

Health status and elderly care: theory and evidence from a randomized trial with COPD patients in China

Health status
and elderly
care

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Abstract

Purpose – This paper theoretically and empirically analyzes the effects of the elderly’s physical health status on their need for care and the choice of care models in China.

Design/methodology/approach – Empirically, the estimation results of a large-sample randomized intervention trial with chronic obstructive pulmonary disease (COPD) patients through the difference-in-difference method indicated the following: (1) After the COPD intervention trial, the physical health status of the elderly in the treatment group improved significantly, the need for care was substantially reduced and the health improvement led to a 35.5% reduction in the probability of using elderly care. (2) The reduction in the need for care regarding the treatment group occurred mainly in social care. The probability of using social care decreased by 67.8% due to the elderly’s health improvement, while that of home care remained unchanged generally. (3) Further heterogeneity tests suggested that families with fewer potential internal resources for caregiving had a more pronounced decline in the need for social care.

Findings – Theoretically, these empirical results support the existence of the “pecking order” theory in the family’s choice of elderly care model, that is, families tend to employ all internal resources for caregiving before resorting to social care, resulting in a higher sensitivity of social care to health.

Originality/value – The main policy implication of this paper is that *ex ante* preventive health intervention policies can significantly alleviate the burden of care, especially social care, on families. And preventive health intervention policies are particularly effective in reducing the burden of the families with relatively few resources for informal internal care.

Keywords Elderly health status, Care needs, Pattern of care, COPD, Randomized trial

Paper type Research paper

1. Introduction

The rapid aging of the population structure in China is accompanied by a serious aging trend of the aged. The oldest-old has a high incidence of disability and dementia. According to the projection of the United Nations, the number of China’s oldest-old (aged 80 years or over) will

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grow from 20 million in 2010 to 100 million in 2050 (U.N., 2011), resulting in huge demand for care. The study by [Zeng et al. \(2012\)](#) indicated that the growth of the handicapped elderly who are incapable of taking care of themselves in the first half of the twenty-first century in China is significantly faster than the growth of the overall elderly population, and the proportion of the total cost of home care for the elderly with disabilities in GDP was growing rapidly. Among all the factors affecting care needs, the health status of the elderly is undoubtedly one of the most critical ones. In October 2017, President Xi Jinping proposed in his report at the 19th National Congress to “implement the health China strategy. . . . As we respond proactively to population aging, we will adopt policies and foster a social environment in which senior citizens are respected, cared for, and live happily in their later years. We will provide integrated elderly care and medical services, and accelerate the development of old-age programs and industries”. The combination of elderly care and medical services and healthy elderly care are critical parts of the Health China Strategy implemented by China. Thus, what exactly is the relationship between health and elderly care? How do health and related health intervention policies affect the demand for elderly care? What are the effects of health and health policies on informal home care and formal social care? These questions have important theoretical value and practical significance.

However, it is never easy to answer the above questions scientifically. As there is significant reciprocal causation between health and care, it is difficult to identify appropriate and powerful recognition strategies. There are both domestic and foreign studies that explore the effect of health on care needs (e.g. [Zunzunegui et al., 2001](#)) as well as massive studies that investigate the role of care in the health production function (e.g. [Chen and Du, 2002](#); [Stabile et al., 2006](#)). With elderly mental health as an example, [Unützer et al. \(1997\)](#) and [Vasiliadis et al. \(2013\)](#) explored the effect of mental health factors, such as depression and anxiety, on the cost of elderly care, while [Barnay and Juin \(2016\)](#) discussed the effect of home care on the mental health status of the elderly. In addition, many factors may affect both health status and care needs, such as family income, living arrangements, number of children and some other unobservable variables, which may easily lead to omitted variable bias in the regression model estimation.

This paper employed a completely randomized controlled trial (RCT), in which a large sample of patients with chronic obstructive pulmonary disease (COPD) were randomly selected and vaccinated (with influenza vaccine or/and pneumonia vaccine) to affect the elderly health status exogenously, and then observed the families’ response to the needs for the elderly care in the treatment group compared with that in the control group. COPD is a common chronic disease characterized by chronic bronchitis and/or emphysema with airflow obstruction, which can further progress to pulmonary heart disease and respiratory failure, with wide distribution among the elderly in China [1]. The incidence rate of COPD has remained high among the elderly in China, and it is also one of the major diseases leading to disability. Data indicated that in 2012, the prevalence of COPD among people aged 40 and above in China was up to 9.9% [2], and the mortality rate of chronic respiratory diseases was 68/100,000 [3]. To the best of our knowledge, this paper is the first economic study to explore the role of elderly health on care through a large-sample RCT. The powerful tool for identifying causal relationships, RCT, can overcome the estimation bias caused by endogeneity problems, such as sample selection bias, omitted variables and bidirectional causality, to the greatest extent and helps us identify the causal effect of health on care needs accurately.

In addition to analyzing the relationship between elderly health and care, this paper further explores the family choice of care models. When elderly care is required, informal home care or formal social care can be selected. The main cost of the former is the time cost of family members, and that of the latter is the price of formal care. China has proposed a goal of “9073” in the provision of elderly services, that is, 90% of the elderly population rely on home-based elderly care, 7% on community-based care and 3% on institution-based care. Care resources are always

scarce, and the integration of and interaction among different care resources is crucial (Mommaerts, 2018). How do various care models differ in the efficiency of care provision? How can limited financial resources maximize the provision of various care resources and reduce the burden on the elderly and their families? Answering these questions requires research on the behavior of elderly family choice of care model. There has been a long history of domestic and international research on family's choice of care model (e.g. Freedman, 1996; Charles and Sevak, 2005; Yamada *et al.*, 2006; Boaz and Muller, 1994; Byrne *et al.*, 2009; Yu and Feng, 2018; Mommaerts, 2018). The scope of research covers the complementary or substitution effects between home care and various social care, the determinants for the choice of different care models and many other aspects. Unlike previous literature, this paper analyzes the response of family's choice of various care models to health shocks, which is essential to explore the effects of health intervention policies and the integrated development of care resources.

Through the difference-in-difference (DID) estimation, we found that after the randomized intervention trial, the scores of the COPD Assessment Test (CAT) in the treatment group were significantly reduced compared with those in the control group. The overall symptoms and six indexes (cough, chest tightness, breathlessness, activities, confidence leaving home and energy) were all significantly improved. The health improvements led to a significant reduction in the total needs of families that have elderly patients for care in the treatment group. The health intervention policy effectively reduced the care burden of elderly families. Meanwhile, this paper indicates that the decline in care needs occurred mainly in social care needs, while there was no significant change in the need for home care. The robustness test suggested that the above empirical results were highly robust.

By building a theoretical model regarding the family's choice of care, we argue that these phenomena support a "pecking order" in the choice of elderly care model in China: Families employ all internal resources for caregiving first and then social care. Thus, in this case, social care is more health-sensitive, and families prioritize a significant reduction in social care needs when the elderly health status improves. Moreover, for families with relatively few or limited care resources, such as few children, few daughters and not living with children, the decline in social care needs should be greater after the elderly's health status improves. The regression results on data from randomized intervention trials also support these theoretical predictions. From a policy perspective, this implies that effective *ex ante* preventive health intervention policies are effective in reducing the high-cost social care burden on families. In particular, preventive health intervention policies are more effective in lowering the burden for families with relatively few internal resources for informal care.

