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Impact of energy poverty on cognitive and mental health among middle-aged and older adults in China

Xuefeng Li¹ , Han Yang¹ & Jin Jia¹

Energy poverty (EPOV) is considered to have a significant impact on health and has become an essential issue on the policy agenda in most countries, especially those with rapid aging. Cognitive and mental health (CMH) for aging well is just as important a component as physical health, but the literature on the effect of EPOV on CMH is still rare. Using 2014–2018 China Family Panel Studies (CFPS), this study explores EPOV and its impacts on CMH among middle-aged and older adults. Six measures based on energy affordability are constructed to capture the state of EPOV. The results show that the proportion of middle-aged and older adults living in EPOV in China ranges from 24.3% to 27.8%, according to different measures. Applying a two-way FE model, the estimates show that overall, the impact of EPOV on CMH is significantly negative. Furthermore, physical health is an important channel through which EPOV affects CMH. Although EPOV has a significant adverse effect on the CMH of both middle-aged and older adults, it harms the latter more.

¹Institute of Western China Economic Research, Southwestern University of Finance and Economics, Chengdu, Sichuan, China. email: fzyanghan@126.com

Introduction

Poverty is not the mere lack of income to meet basic needs but multidimensional deprivations in basic human capabilities (Sen, 1995; Sen, 1999). Energy drives human life and is crucial for continued human development (Asif and Muner, 2007). In the composition of poverty, energy-related deprivations are known as “energy poverty” (EPOV), which adversely affects people’s wellbeing (Awaworyi Churchill and Smyth, 2021; Llorca et al., 2020). EPOV is a global problem affecting both developing and developed countries. The International Energy Agency (IEA) states that nearly 1 billion people were still in EPOV in 2019 (IEA, 2019), and more than 100 million people who already had electricity connections will again rely on dirtier and less efficient energy sources in 2020 because they cannot afford basic electricity expenditure (IEA, 2020). In some countries, EPOV has been officially recognized as a distinct problem, separate from general poverty (Bednar and Reames, 2020). Many researchers have explored the negative impact of EPOV, especially on health (Banerjee et al., 2021; Bukari et al., 2021; Kahouli, 2020). Several of these studies point out that such impacts are more severe among older adults than others (Porto Valente et al., 2021). Considering the close correlation between EPOV and health (Bukari et al., 2021; Rafi et al., 2021), EPOV may become a severe challenge to healthy aging.

Population aging is associated with various societal impacts, especially health issues (Lin et al., 2010). Healthy aging is related to the quality of life of older adults and potentially lessens the burden on the whole society by reducing or delaying the need for economic support and elderly care (Smith et al., 2014). With the aging issues becoming severe, the studies increasingly emphasize the importance of health promotion targeting middle-aged and older adults (Elliott et al., 2021; Sun and Yang, 2021). A comprehensive understanding of the factors affecting the health of middle-aged and older adults is a prerequisite for health promotion. Cognitive and mental health (CMH), such as dementia and depression, are essential components of healthy aging. Taking dementia as an example, its annual cost in the United States is \$109 billion, which remains the costliest of all diseases (Hurd et al., 2013). For the influencing factors of CMH, the current research mainly discusses gender (Zhao et al., 2021), cultural context (Haas et al., 2021), residential settings (Lee et al., 2019), family involvement (Hawkins et al., 2021), but rarely explores how EPOV affects CMH.

As the most populous country, China is facing severe challenges brought by population aging. According to the statistics of the National Bureau of Statistics of China (NBSC), the proportion of people over 60 years old increased from 10.27% to 18.70% in China (NBSC, 2021). Like many developed countries, China needs to implement health promotion interventions conducive to healthy aging, especially for CMH, to reduce the burden of aging. On the one hand, the rapid socioeconomic transition may lead to a decline in mental health (MH) among Chinese older adults, such as depression (Zeng, 2012), which are common and often neglected (Fang et al., 2015). On the other hand, the cognitive health (CH) of older adults in China is also not optimistic. In 2010, about 9.19 million people in China had dementia, and 5.69 million had Alzheimer’s disease (Chan et al., 2013). However, compared with physical health (PH), CMH in older adults receives less attention in China (Fang et al., 2015). Meanwhile, China is facing a severe challenge with EPOV. Some researchers have measured the incidence of EPOV in China, ranging from 22.6% to 41.3% (Nie et al., 2021; Zhang et al., 2019; Zhang et al., 2021b). Therefore, China provides a typical example to explore the impact of EPOV on CMH in the context of rapid aging.

