of LLF policy exposure

Notes: $CF\_LLF_{\mathrm{p,c}} = \sum_{\mathrm{a=15}}^{\mathrm{a=49}}[\mathrm{AFR_p(a)} \cdot \mathrm{I}(\mathrm{c + a > T_p})]$ and $LLF_{p,c} = \sum_{a=15}^{a=49}[AFR_{p,1969}(a) \cdot I(c + a > T_p) \cdot I(c + a \leq 1979)]$. We show the averages of CF_LLF and LLF across provinces by taking the means of $CF\_LLF_{\mathrm{p,c}}$ and $LLF_{p,c}$ across provinces for each cohort, respectively.



Panel A

Panel B

Panel C

Figure A3. The estimates of fertility on late-life cognition using a nonparametric approach

Notes: The effects of having at least two, three, four, five, and six children on late-life cognition are shown for memory, mental intactness, and graphical cognition in Panels A, B, and C, respectively.

Table A1. IV estimates on each component of mental intactness

	Linear IV	Nonparametric approach					Quadratic IV
		2+ children	3+ children	4+ children	5+ children	6+children	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A. Orientation score (N=5,342)							
Number of children	0.1241						0.5236**
	(0.1110)						(0.2074)
At least x children		0.5683***	0.3128	0.2761	-0.3167	-0.6431*	
		(0.1901)	(0.2056)	(0.3946)	(0.2927)	(0.3855)	
Quadratic number of children							-0.0746**
							(0.0296)
KP F-statistics	12.47	23.92	45.77	58.44	7.534	23.74	15.47
Hansen J test (p-value)	0.471	0.925	0.588	0.422	0.509	0.637	
Panel B. Serial-7 score (N=5,342)							
Number of children	0.3557**						1.0593***
	(0.1650)						(0.2876)
At least x children		1.4904***	0.9636***	0.9101	-0.9943*	-2.0462**	
		(0.2572)	(0.2939)	(0.5611)	(0.5395)	(0.9102)	
Quadratic number of children							-0.1315***
							(0.0465)
KP F-statistics	12.47	23.92	45.77	58.44	7.534	23.74	15.47
Hansen J test (p-value)	0.0471	0.276	0.340	0.0577	0.138	0.306	

Notes: The dependent variables are standardized scores of knowing the correct date in Panel A, and standardized scores of serial subtraction 7s from 100 up to five times in Panel B. Reported under the nonparametric approach are the IV estimates of the effect of having at least two, three, four, five, and six children. All regressions include the following controls: age, marital status, health insurance, childhood health, education, spousal education, and two province-level characteristics (GDP per capita and number of hospital beds per 10,000 population). We also control for year fixed effects, province fixed effects, and province-specific cohort trends. In parentheses are standard errors clustered at the province level. *** p<0.01, ** p<0.05, * p<0.1.

Table A2. Robustness checks

	Baseline	CF_LLF and OCP to predict	CF_LLF and its squared as IVs	Add zero children families	Not capped number of children	Add season check to mental intactness	Add draw and season check to mental intactness
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A. Episodic memory							
Number of children	0.1792	-0.0127	0.7479**	0.2164	0.1702	-	-
	(0.1630)	(0.1820)	(0.3563)	(0.1657)	(0.1521)	-	-
Quadratic number of children	-0.0117	0.0017	-0.1296*	-0.0201	-0.0142	-	-
	(0.0247)	(0.0291)	(0.0674)	(0.0211)	(0.0131)	-	-
KP *F*-statistics	15.47	14.27	2.893	12.65	15.67	-	-
Observations	5,342	5,342	5,342	5,367	5,342	-	-
Panel B. Mental intactness							
Number of children	1.0332***	0.8766***	1.1486***	1.0883***	0.7990***	1.0752***	1.0268***
	(0.2374)	(0.2021)	(0.4428)	(0.2738)	(0.2270)	(0.2456)	(0.2335)
Quadratic number of children	-0.1330***	-0.1257***	-0.1815**	-0.1376***	-0.0897***	-0.1294***	-0.1288***
	(0.0357)	(0.0319)	(0.0738)	(0.0404)	(0.0284)	(0.0345)	(0.0316)
KP *F*-statistics	15.47	14.27	2.893	12.65	15.67	14.33	14.33
Observations	5,342	5,342	5,342	5,367	5,342	5,089	5,089
Panel C. Graphical cognition							
Number of children	0.2198	0.1928	0.3785	0.1274	-0.0038	-	-
	(0.2432)	(0.2147)	(0.4464)	(0.2534)	(0.2218)	-	-
Quadratic number of children	-0.0591	-0.0440	-0.0692	-0.0436	-0.0217	-	-
	(0.0373)	(0.0311)	(0.0751)	(0.0378)	(0.0227)	-	-
KP *F*-statistics	15.47	14.27	2.893	12.65	15.67	-	-
Observations	5,342	5,342	5,342	5,367	5,342	-	-

Notes: Column (1) is the baseline model. Column (2) uses predicted number of children and its squared as IVs with LLF exposure as in Chen and Fang (2021) and OCP. Column (3) directly uses LLF exposure as in Chen and Fang (2021) and its squared term as IVs. Column (4) adds childless families to the sample. Column (5) uses the total number of children instead of capping it to six. Column (6) adds season check to the raw score of mental intactness. Column (7) further adds graphical cognition to mental intactness. All models include the same controls and fixed effects as shown in Table 3. In parentheses are standard errors clustered at the province level. *** p<0.01, ** p<0.05, * p<0.1.