The following sections of the paper are structured as follows: In Section 2, we analyze families' total needs for care and the responses of home care and social care under health shocks through a model of family's choice for care. Section 3 presents the randomized trial design and the descriptive statistics of data. Section 4 is the empirical analysis and Section 5 is the conclusion of the research findings and policy implications.

2. Model of family's choice for care

Considering the care choice model for a typical family containing two kinds of members: the elderly who need care and the others who can provide home-based care, we assumed the family utility function in the following common form:

$$U = U(X, H), U'_X > 0, U'_H > 0, U''_H < 0 \quad (1)$$

where X represents the consumption and services used by the family and H the health status of the elderly. Assuming that the utility function is a common quasi-linear function, a decision problem faced by the family is as follows:

$$\begin{aligned} \max_{X,F,I} U(X, H) &= X + u(H) \\ \text{s.t. } H &= H(h(\chi), Q) = H\left(h(\chi), [\alpha F^\rho + (1 - \alpha)(nI)^\rho]^{1/\rho}\right), \chi \in \{0, 1\} \\ X + pF + w(nI) &\leq M + wnT, I \leq T \end{aligned} \quad (\text{P-1})$$

As shown in the second row of problem (P-1), the health production function is positively correlated with the health factor $h(\chi)$, which is unrelated to care, and the total care service Q . χ is an indicator function, of which value is 1 for the treatment group and 0 for the control group. When the COPD intervention trial is effective, $h(1) > h(0)$. The total care production function Q is in the form of a CES production function and is determined by the family's input of informal home care nI and input of formal social care F . n is the potential caregiving labor force in the family and is determined by the number of children, daughters, children living together, etc. I represents the average informal home care services provided by an individual family member. The third row of problem (P-1) is the budget constraint of a family, where X indicates the family's various consumption and services other than health, with the consumption and services as equivalents, i.e. their price normalized to 1; p the price of formal social care; w the opportunity cost of home care, such as the caregiver's income; M the nonlabor income of the family; T the total available time of family members to care for the elderly and nT the total care resources available for the family. The more potential labor force, the more resources for home care.

The Lagrangian function corresponding to problem (P-1) is

$$L = X + u(H(h(\chi), Q)) + \lambda_1[M + nw(T - I) - X - pF] + \lambda_2(T - I)$$

Solving the first-order condition for the above problem yields the following:

$$X : U'_X = \lambda_1 > 0 \quad (2)$$

$$F : U'_H \cdot H'_Q \cdot [\alpha F^\rho + (1 - \alpha)(nI)^\rho]^{1/\rho-1} \alpha F^{\rho-1} - \lambda_1 p = 0 \quad (3)$$

$$I : U'_H \cdot H'_Q \cdot [\alpha F^\rho + (1 - \alpha)(nI)^\rho]^{1/\rho-1} (1 - \alpha)(nI)^{\rho-1} n - \lambda_1 nw - \lambda_2 = 0 \quad (4)$$

$$\lambda_1 : \lambda_1 [M + nw(T - I) - X - pF] = 0 \quad (5)$$

$$\lambda_2 : \lambda_2 (T - I) = 0 \quad (6)$$

Equations (5) and (6) are complementary slackness conditions. Under the quasi-linearity assumption, the family budget line is bound to tighten. It should be noted that in the above problem, improvement in health status does not necessarily imply a decrease in care needs. The above optimization problem can also be described step by step as two problems. The first is the family's choice of the optimal quantity Q of care to maximize utility, similar to a manufacturer maximizing profits by choosing output. The second is the choice of the optimal input of intra-home care and social care, which is similar to the manufacturer's cost minimization problem. By describing the problem step by step, we find that the optimal care needs should meet the following conditions:

$$C'(q) \equiv u'_H(H(h(\chi), q)) \cdot H'_q(h(\chi), q) \quad (7)$$

The left end of the above equation is the marginal cost $C'(q)$ of care, which is increasing, that is, $dC'(q)/dq > 0$. The right end is the marginal benefit, which is determined by the health status and the marginal utility of health, and is decreasing, that is, $u''_{HH} < 0$. Obviously, due to the increasing marginal cost, $h(\chi)$ increases after the health interventions for COPD. In fact, only when the health status of the elderly improves, the marginal utility of health decreases

and the family's need for health are met, will the family's needs for care decrease. In other words, a lemma exists as follows:

Lemma 1. Given the family care decision in Equation (P-1), health improvement leads to a reduction in care needs when and only when $u''_{HH}H'_h + u''_H H'_{qh} < 0$ or $-\sigma_H(H'_h/H) + H''_{qh} < 0$.

σ_H represents the curvature of the utility function $u(H)$, which measures the degree of diminishing marginal utility of health improvement; a larger curvature indicates the marginal utility diminishing faster with health improvement. H'_h/H measures the degree of health improvement from the vaccine intervention. The condition in Lemma 1 is also related to H''_{qh} , that is, there is a substitution and complementary relationship between vaccine intervention and care services in the health production function. The condition in Lemma 1 is naturally met if $H''_{qh} < 0$, that is, health improvement reduces the marginal productivity of care to health; conversely, the specific scale of the positive and negative effects of health improvement shall be compared. Although it seems intuitively plausible that health improvements lead to a reduction in care from a realistic perspective, there is no guarantee for it, at least in theory. Hence, the relationship between health and care needs still needs to be answered with experimental data.

If $\lambda_2 > 0$, then $T = I$, that is, the family employs all the care resources, and the corner solution is taken for the family care decision model; otherwise, if $\lambda_2 = 0$, then the interior solution is taken. According to Equations (3)–(4), $F = nI[(1 - \alpha)\beta/(aw)]^{1/(\rho-1)}$ can be obtained, that is, the following theorems exist:

Theorem 1. Given the care decision problem in (P-1), when $\lambda_2 = 0$, the ratio of social care F to home care I is fixed and independent of the health shock χ .

Theorem 1 implies that if the interior solution is taken for the model, there should be a balanced change in social care F and home care I after the randomized intervention trial, instead of a dramatic change in the use probability of one care type and no change in the other. However, if the corner solution is taken for the model, that is, when the complementary slackness condition of Equation (6) tightens, health will have a highly unbalanced effect on family and social care.

Theorem 2. Given the care decision problem in (P-1) and $u''_{HH}H'_h + u''_H H'_{qh} < 0$, when $\lambda_2 > 0$, $I = T$, that is, the family uses all internal resources for care, $U'_I = u'_H \cdot H'_Q \cdot Q'_I > w$, the marginal utility U'_I from home care exceeds the marginal cost w . At this point, $dI/dh = 0$, $dF/dh < 0$, that is, informal home care does not respond to health shocks, while formal social care decreases. Moreover, $dC(F, nT)/dq > dC(F, nI)/dq$, that is, the effect of preventive health intervention policies is more pronounced in reducing the care burden on families with limited internal resources for caregiving.