Our research contributes to studies of the relationship between EPOV and CMH in the following aspects. Apart from being one

of the first studies to use nationally representative data to investigate this relationship among middle-aged and older adults, this study also provides a rich set of EPOV measures regarding energy affordability. To our knowledge, only one recent research indicates that EPOV harms the MH of the head of household in China (Zhang et al., 2021b). However, our research differs significantly from Zhang et al. (2021b): First, our sample is mainly for people aged 45 and above, which helps obtain accurate information about the impact of EPOV on healthy aging. Second, based on the concept of healthy aging, PH, CH, and MH are put into the same framework to explore the comprehensive effects of EPOV on the health status of middle-aged and older adults. Third, unlike the EPOV measure based on energy availability in Zhang et al. (2021b), we measure EPOV from the perspective of energy affordability, which is more in line with the actual situation in China. Fourth, we use panel data instead of cross-sectional data, which makes the conclusion more accurate and enables more informative discussion, such as the lag effect of EPOV.

The rest of this research is as follows. Section “Literature review” presents relevant literature on the concept and measure of EPOV, EPOV-CMH association, and its potential mechanism. Data sources, variables definitions, and empirical strategies are discussed in Section “Methodology”. Empirical results are reported in Section “Results”. Section “Conclusion” summarizes our research.

Literature review

The concept and measure of EPOV. The concept of EPOV was first put forward in 1982 (Lewis, 1982). There are many definitions of EPOV, but most believe that EPOV is a state that does not meet people’s energy consumption needs (Bukari et al., 2021; Druică et al., 2019; Nie et al., 2021; Rafi et al., 2021). According to Reddy (2000), EPOV is considered to be “the absence of sufficient choice in accessing adequate, affordable, reliable, high quality, safe and environmentally benign energy services to support economic and human development.” This definition is selected here because it not only includes the absence of sufficient choice in accessing energy services, which meets the deprivations in human capabilities, but also describes the observable characteristics of energy services, including availability, affordability, reliability, high quality, safety, and environmental friendliness (González-Eguino, 2015).

Among these characteristics proposed by Reddy (2000), researchers often use energy availability and affordability to measure EPOV. Some studies emphasized the importance of energy availability (Acheampong et al., 2021; Pan et al., 2021; Poblete-Cazenave and Pachauri, 2021; Zhang et al., 2021a). They construct some representative indicators, such as the use of electricity or other fuels and the use of household appliances to measure EPOV. Some studies focus on energy affordability, measuring EPOV by the proportion of household energy consumption. The earliest studies set the threshold of energy expenditure at 10% of household income (Legendre and Ricci, 2015; Mould and Baker, 2017). As this field of research continues to grow, several studies employ improved measures to suit local conditions and energy costs in different regions (Koomson and Danquah, 2021; Prakash and Munyanyi, 2021). We summarize some widely used EPOV measures in Table 1.

However, different countries have different performances in EPOV (Awaworyi Churchill and Smyth, 2021; Zhang et al., 2019; Rafi et al., 2021; Phoumin and Kimura, 2019). Some countries are still striving to achieve universal energy access, while others have already achieved this goal and need to focus on energy affordability. Thus, when choosing the specific EPOV measure,

Table 1 Literature related to EPOV measures.

Conceptual focus	Measure	Literature source
Focus on energy affordability	10% of household income for energy expenditure. Amended 10% measure. Double median percentage. Low-income-high-cost (LIHC)	Legendre and Ricci (2015), Mould and Baker (2017), Zhang et al. (2019), Phoumin and Kimura (2019) Farrell and Fry (2021), Kahouli (2020), Lin and Wang (2020) Moore (2012), Nie et al. (2021)
Focus on energy availability	Access to energy supply: access to electricity or other fuels, access to household electric appliances.	Awaworyi Churchill and Smyth (2021), Hills (2011), Li et al. (2014) Acheampong et al. (2021), Pan et al. (2021), Poblete-Cazenave and Pachauri (2021), Rafi et al. (2021), Zhang et al. (2019), Zhang et al. (2021a)

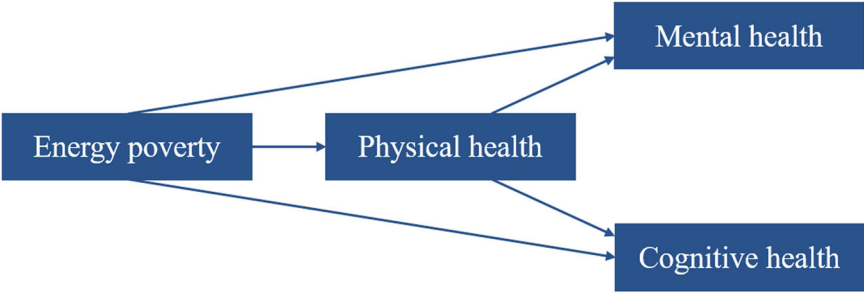


Fig. 1 Mechanism diagram. The mechanism of the impact of EPOV on the health of middle-aged and older adults.

the research object’s actual situation must be considered. Considering that China’s electrical access has reached 100% since 2013 (World Bank, 2020), and energy infrastructure in backward areas has been improved after China’s poverty alleviation policy. The problem of energy accessibility in China has been roughly solved. Therefore, energy affordability is more representative of EPOV than energy availability in China.

Impacts of EPOV on CMH. Many researchers have analyzed the linkage between EPOV and health, but direct evidence for the effect of EPOV on CMH is still rare. A small body of extant research provides evidence of EPOV’s detrimental effects on MH. For instance, Shupler et al. (2022), drawing on data from Africa, find that eliminating EPOV helps reduce the probability of depression in women. Mould and Baker (2017) conduct fifteen case studies in Scotland and find that EPOV can lead to MH problems, such as depression and anxiety. Similarly, Zhang et al. (2019) use household-level survey data from the China Family Panel Studies further confirm a statistically significant and robust negative impact on MH from EPOV.

Fortunately, various studies provide indirect evidence for the effect of EPOV on CMH. On the one hand, some researchers provide evidence on the linkage between EPOV and academic achievement, one of the common indicators representing cognitive function (Pascoe et al., 2021). Rafi et al. (2021) research Indian children and find that EPOV harms children’s academic achievements. Based on the data from 50 developing countries, Banerjee et al. (2021) find that lower EPOV can bring higher educational outcomes. On the other hand, some researchers have studied the influence of EPOV on subjective wellbeing, which is closely related to MH (Okbay et al., 2016). For instance, Phoumin and Kimura (2019) use survey data from Cambodia to find that EPOV lowers subjective wellbeing. Using data from 13 waves of the Household, Income and Labour Dynamics in Australia (HILDA) survey, Awaworyi Churchill et al. (2020) link EPOV with poor subjective wellbeing. Nie et al. (2021) conduct the same research in China, supporting the above conclusions.

The mediating role of PH. To explore the potential channel between EPOV and CMH, we tested the mediating role of PH. The impact of EPOV on PH is widely discussed. Most researchers suggest that EPOV has a negative effect on the PH. Specifically, these households living in EPOV may turn to alternative energy sources to meet their daily energy needs. Some researchers find that these alternative energy sources are usually of poor quality, and may emit toxic gases and damage body functions, leading to chronic diseases and other health problems (Lacroix and Chaton, 2015; Sharpe et al., 2015). Meanwhile, due to financial constraints, many households need to trade between adequate nutrition and energy services, leading to the “heat or eat” dilemma (Anderson et al., 2012). Some of them may limit their energy costs to avoid debt from energy consumption (Awaworyi Churchill et al., 2020), resulting in insufficient energy use and affecting their health. With limited literature, EPOV is also confirmed to have a negative impact on food expenditure (Nie et al., 2021), and inadequate food intake ultimately affects health.