Equations (3)–(4) and (6) indicate that a “pecking order” exists when $(Q'_F - Q'_I)U'_H H'_Q/\lambda_1 - (\beta - nw) < 0$. According to this condition, the main reasons for the “pecking order” in the choice of elderly care model are as follows: (1) the relative price between social and home care $(\beta - nw)$: When the relative price is higher, the elderly are more inclined to use home care. (2) the difference between the marginal effects of social and home care on health $(Q'_F - Q'_I)$: When the marginal effect of social care on health is lower, the elderly are more inclined to use home care. It should be noted that the marginal effect of care on health should include not only the marginal output of care but also the quality of care and the elderly's feeling caused by care. In the previous sections, we did not strictly distinguish between the aspects of care

quantity, quality and subjective perception. Hence, the small marginal effect of social care on health should include three possibilities: First, the marginal output of social care is low, while family members make more “efforts” in providing care; secondly, the quality of social care is relatively inferior, while home care is more “attentive” and thirdly, in terms of the subjective perception of the elderly, social care is inferior to home care, that is, home care is more “comforting” to the elderly. Moreover, the relative preference of the elderly for health and price $U'_H H'_Q / \lambda_1$ may also have an impact, which portrays whether the elderly care more about health or the price of care services, and a smaller ratio indicates that the elderly are more sensitive to the price of care. If the formal social care market is underdeveloped and care institutions and caregivers are not insufficiently professional of which service is low quality, the care receiver often has a better feeling regarding home care than social care, even if the care services provided by social caregivers are the same as those provided by family members, due to factors such as cultural background and living habits. In addition, as the elderly’s income is relatively low, they are often price-sensitive. If social care is relatively expensive, they will choose to use all of their resources for home care before using social care, resulting in a “pecking order” that makes social care more health-sensitive. When the elderly’s health status improves, social care is first withdrawn.

The implications of **Theorems 1** and **2** are shown in **Figure 1**. The horizontal axis I in **Figure 1-a** indicates the family informal care input, which is subject to a resource constraint, that is, it cannot exceed T . The vertical axis indicates the social formal care input and Q is the total care isoquant line. If the interior solution in **Theorem 1** is taken for the care choice model, the total care isoquant line is presented like the $Q(f, i)$ curve in **Figure 1**, that is, the family will reduce informal and formal care at the same time when its care need decreases, like the optimal care model changing from point a to point b, as shown in **Figure 1-a**. At this time, the effect of health shock on care needs is shown as a balanced change in the care needs. **Theorem 2** implies that if there is a “pecking order” in the family choice, that is, the family prioritizes the use of all internal resources for home care before using social care. And after the elderly’s health status improved, the elderly’s need for care decreased, the isoquant curve in **Figure 1** shifted downward, and the optimal choice of care model changed from point A to point B, as indicated by arrow 1 in the figure. At this point, improvement of health status led to a highly unbalanced shift in internal home care and formal social care, as families reduced their use of formal social care substantially, and no significant change occurred in informal care. In other words, social care is much more sensitive to health than home care.

Figure 1-b visually explains the second half of **Theorem 2**. The horizontal axis in the figure indicates the total care needs and the vertical axis indicates the cost of care. If the family uses

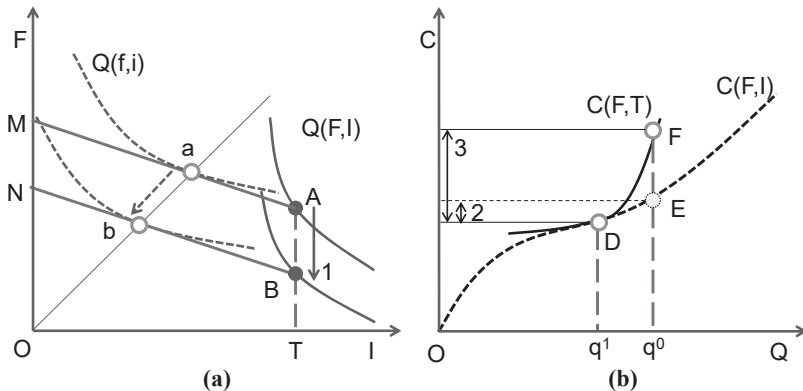


Figure 1.
Schematic diagram of
optimal choice of
care model

both types of care, the care cost curve is $C(F, I)$; while if the family has limited care resources, the care cost curve is $C(F, T)$. Apparently, the constrained cost curve does not lie above the unconstrained one, which is actually the lower envelope of the former [4]. At this point, if the elderly's health status deteriorates, for example, care needs increase from q^1 to q^0 , for families that can adjust both formal and informal care, the cost of care rises by a small extent, as shown by arrow 2 in the figure; on the other hand, for families with limited internal informal care resources, they can only passively increase social care use significantly, as shown by arrow 3 in the figure, and these families will be left with a heavier burden. Conversely, when the elderly's health status improves, for example, care needs decline from q^0 to q^1 , families with limited care resources show a greater decrease in care costs. Preventive health intervention policies have stronger effects on these families with less home care.

If the use of formal social care declines more after the elderly's health improvement, how does the decline vary across various families? What heterogeneity does the effect of preventive health intervention policies exhibit across families, given that each family may be endowed with different resources for care? How is this decline related to the technical complementarity between informal home care and formal social care? We can prove the following theorem:

Theorem 3. Given the care decision problem in (P-1), when $\lambda_2 > 0$, $I = T$, then the elasticity $\varepsilon(F, h)$ of formal social care to health shocks meets $d\varepsilon(F, h)/dn = d^2 \log F / (d \log h \cdot dn) < 0$, that is, families with fewer internal resources for caregiving have a greater decline in the use of social care. If $d\varepsilon(F, h)/d\rho = d^2 \log F / (d \log h \cdot d\rho) > 0$, that is, the weaker technical complementarity between formal social care and informal home care (the greater ρ), the decline in the use of social care will be greater after preventive health interventions.

In Theorem 3, $\varepsilon(F, h)$ is the elasticity of social care to non-care health factors, which is expressed as follows:

$$\varepsilon(F, h) = (1 - \sigma_H) / [(1 - \rho)(1 - R_F)] < 0, R_F = \alpha F^\rho / [\alpha F^\rho + (1 - \alpha)(nT)^\rho] \quad (8)$$

As shown in Equation (8), apparently, families with fewer resources n for home care have a higher use rate of social care R_F , and thus a larger $\varepsilon(F, h)$ and greater decline in the use of social care after the elderly's health status improves. Also, the decline in social care depends on the elasticity of substitution between formal care and informal care. If ρ is relatively high, it means that formal social care is less professional and can be perfectly replaced by informal care. In this case, $\varepsilon(F, h)$ is also relatively large, which means that the decline in formal social care is greater after the preventive health intervention.

In summary, from the results of solving the theoretical model of care decisions in Equation (P-1), some basic conclusions can be drawn as follows: (1) The improvement in the elderly's health status due to COPD does not necessarily lead to a decrease in care needs. The improvement in health status will lead to a decrease in care needs only if the curvature σ_H of health utility $u(H)$ is relatively large, that is, the marginal utility of health decays relatively fast, or the marginal productivity of health in care decreases. (2) If the interior solution is taken for family and social care choices, the family uses both types of care, and health improvements reduce both family and social care use. (3) If the corner solution is taken for the family's choice for care, the family presents a "pecking order", that is, employing all internal, informal resources for care before seeking social care. At this point, social care is more sensitive to health than home care. (4) The decline in social care is more pronounced in families with relatively few resources for home care and much use of social care and is more likely to be replaced by home care when social care is less specialized and lacks technical

complementarity. (5) The health improvements brought about by vaccines are more crucial and have a more significant effect on lowering the burden for families with relatively few internal resources for caregiving.