The correlation between PH and CMH has been widely discussed, especially among older adults (Kivimäki and Livingston, 2022; Kubzansky et al., 2018; Yang and D’Arcy, 2022). Human function deteriorates with age, which in turn affects CMH (Walston et al., 2006). On the one hand, PH is significantly related to MH (Kubzansky et al., 2018). The probability of suffering from chronic diseases increases with age, and chronic diseases negatively affect MH (Yang and D’Arcy, 2022). On the other hand, PH also has significant effects on CH. For instance, Kivimäki and Livingston (2022) find that poor PH significantly increases the long-term risk of Alzheimer’s disease. Therefore, EPOV may have an indirect effect on CMH by affecting PH. Considering that both CMH and PH are important components of healthy aging, we attempt to put them into the same framework to explore the comprehensive effects of EPOV on the health status of middle-aged and older adults. Fig. 1 shows a simple heuristic of the above factors as a possible mechanism by which EPOV affects CMH among middle-aged and older adults in China.

Table 2 Descriptive statistics.

Variable	Definition	Mean	SD
CH	Score based on the response to the question “to what extent can you remember the main things that happened to you in a week”.	2.975	1.315
MH	Average score of six indicators related to mental health.	3.410	0.604
EPOV1	Dummy variable equals 1 if “the respondent’s household energy consumption exceeds 10% of income”.	0.278	0.448
EPOV2	Dummy variable equals 1 if “the respondent’s household energy consumption exceeds 10% of income, and the income is at the bottom 50% of the total distribution”.	0.252	0.434
EPOV3	Dummy variable equals 1 if “the respondent’s household energy consumption exceeds double median percentage of the total sample”.	0.277	0.447
EPOV4	Dummy variable equals 1 if “the respondent’s household energy consumption exceeds double median percentage of the sample by provinces”.	0.262	0.440
EPOV5	Dummy variable equals 1 if “the respondent’s household energy consumption exceeds the median percentage of the total sample, and the income is at the bottom 25% of the total distribution”.	0.243	0.429
EPOV6	Indicator based on the combination of EPOV1, EPOV2, EPOV3, EPOV4, and EPOV5.	0.263	0.396
Age	Age of the respondent.	60.133	9.493
Gender	Dummy variable equals 1 if “respondent is male”.	0.495	0.500
Educational levels	The highest level of education received by the respondent.		
Illiteracy	Dummy variable equals 1 if “respondent is illiterate”.	0.135	0.342
Primary school	Dummy variable equals 1 if respondent’s highest education level is primary school”.	0.333	0.471
Middle school	Dummy variable equals 1 if respondent’s highest education level is middle school”.	0.233	0.423
High school	Dummy variable equals 1 if respondent’s highest education level is high school”.	0.193	0.394
Vocational school	Dummy variable equals 1 if respondent’s highest education level is vocational school”.	0.082	0.275
University or higher	Dummy variable equals 1 if respondent’s highest education level is university or higher”.	0.024	0.152
Currently employed	Dummy variable equals 1 if “respondent is currently employed”.	0.604	0.489
Training	Weekly exercise frequency of respondent.	2.572	3.219
Social status	Respondent’s response to “how do you evaluate yourself in local society”, ranging from 1 (lowest) to 5 (highest).	3.083	1.100
Married	Dummy variable equals 1 if “respondent is married”.	0.867	0.339
Hukou	Dummy variable equals 1 if respondent’s registered residence is urban”.	0.460	0.498

Source: CFPS 2014–2018.

Methodology

Data. The data of this paper comes from a nationally representative survey in China, China Family Panel Studies (CFPS), conducted by the Institute of Social Science Survey of Peking University. The survey collects data from the individual, household, and community levels, covering all members of 16,000 households in 25 provincial administrative units, including detailed information on various aspects of China, such as culture, economy, education, and healthcare. Many previous studies use CFPS data to explore China issues, including EPOV (Nie et al., 2021; Zhang et al., 2021a) and CMH (Gao et al., 2021; Xue et al., 2019), have verified the validity of the database. CFPS has disclosed five waves of data, but the details about energy related to our research only have been collected since 2014. Therefore, three waves are used in this study: 2014, 2016, and 2018. Considering that our research targets are middle-aged and older adults, we limit the sample age to 45 years old and above. To focus on energy affordability, we delete the samples using cheap solid fuels and those with an income of 0. Finally, the analysis unit in this study is individual. We obtain an unbalanced panel of 19,664 individuals from 11,108 households. Among all individuals, 9972 individuals span all three waves, and 4319 individuals appear in only one. So we obtain 44,981 individual observations.

Variables

Measures of CH and MH. Memory is an important component of cognitive function in older adults (Shin, 2021). Many studies on the CH of older adults regard memory as a crucial criterion for evaluating cognitive function (Ahn et al., 2021; Zhao et al., 2021). Our main proxy of CH is memory. This indicator is selected from the question, “to what extent can you remember the main things that happened to you in a week”. Responses are scored on a

5-point scale, from 1 (I can only remember a little) to 5 (I can remember anything). In addition, some researchers use academic test scores to measure CH (Gao et al., 2021; Zhang et al., 2018). Therefore, we introduce mathematics and verbal test scores into the robustness test as another measure of CH.

The measure of MH is based on a series of indicators. Consistent with the previous literature to measure MH (Ao et al., 2021; Jiang et al., 2020), we select six indicators to measure comprehensively, all of which belong to the 10-item Center for Epidemiologic Studies Depression (CES-D) scale for older adults (Andresen et al., 1994). These indicators are selected from the question “the frequency of your feelings or behaviors in the past week”, involving six aspects: depressed, hard to do things, sleepless, lonely, sad, and cannot go on with life. Scale responses are made on a 4-point rating scale, from 1 (5–7 days), 2 (3–4 days), 3 (1–2 days), to 4 (less than 1 day). We take the average of these indicators as a measure of MH. In the robustness test, we use satisfaction and happiness as another measure of MH.

Measures of EPOV. We adopt six different measures based on energy affordability to evaluate EPOV. Consistent with the current research, our multiple measures of EPOV are based on the proportion of energy consumption to household income (Awaworyi Churchill et al., 2020; Farrell and Fry, 2021; Nie et al., 2021; Pan et al., 2021; Zhang et al., 2021a). Since the energy consumption of one household is shared, we measure the EPOV at the household level and allocate this value to each individual sample according to the household ID. According to the items in the questionnaire, energy consumption is a summary of the amount of annual spending on household energy. The specific measure methods are as follows:

Our first measure of EPOV (EPOV1) is a commonly used method, regarding EPOV as the standard that the proportion of