Do the empirical results support that health improvements reduce care needs? If care needs decline, do families adopt a balanced or unbalanced approach to adjusting family and social care? Are there many families who need health intervention policies more because of limited internal resources for caregiving? Next, we will answer these questions based on data from a randomized trial of COPD intervention.

3. Data description and econometric model setting

3.1 Data sources and experimental design

The data used in this paper mainly came from a large-sample microscopic, randomized trial survey conducted in Ningbo and Chongqing from October 2013 to October 2014 by the Institute of Economic Policy Research, Peking University (IEPR-PKU) and the Chinese Center for Disease Control and Prevention (China CDC) in a collaborative project “Socio-economic Benefit Assessment of COPD Preventive Interventions”. The primary purpose of this project was to assess the economic cost-benefit of vaccination scientifically through a randomized trial approach (Zong, 2015). Although the prevalence of COPD is high in China, there is a lack of systematic management regarding COPD. Hence, it is inherently difficult to identify patients with COPD in the population. Ningbo and Chongqing Centers for Disease Control and Prevention are model units in the management of chronic diseases, especially in the electronic management of information on patients with chronic diseases. Hence, we chose Ningbo and Chongqing as the study sites.

According to our sample size and considering the sample balance between cities, we collected samples in Ningbo and Chongqing (936 samples from each city), which accounted for 87 and 69% of the total number of COPD patients managed locally on file, respectively. The specific sampling process included the following steps:

- (1) Select three state-level model chronic disease management zones filed with the National Health and Family Planning Commission (renamed as the National Health Commission after March 2018) in each city: which are Fengdu County, Shapingba District and Beibei District in Chongqing; Jiangdong District, Haishu District and Yinzhou District in Ningbo.
- (2) Determine the number of samples collected from each demonstration zone. The relevant staff at the Center for Disease Control and Prevention (CDC) in Chongqing and Ningbo retrieved the basic information (name, age, contact information, etc.) of all patients who met the inclusion criteria and were screened based on the exclusion criteria in each chronic disease demonstration zone, based on the relevant electronic data records of the chronic disease demonstration zones. Subsequently, we calculated the sample size for each district and county based on the ratio of the number of patients who met the sampling criteria in the district to that in the whole city. The inclusion criteria for samples were as follows: 50 years of age or older and stable cases of COPD. The period of COPD can be generally divided into the stable stage and the acute exacerbation stage. Patients present stable or mild symptoms in the stable stage, such as cough, sputum and shortness of breath, and present a significant increase of accompanying inflammation within a short period, such as exacerbated cough, sputum, shortness of breath and fever in the acute exacerbation stage. According to the suggestions of the medical expert group of the China CDC, the subjects we selected for the trial were all COPD patients in the stable stage. The exclusion criteria were as follows: (1) those with respiratory diseases besides COPD;

- (2) those who were allergic to the components of influenza or pneumonia vaccine (including active ingredients and excipients of the vaccines); (3) those in the acute exacerbation stage of COPD: persistent exacerbation of respiratory symptoms beyond the daily variation range within four weeks prior to enrollment and requiring a change in medication regimen, symptoms including exacerbated cough, expectoration, shortness of breath and/or panting, increase of sputum volume, purulent or mucopurulent sputum or significant increase of inflammation such as fever; (4) those undergoing hormone therapy (such as cancer and tumor patients); (5) those having received pneumonia vaccination in the last five years and (6) those with suspected or confirmed pneumococcal infection.
- (3) Selection and random grouping of sample residential areas. We randomly selected four residential areas (communities/subdistricts/towns) in each of the above demonstration zones, with a total of 24 sample residential areas that met the selection criteria. In particular, we did not perform random grouping at the individual patient level in the trial, as the random grouping of different residents within the same residential area was highly likely to cause intergroup spillover of information. Specifically, vaccinated elderly or their family members in the same residential area were likely to pass on vaccine-related information (vaccine effects, side effects, etc.) to their neighbors in the control group. As a result, it was highly likely that the samples in the control group received vaccination voluntarily during the study, leading to confusion in the study design. Hence, we adopted the cluster sampling method and randomly divided the sample residential areas into four groups. The first three groups were treatment groups, which received injection interventions with influenza virus lysate vaccine (influenza vaccine), 23-valent pneumococcal polysaccharide vaccine (pneumonia vaccine) and combined vaccine, respectively [5]. The last group was the control group, which did not receive any vaccination intervention.

Moreover, we should try to ensure the comparability between different groups of samples, which often requires a thorough analysis of socioeconomic characteristics between samples. However, due to the lack of relevant statistical data, we could not acquire information about the residents in the sample residential areas before carrying out the research. Hence, we balanced the comparability between residential area groups based on two main dimensions. First, we determined the geographical location of each residential area on the electronic map and selected the residential areas that were not close to each other for random grouping if possible. Secondly, we used the information on the house prices in the residential areas provided by “Sofang.com” as a proxy variable for residents’ income and tried to achieve an even distribution of high, medium and low house prices (income) within the same group.

Our randomized trial was approved by the Ethics Committee of Peking University Health Science Center, and all subjects of the study completed the informed consent form. We selected community hospitals with vaccination and other relevant qualifications in each residential area to complete the vaccination intervention and questionnaire survey. Community physicians completed vaccination of subjects in the treatment groups and baseline survey of all samples in October 2013 and four follow-up questionnaire surveys in the first two weeks of January, March, May and October 2014, respectively. As this set of data spanned two periods before and after the vaccination intervention trial, exogenous health shocks were generated, which complied with our study requirements.

3.2 Data, variables and statistical description

As the data involved a baseline survey and four rounds of the follow-up survey with a long time span, a large sample size and many follow-up visits, we identified individuals by key information such as “ID number” and “name” and matched the data. After matching, 1,781 effective samples were finally obtained, including 1,334 in the treatment group and 447 in the control group.

We constructed three main dummy variables as explained variables. The first one was whether the patient had children around providing care during acute exacerbation of COPD, that is, whether home care was available. If so, it was recorded as 1 otherwise 0. The second was whether the patient employed a nonfamily member to provide care service during the acute exacerbation of COPD, that is, whether social care was available. If so, it was recorded as 1 otherwise 0. The third was whether care was available to the patient during the acute exacerbation of COPD. As long as home care or social care was available, it was recorded as 1 otherwise 0.

The CAT can reflect COPD symptoms in sample patients. China revised the guidelines for diagnosis and management of COPD in 2013 and recommended selecting either the breathlessness measurement using the modified British Medical Research Council (mMRC) questionnaire or CAT score as the symptom assessment method. The mMRC only evaluates the severity of dyspnea, but COPD can cause systemic symptoms such as cardiovascular disease, osteoporosis and depression in addition to pulmonary involvement. Hence, we collected CAT scores to comprehensively assess COPD patients’ symptoms (COPD Group of the Chinese Thoracic Society, Chinese Medical Association, 2013; Wen *et al.*, 2018). The test consists of eight specific indexes: cough, sputum, chest tightness, sleeplessness, energy, confidence leaving home, limited activities and impact on daily physical activities. The community physicians rate each index item (0–5) based on the responses of every patient to the eight questions, with higher scores indicating a more severe condition of COPD. The total score is 0–40.

In addition to control for some other factors that may affect the needs of the elderly for care, we selected some observable individual characteristics of the elderly as control variables, including age, gender (1 for male, 0 for female), marital status (1 for married, 0 for single, divorced or widowed), whether registered urban household, years of education, the total number of children, whether living with children, whether retired and the individual monthly income (monthly pension if retired).

Table 1 gives descriptive statistics of the main variables in the year before we carried out the trial. Due to acute exacerbation of COPD, 32.3% of elderly patients require care. The proportion of patients using home care was about 24.1%, approximately one-fourth of all samples, while the proportion of patients using social care use was relatively low, about 11.8%. The mean CAT score was 21.64, with a standard deviation of 6.7, indicating that COPD was relatively severe in our sample patients [6]. About 60% of the samples were men, which was consistent with the fact that men are more likely to have COPD than women in China; 84.3% of the COPD patients were married. About half of the samples lived in urban areas. The average years of education received by the sample patients was approximately 6.6, roughly equivalent to the primary school graduation level. The average number of children in the sample families was 2.369, and about 30% of the sample patients lived with their children. Among the sample patients, 96% were retired, which was generally consistent with the arrangement of the pension system in China, considering that the sample patients were all over 50 years of age. The average monthly individual income was RMB 1,880, which basically represented the average monthly pension of the samples since 96% of them were retired. It was very close to the national average monthly pension of RMB 1,845 in 2013 published by the National Bureau of Statistics, with a difference of less than 2%, indicating that the elderly samples we collected were highly representative in terms of income.

Table 1.
Descriptive statistics of
main variables (before
the trial)

Variables	Observed value	Mean	Standard deviation	Minimum	Maximum
Total care	1781	0.323	0.468	0	1
Home care	1781	0.241	0.428	0	1
Social care	1781	0.118	0.323	0	1
CAT score	1777	21.64	6.699	8	40
Age	1781	68.01	5	50	92
Male or not	1781	0.583	0.493	0	1
Married or not	1780	0.843	0.364	0	1
Urban household or not	1777	0.523	0.500	0	1
Years of receiving education	1775	6.559	3.760	0	14
Number of children	1738	2.369	1.228	0	15
Living with children or not	1770	0.298	0.458	0	1
Retired or not	1780	0.958	0.201	0	1
Monthly income (RMB)	1729	1880	2,652	0	72,000

3.3 Empirical model and estimation method

We first set a DID model to estimate the change in care due to health improvement as follows:

$$y_{it} = \alpha_0 + \alpha_1 Treat_i + \alpha_2 After_t + \alpha_3 Treat_i \times After_t + \varepsilon_{it} \quad (9)$$

where y_{it} represents the variable of interest to the investigator for individual i at time t ($t = 1, 2$) [7]; $Treat_i$ the dummy variable for the treatment group, of which the value is 1 if the individual is subject to the vaccination intervention and 0 otherwise; $After_t$ the time dummy variable, of which value is 1 after the trial and 0 before the trial and ε_{it} denotes the random perturbation term as usual. We estimate the above equation by ordinary least squares (OLS), and the coefficient α_3 represents the causal effect of interest.

The key assumption of the DID model is the “Parallel Trend Assumption”. This assumption requires that the “counterfactual” in the treatment group, that is, the amount of change in the outcome variable before and after the trial is assumed to be the same as that in the control group when the treatment group is not intervened. Our random sampling at the residential area level can partially ensure this [8] but is still insufficient. We will use a variety of approaches to make corrections in the subsequent analysis to improve the reliability and robustness of the model conclusions.

First, we used a generalized DID model and introduced a set of individual characteristic variables collected at the baseline survey into model Equation (9), mainly including initial individual CAT score, age, gender, marital status, whether registered urban household, years of education, number of children, whether living with children, whether retired and individual monthly income. In addition to these individual characteristics, we also controlled for district/county dummy variables to capture unobservable district/county heterogeneity. Moreover, we further allowed for unobservable individual heterogeneity in the subsequent regressions to correct for possible estimation bias from omitted variables.

Besides, we used Propensity Score Matching-Difference in Difference (PSM-DID) to correct for possible selectivity bias (Heckman *et al.*, 1998). The basic logic is that we use propensity scores to match samples in the treatment group and the control group before performing the DID regression to eliminate the bias introduced by the difference between the two groups before the intervention trial (Rosenbaum and Rubin, 1983). Through parametric (such as probit or logit model) or nonparametric methods, we can estimate the individual propensity scores before the trial, that is, the probability that an individual given a covariate will be intervened, which will be explicitly discussed later in this paper.

4. Analysis of empirical results

This section reports the main empirical results. With the data from the randomized trial of COPD intervention, we conducted testing based on a DID approach. We first examined the role of elderly health on the total needs for care, then assessed the effect of elderly health on the choice of care model separately and finally examined the heterogeneity of the effect of elderly health on the care model.

4.1 Elderly health and total needs for care

Before investigating the effect of elderly health on the total needs for care, we first tested whether the intervention to COPD patients improved the health level of patients. Table 2 reports the causal effect of the vaccination intervention on elderly health. In the table, column (1) indicates the results of DID regression without adding any other control variables (that is, only dummy variables in the treatment group, dummy variables before the trial and cross terms for both). Column (2) controls for district/county dummy variables and individual characteristic variables, mainly including age, gender, whether married, whether registered urban household, years of education, number of children, whether living with children, whether retired and individual monthly income. To avoid the effect of income extremes, we took logarithms of income. Considering the definition of the logarithmic function, for individuals with 0 income, we change their income to 1 before taking the logarithm. Column (3) further controls for unobservable individual heterogeneity by using the fixed-effects estimation framework of the panel data model, where dummy variables in the treatment group are absorbed by individual fixed effects as they do not change over time. The regression results indicate that our randomized intervention did produce an exogenous positive health shock that significantly improved the elderly health, with a causal effect of 1.879 points reduction in CAT score (see column (2)) [9].

Next, we observed the change in the proportion of total elderly care in the sample patients before and after the trial. The statistics indicated that the proportion of patients needing elderly care in the control group was 35.1 and 33.3% before and after the trial, respectively, with a minor change. Before the trial, 31.3% of the elderly in the treatment group had care needs, while this value dropped significantly to 18.9% one year after the trial. This result

Explanatory variables	Explained variable: CAT score		
	(1)	(2)	(3)
Treatment group	-2.171*** (0.359)	-1.645*** (0.360)	
After the trial	-0.801* (0.439)	-0.919** (0.428)	-0.786** (0.359)
Treatment group* after the trial	-2.093*** (0.507)	-1.879*** (0.497)	-1.916*** (0.418)
Individual characteristic variables	No	Yes	Yes
District/county fixed effects	No	Yes	Yes
Individual fixed effects	No	No	Yes
Observed value	3,558	3,285	3,285
R ²	0.077	0.162	0.092

Table 2. Causal effects of preventive interventions for COPD on elderly health

Note(s): (1) Individual characteristic variables include age, gender, whether married, whether registered urban household, years of education, number of children, whether living with children, whether retired and individual monthly income (logarithm). (2) Values in parentheses in the table indicate standard deviations. (3) *, ** and *** indicate statistical significance levels of 10%, 5% and 1%, respectively. (4) Estimates of constant terms were omitted

preliminarily suggested that the health improvements resulting from the preventive intervention trial significantly reduced the elderly care needs.