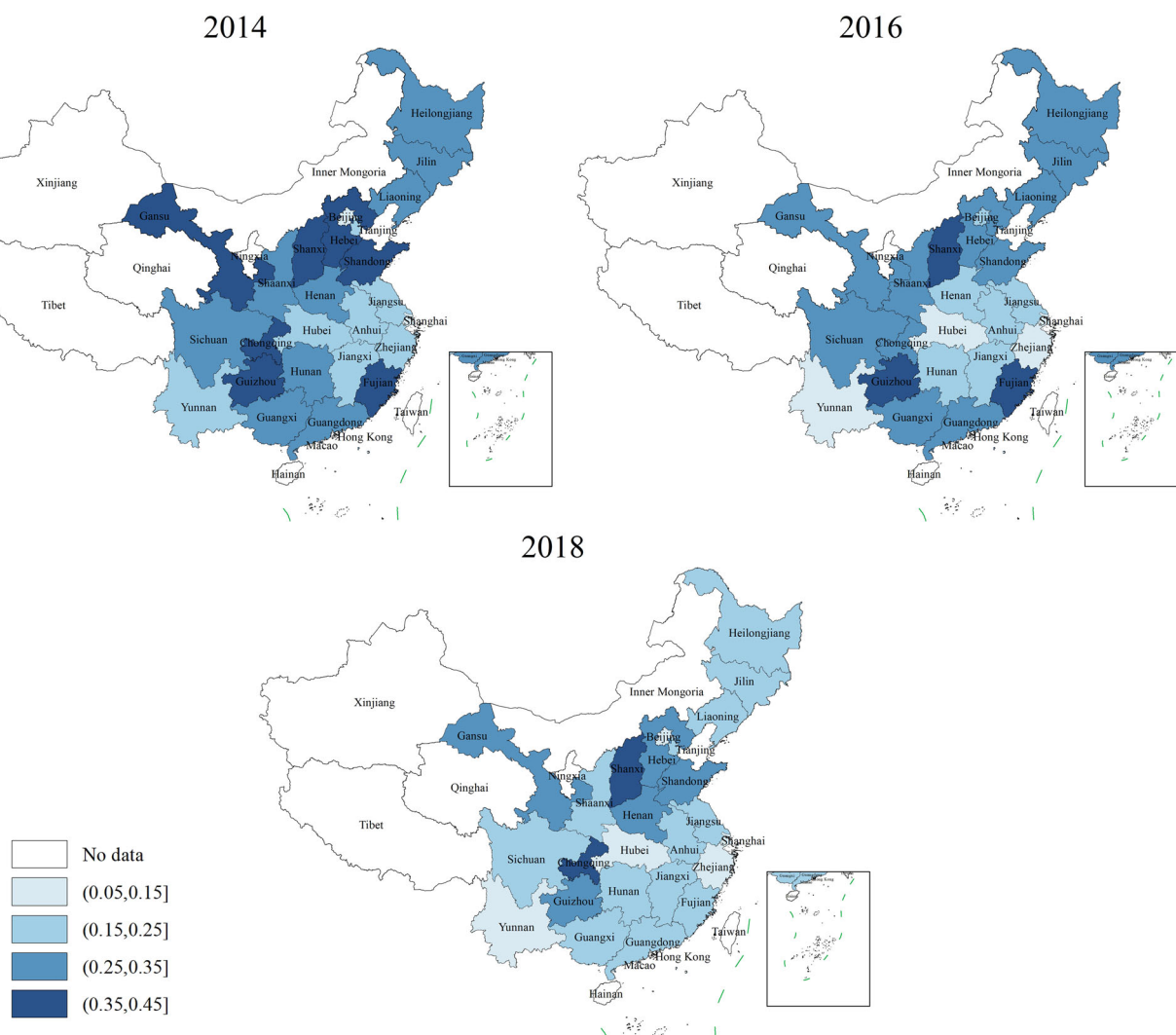


Fig. 2 EPOV in maps. The spatial distribution of EPOV in 2014, 2016, and 2018.

energy expenditure in income exceeds a certain threshold. The most widely used measure proposed by Boardman (1991) in the book “Fuel Poverty: From Cold Homes to Affordable Warmth”, which defines EPOV as the situation where energy consumption accounts for 10% of income. Following this definition, EPOV1 depends on whether energy expenditure is greater than 10% of income.

However, many researchers point out that the 10% standard of Boardman (1991) may lead to the misjudgment of EPOV (Farrell and Fry, 2021; Kahouli, 2020; Lin and Wang, 2020). Some vulnerable people may ration energy expenditure to avoid debt caused by energy consumption (Awaworyi Churchill et al., 2020). To improve measuring accuracy, Kahouli (2020) proposes the amended 10% measure, which only targets the low-income people in the last three deciles of the income distribution. Referring to the amended 10% measure proposed by Kahouli (2020), the second measure of EPOV (EPOV2) is mainly aimed at the low-income population whose income is in the bottom 50% of the total distribution.