Table 3 presents the results of the formal DID regression estimated by OLS [10]. Regression (1) represents the DID results according to model (9) equation, indicating that health improvement results in a statistically significant reduction of 0.107 in the probability of total elderly care use at the significance level of 1%. Regression (2) further controls for district/county dummy variables and individual characteristic variables. It should be noted that in addition to demographic characteristics and income variables, we included initial CAT scores to control for possible estimation bias resulting from differences in initial conditions. The results show little change in the coefficients of the cross terms while the health improvement from the randomized intervention results in a statistically significant reduction of 0.111 in the probability of elderly care use. Given that the probability of elderly care use in the treatment group before the trial was 0.313, this implied a reduction of 35.5% (0.111/0.313) in the probability of elderly care use due to health improvement. The results controlling for individual fixed effects (regression (3)) show that there is no change in the values of causal effects compared to regression (2), indicating that unobservable individual heterogeneity will hardly have any effect on our main conclusions.

In summary, the health improvements resulting from the preventive intervention policy led to a reduction of about 35.5% in the total needs for elderly care. This finding implies that Lemma 1 and the assumptions underlying the subsequent theorem hold. As the elderly's health improves, the marginal benefit from care decreases to a greater extent, the needs of families for health are met and the total need for care decreases.

4.2 Elderly health and care model choice

The preceding section argued for the significant role of health improvements from preventive intervention policies in reducing the total needs for elderly care. This section further tests whether Theorems 1 or 2 holds, that is, whether the effect of preventive health intervention policies on the needs for informal home care and formal social care is balanced and whether elderly families reduce their use of informal care and formal social care in equal proportion. The most direct way is to observe how families using both types of care before the trial would

Explanatory variables	Explained variable: Availability of family or social care		
	(1)	(2)	(3)
Treatment group	-0.0379 (0.0241)	-0.0136 (0.0250)	
After the trial	-0.0179 (0.0295)	-0.0137 (0.0297)	-0.0140 (0.0212)
Treatment group* after the trial	-0.107*** (0.0341)	-0.111*** (0.0345)	-0.111*** (0.0246)
Individual characteristic variables	No	Yes	Yes
District/county fixed effects	No	Yes	Yes
Individual fixed effects	No	No	Yes
Observed value	3,562	3,282	3,282
R^2	0.023	0.056	0.057

Note(s): (1) Individual characteristic variables include age, gender, whether married, whether registered urban household, years of education, number of children, whether living with children, whether retired and individual monthly income (logarithm). (2) Values in parentheses in the table indicate standard deviations. (3) *, ** and *** indicate statistical significance levels of 10%, 5% and 1%, respectively. (4) Estimates of constant terms are omitted

Table 3. Effect of elderly health on total care: DID estimates

choose their care model after the trial. Statistical analysis revealed that only 15% of the families in the control group using both types of care before the trial withdrew the social care after the trial. Compared with it, up to 43.48% of the families who used both types of care before the trial withdrew social care and retained home care after the trial, while only 4.35% of the families chose to use social care and withdrew home care. This preliminary finding strongly suggests that there may be a “pecking order” in the family choice of elderly care model as indicated by [Theorem 2](#).

To further verify this, the changes in the proportion of different types of care for elderly COPD patients before and after the trial are shown in [Figure 2](#), where the left panel indicates the changes in the proportion of home care before and after the trial, and the right panel reflects the difference in the proportion of social care before and after the trial. We made descriptions of the treatment group and the control group. The results indicate that, first, in terms of home care, the proportion in the control group decreased from 0.275 to 0.251, which was a minimal decrease. In contrast, the proportion in the treatment group decreased from 0.23 to 0.167, slightly higher than that in the control group. Secondly, regarding social care, the proportion in the control group showed no significant change before and after the trial (0.121 and 0.119, respectively), but interestingly, the proportion in the treatment group plummeted from 0.118 to 0.038, a decrease of 8%, which was significantly greater than that in the treatment group numerically.

[Table 4](#) examines the impact of elderly health on different care patterns through formal DID regressions. Regressions (1)–(3) show the results of home care. As usual, we first report the regressions without adding any other control variables, followed by those with individual characteristic variables and district/county dummy variables added and finally, further controlling for individual fixed effects. The results indicate that the proportion of home care for the subjects in the treatment group decreased by about 0.4, which, however, was not statistically significant. Regressions (4)–(6) report the estimation results of social care. The results indicate that health improvement led to a decrease in the probability of social care use by about 0.08, which was statistically significant at the significance level of 1%. Given that the probability of elderly social care use in the treatment group before the trial was 0.118, this implied a reduction of 67.8% (0.008/0.118) in the probability of elderly care use due to health improvement, suggesting that the reduction in elderly care in the treatment group occurred mainly in social care use, while there was no significant change regarding home care. This finding supports [Theorem 2](#) of the above theoretical model, which states that families have a

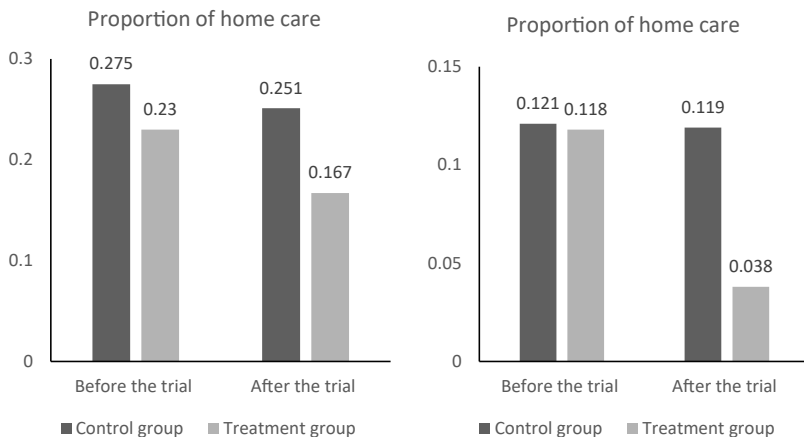


Figure 2. Changes in the proportion of different types of care before and after the trial: home care vs. social care

Table 4.
Effect of elderly health
status on care model
choice: DID estimates

Explanatory variables	Home care			Social care		
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment group	-0.045** (0.022)	-0.031 (0.023)		-0.0031 (0.015)	0.0097 (0.016)	
After the trial	-0.025 (0.027)	-0.023 (0.028)	-0.023 (0.019)	-0.0022 (0.019)	-0.00083 (0.019)	-0.0001 (0.015)
Treatment group*after the trial	-0.038 (0.032)	-0.040 (0.032)	-0.040 (0.022)	-0.077*** (0.022)	-0.080*** (0.022)	-0.080*** (0.017)
Individual characteristic variables	No	Yes	Yes	No	Yes	Yes
District/county fixed effects	No	Yes	Yes	No	Yes	Yes
Individual fixed effects	No	No	Yes	No	No	Yes
Observed value	3,562	3,282	3,282	3,562	3,282	3,282
R ²	0.009	0.037	0.019	0.019	0.045	0.049

Note(s): Same as in [Table 3](#)

“pecking order” in the choice of elderly care model [11]. The elderly prioritize the use of all home care resources before resorting to social care. Thus, when the elderly’s health status improves, social care is also first withdrawn, leading to a higher sensitivity of social care to health.