In addition to taking fixed values like 10% as recognition thresholds, some researchers measure EPOV according to the median percentage level. For example, Moore (2012) proposes using a double median percentage to identify EPOV. Nie et al. (2021) adopt this measure in their research. Therefore, we define the third measure of EPOV (EPOV3) as twice the median

ratio of energy consumption to income in the total sample. Further, we construct the fourth measure of EPOV (EPOV4) due to possible regional differences. The identification standard of EPOV4 is a double median percentage of the province where the sample is located.

Referring to the idea of “low-income-high-cost (LIHC)” by Hills (2011), the fifth measure of EPOV (EPOV5) combines energy consumption with residents’ income level. This measure eliminates the situation in which people with high energy consumption and income are identified as EPOV (Li et al., 2014). According to this measure, we select the sample whose income level is at the bottom 25% of the total as the low-income group and regard those whose energy consumption exceeds the median as EPOV5.

The sixth measure of EPOV (EPOV6) is the comprehensive generation from EPOV1 to EPOV5. The score of EPOV6 is between 0 and 1, which is expressed as:

$$EPOV6 = \sum_{i=1}^5 (\alpha_i \times EPOVi)$$

where α_i is the weight corresponding to $EPOVi$. Owing to the lack of evidence to judge the importance of each measure, we adopt an equal weighting method for the above measures according to Awaworyi Churchill et al. (2020), i.e., $\alpha_i = 1/5$. EPOV6 is the main research object in this paper, and the other five measures