4.3 Robustness test

This section focuses on discussing the robustness of the basic conclusions in the preceding sections. We provided a series of tests to verify the sensitivity of the main results. First, we controlled for multiple individual characteristic variables (such as demographic characteristics and income variables) in the regressions. Second, we controlled for district/county dummy variables to capture the effect of district/county factors on care needs that do not change over time. Thirdly, we controlled for unobservable individual heterogeneity to correct for possible bias. The results in [Tables 3 and 4](#) indicate that none of the aforesaid approaches alter the basic conclusions.

To further correct for the selectivity bias, that is, the bias introduced by the differences in the samples between the treatment group and the control group before the trial, we conducted regression using the PSM-DID method. The results indicate that the use of nearest neighbor matching, radius matching and kernel matching did not alter the basic conclusions of the preceding sections, and there was little change in the magnitude and significance of coefficients [12]. In summary, all the aforesaid tests have verified the robustness of the conclusions in this paper.

4.4 Further analysis: heterogeneity test

As demonstrated earlier, improved health of the elderly brings about a decrease in an unbalanced decline in family and social care. As families may have a “pecking order” in the choice of care model, the elderly prefer employing all home care resources before resorting to social care. Thus, when the elderly’s health status improves, social care tends to be first withdrawn. The theoretical model in this paper also predicts that, according to [Theorem 3](#), families with fewer care resources are more likely to reduce social care considerably after the elderly health improves. Observation of the statistical data also indicates that those who withdrew social care were mainly among families who used only social care before the trial and did not use any care after the trial, accounting for 62.68% of the total samples with decreased social care [13]. Based on [Theorem 3](#), it is reasonable to speculate that this is

because this group of families had scarce internal resources for caregiving. Thus, they used only social care before the trial and significantly reduced their use of social care when their health status improved after the trial.

To verify that families using only social care did so because of few internal resources for caregiving, we conducted linear probability model regressions using the survey data in the base period. The number of children and whether they were married (with an older caregiver) are variables that provide a direct measure of how many resources the family is endowed with. Moreover, many studies argued that daughters were more likely to provide informal home care than sons (e.g. [Wolf et al., 1997](#); [Van Houtven and Norton, 2004](#)), and living arrangements were also closely related to care resources (e.g. [Mommaerts, 2018](#)). In [Table 5\(1\)–\(4\)](#), we added variables reflecting home care resources and endowment on a case-by-case basis. The results indicate that the probability of using social care is significantly higher for the elderly with fewer children or daughters, not living with children, single, divorced or widowed. Regression (5) controls for all variables (given that the number of children is highly correlated with the number of daughters, we only control for one of them to avoid the interference of collinearity). The results again indicate that the elderly with insufficient home care endowment are more likely to use social care to improve their health. [Table 5](#) clearly reveals that families who use only social care in the base period are constrained by the scarcity of home care resources, and they can only resort to social care. Hence, they substantially reduce their use of social care after health improvement, which is totally consistent with the conclusions of [Theorem 3](#) in the model derivation. Furthermore, the coefficients of regressions (1)–(4) in [Table 5](#) indicate that whether the elderly live with their children and whether they are married have the most significant effect (in absolute value) on the probability of social care use and that the number of daughters is more important than that of children, which is consistent with intuition.

To test [Theorem 3](#) more directly, we designed a group test to investigate whether the decline in formal social care brought about by health improvement was more significant in families with relatively few informal internal resources for caregiving. [Table 6](#) uses three variables (number of children, number of daughters and whether living with children) to examine the amount of care resources families are endowed with and analyze the heterogeneity of health shocks. First, we constructed the dummy variable of whether the number of children is large, recorded as 1 if the elderly patient has more than a child and 0 if the patient has a child or no child. Columns (1) and (2) in [Table 6](#) present the sample regression results, indicating that elderly health improvement leads to a decrease of 0.15 in social care

Explanatory variables	Explained variable: Use of social care				
	(1)	(2)	(3)	(4)	(5)
Number of children	-0.0261*** (0.00779)				
Number of daughters		-0.0381*** (0.00829)			-0.0364*** (0.00819)
Living with children			-0.0876*** (0.0175)		-0.0972*** (0.0175)
Married or not				-0.120*** (0.0223)	-0.131*** (0.0226)
Individual characteristic variables	Yes	Yes	Yes	Yes	Yes
District/county fixed effects	Yes	Yes	Yes	Yes	Yes
Observed value	1,649	1,662	1,680	1,686	1,654
R ²	0.024	0.030	0.033	0.035	0.064

Table 5.
Factors affecting social care (before the trial)

Note(s): Same as in [Table 3](#)

Explanatory variables	Number of children		Whether there are daughters		Whether living with children	
	Few (1)	Many (2)	No (3)	Yes (4)	No (5)	Yes (6)
Treatment group	0.0424 (0.0406)	-0.00556 (0.0173)	0.0665* (0.0391)	-0.00628 (0.0165)	0.0505** (0.0207)	-0.0941*** (0.0226)
After the trial	-0.0105 (0.0481)	-0.000161 (0.0204)	-0.00405 (0.0469)	0.000440 (0.0194)	0.00293 (0.0244)	-0.0117 (0.0270)
Treatment group* after the trial	-0.15*** (0.0547)	-0.0579** (0.0238)	-0.157*** (0.0539)	-0.0502** (0.0226)	-0.114*** (0.0285)	0.00062 (0.0308)
Individual characteristics variables	Yes	Yes	Yes	Yes	Yes	Yes
District/county fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observed value	740	2,542	892	2,390	2,318	964
R^2	0.115	0.043	0.090	0.049	0.046	0.068

Note(s): Same as in Table 3

Table 6.
Effect of elderly health on social care: heterogeneity test

use among elderly families with relatively few children and a significant decrease of 0.0579 among those with many children. Secondly, we used the dummy variable of whether there are daughters, recorded as 1 if the number of daughters is greater than or equal to 1 and 0 if no daughters. Columns (3)–(4) in Table 6 present the DID regression results, which indicate that social care decreased significantly by 0.157 after health improvement regarding the elderly without daughters but decreased less significantly regarding families with daughters, with a causal effect of 0.05. Finally, we also examined the possible heterogeneity of whether living with children. The regression results of columns (5)–(6) in Table 6 indicate that social care decreased significantly by 0.114 for the elderly living with children, while there was no significant change in social care for those not living with children. In summary, the results of the heterogeneity test suggest that the use of social care declines more significantly for the elderly with fewer home care resources, such as fewer children, fewer daughters or not living with their children. This finding is consistent with Theorem 3, where families with relatively few or limited internal resources for caregiving tend to have a higher rate of using social care before the trial and a more significant decline in social care use after the elderly health improves.

Since the 1970s, the total fertility rate in China has declined substantially, leading to a sharp decrease in the internal resources of families for elderly care in recent years. As the latter part of Theorem 3 illustrates, the burden alleviation effect of preventive health intervention policies is more pronounced for families with limited internal resources for caregiving. This suggests that when evaluating the effect of preventive health intervention policies, it is important to note not only the substantial reduction in overall needs of family for care due to these policies but also the structural features of such effect. Analysis of Theorem 3 and Tables 5 and 6 indicate that the effect of preventive health intervention policies for COPD researched in this paper is primarily about reducing the burden on families with relatively few internal resources for caregiving and forced to use social care, which are social policies should primarily care for and target.

5. Conclusions and policy implications

In the practical context of China's rapidly aging population, the huge demand for elderly care and the implementation of the Healthy China strategy, it is undoubtedly of great theoretical

value and practical significance to explore how elderly health affects care needs and patterns. With the data from a large, controlled intervention trial on COPD patients conducted by IEPR-PKU and China CDC from 2013 to 2014, this paper empirically analyzed these issues in detail. The results of the DID estimation method indicated that, first, the CAT scores of the elderly in the treatment group decreased significantly, suggesting a significant improvement in their health condition, which led to a 35.5% reduction in the probability of care use among elderly patients in the treatment group. Secondly, the reduction in care needs in the treatment group occurred mainly in needs for social care, with health improvement leading to a 67.8% reduction in the probability of social care use, while the effect of health improvement on home care was not significant. The PSM-DID results indicated that the above conclusions were essentially robust. Further heterogeneity analysis suggested that the decline in social care was more pronounced after health improvement for the elderly with fewer children, fewer daughters and not living with their children because they had minimal or limited resources for home care before the trial.

We explained the results of the empirical findings in the paper through a theoretical model of families' choice for care. The conclusions of the theoretical model indicate that there is a "pecking order" in the elderly's choice of care model, that is, families would employ all internal resources for caregiving first before resorting to social care. In the "pecking order" case, social care is more health-sensitive, resulting in a rapid decline in the needs for social care after the elderly's health status improves.

The potential policy implications of this paper are, first, *ex ante* health preventive intervention policies can be effective in reducing the burden of elderly care in general, especially the high-cost social care. Secondly, our study has provided a useful reference for the formulation of precise supportive policies for elderly care. Our theoretical model and empirical results indicate that for families with more constraints on internal resources for informal care, preventive intervention policies are more effective in reducing burden on them. This reveals that we should mainly target and address families with relatively few internal resources for caregiving when developing formal social care in the future. From the perspective of the empirical results, as many samples presented a significant decline in social care but no significant change in home care, this suggested that the potential families with limited internal resources for caregiving may account for a quite high proportion. Finally, according to [Theorem 3](#), if home care and social care have strong technical complementarity, we should not observe a significant decline in social care. However, the empirical results indicate that the use of social care declined significantly after the elderly health improvement, suggesting that the current professional level of social care for the elderly in China still requires further improvement and its technical complementarity with informal home care is not strong enough. Therefore, in the future, efforts should be made to improve the technical complementarity and synergetic development of social care and home informal care and enhance the quality and efficiency of social care.

Notes

1. According to the statistics of *National Program for Chronic Disease Control and Prevention (2012–2015)*, 260 million people in China have been diagnosed with chronic diseases. The number of chronic disease patients will continue to grow rapidly in the future with the aging of China's society. Respiratory diseases, especially COPD, are major chronic diseases in China.
2. Source: *Report on Chinese Residents' Chronic Diseases and Nutrition (2015)*, published by the National Health and Family Planning Commission (China) on June 30, 2015.
3. [Lin et al. \(2008\)](#) stated that it was estimated that 65 million people in China would die from COPD from 2003 to 2033 due to smoking, use of solid fuels, etc.

4. This is similar to the relationship between short-term and long-term costs of manufacturers. In the short term, manufacturers can only adjust variable costs but not fixed ones, resulting in short-term costs lying above the long-term cost line, with the latter costs becoming the lower envelope of the former.
5. The administration of these two kinds of vaccines has been specified in international clinical guidelines as effective measures for the management of chronic diseases, with a one-year duration of protection for influenza vaccine and a five-year duration of protection for the pneumonia vaccine. The Global Initiative for Chronic Obstructive Lung Disease (GOLD) states that these two vaccines are an effective means of preventing acute exacerbation in stable COPD patients and play a vital role in alleviating symptoms and improving quality of life in COPD patients (GOLD, 2016). Domestic medical research (Wen *et al.*, 2018) also indicated that these two vaccines could significantly improve the overall symptoms and multiple index symptoms such as cough, chest tightness, shortness of breath, activities, confidence leaving home and energy in Chinese COPD patients.
6. According to the COPD Group of the Chinese Thoracic Society, Chinese Medical Association (2013) and the GlaxoSmithKline group of companies (2016), if a patient's CAT score exceeds 20, it indicates a high impact of COPD (0–10 indicates a mild impact; 11–20 moderate impact; 21–30 relatively high impact; 31–40 very high impact). That is, patients are unable to do most of the things they desire due to COPD.
7. Since our base period survey inquired about care in the previous year (October 2012–October 2013) before the trial, for comparison, we need to integrate the relevant data in the subsequent four follow-ups into care across a year (October 2013–October 2014). The econometric regression involves data in “two periods (before intervention and after intervention)”.
8. We tested whether the differences in the main variables were statistically significant between the treatment group and the control group. The results indicated that the differences in the variables such as income, education, whether married and whether living with children were not statistically significant. The differences in age and whether male were marginally significant between the treatment group and the control group. However, they were numerically insignificant in fact and could be considered insignificant in economic significance. The only variable that differed relatively significantly was whether the family was a registered urban household. The reason was that we conducted random sampling at the residential area level, and the total number of COPD patients in each sample residential area was not homogeneous. Therefore, we could not fully ensure a balanced urban–rural distribution between the treatment group and the control group during the sampling process. Due to space limitations, the specific results are omitted and available to interested readers upon request.
9. We also conducted DID regressions for each of the eight subindexes of CAT scores, respectively. The results indicated that six indexes (cough, chest tightness, breathlessness, activities, confidence leaving home and energy) of patients were significantly improved. Moreover, the density plots of the COPD condition index for samples in the treatment group and the control group before and after the trial also showed that there was a significant decrease in CAT scores (that is, a significant improvement in COPD condition) of patients in the treatment group, especially those who were originally more severely ill (CAT score >20); whereas this trend was not found when observing the changes in COPD condition of subjects in the control group. Due to space limitations, the results are omitted.
10. The Probit and Logit model estimates do not alter our basic conclusions. Due to space limitations, the estimation results are omitted.
11. The unbalanced decline in home care and social care after the intervention may also be caused by non-homothetic production function, which, however, is insufficient to generate the case where family care hardly changes. Hence, we used the CES production function form in the theoretical model section. We appreciate the anonymous reviewers for pointing this out.
12. Due to space limitations, the estimation results are omitted and available to interested readers upon request.

13. The other three types of families were those who used only social care before the trial but adjusted to home care after the trial, those who used both social and home care before the trial but used only home care after the trial and those who used both social and home care before the trial but used neither care after the trial.

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Further reading

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