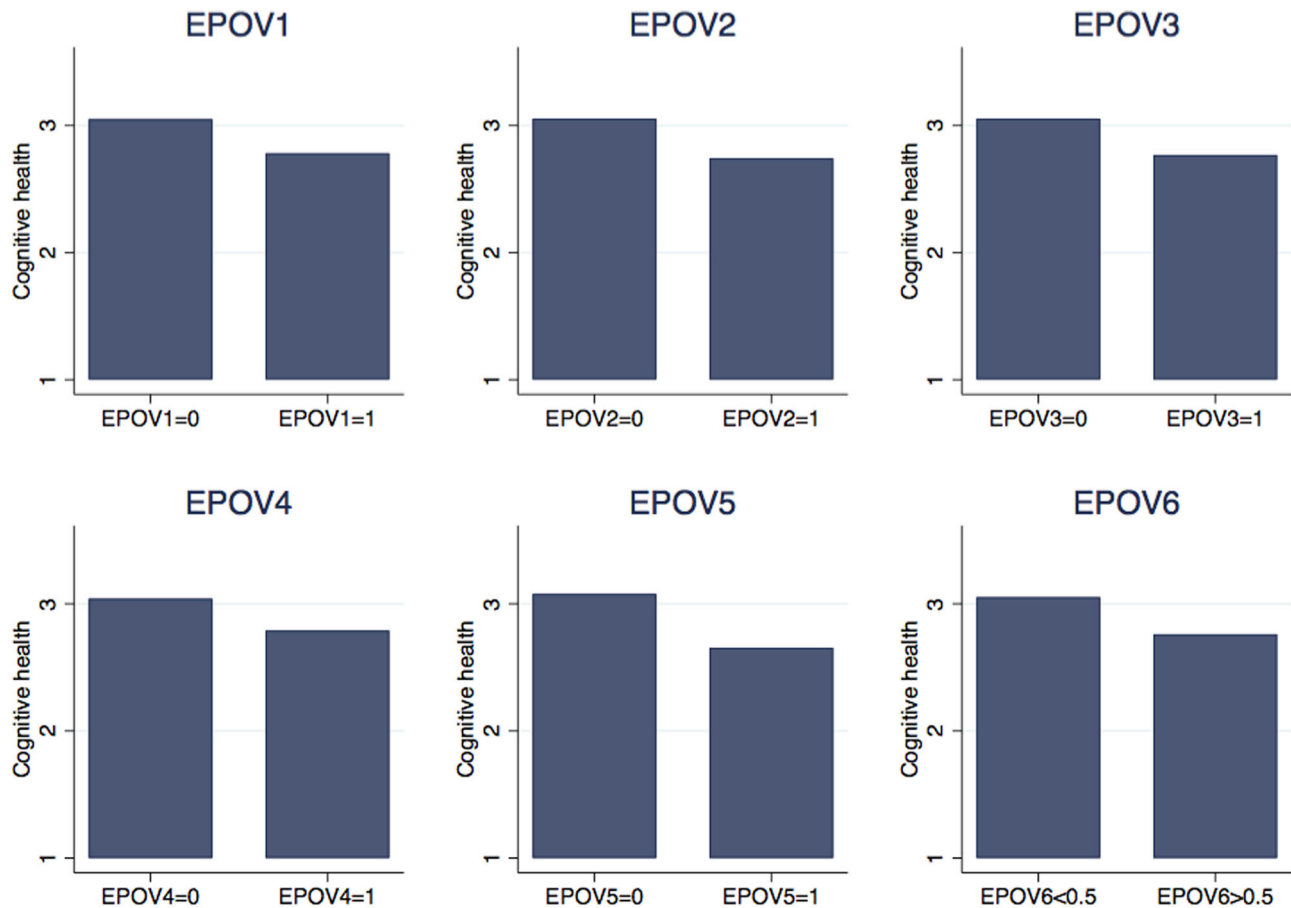


Fig. 3 Different measures of EPOV and CH. EPOV1-EPOV6 represent six different EPOV measures. Higher scores represent better CH status.

are used for robustness checks. Nie et al. (2021), Phoumin and Kimura (2019) also adopt this method to measure EPOV.

Control variables. Referring to previous relevant studies, we control a series of variables that may affect EPOV-CMH relation (see, e.g., Awaworyi Churchill and Smyth (2021); Nie et al. (2021); Prakash and Munyanyi (2021)). This paper selects the control variables of age, gender, education levels, employment status, training frequency, social status, marital status, and Hukou (registered residence location). Details of the variables in this study are shown in Table 2.

Empirical strategy. Considering the possible deviation of individual time-invariant unobservables, the effect of EPOV on CMH is estimated by a two-way FE model as follows:

$$CH_{it} = \beta_1 EPOV_{it} + \beta_2 X_{it} + \beta_3 P_i + \beta_4 Y_t + \delta_{it} + \mu_i \quad (1)$$

$$MH_{it} = \beta_1 EPOV_{it} + \beta_2 X_{it} + \beta_3 P_i + \beta_4 Y_t + \delta_{it} + \mu_i \quad (2)$$

where CH_{it} is the scores of CH of individual i at time t ; MH_{it} is the scores of MH of individual i at time t ; $EPOV_{it}$ stands for EPOV; X_{it} is a series of control variables at the individual level, such as education level and gender; P_i and Y_t represent provincial and year dummies, respectively; δ_{it} refers to error term; μ_i reflects the unobservable time-invariant individual effects; β indicates the relationship between CMH and related variables.

For our baseline, using FE estimators may create endogenous problems caused by omitted variables, reverse causation, sample selection bias, measurement errors, and other factors. Since FE estimation cannot eliminate the potential time-varying unobserved factors simultaneously affecting both EPOV and CMH,

it may lead to bias in the estimation coefficient of EPOV. Some studies demonstrate the reverse causality between EPOV and types of health (e.g., PH and MH) (Awaworyi Churchill and Smyth, 2021; Zhang et al., 2019; Zhang et al., 2021b). We adopt two-stage-squares (2SLS) estimations to address this concern by taking the average of EPOV at the provincial level as an instrumental variable (IV). In previous studies, the provincial average is proved to be a valid IV of EPOV (Zhang et al., 2021b). The logic is that people in the same province have similar income and living habits and enjoy the semblable municipal services and infrastructure. Therefore, the provincial average of EPOV is closely related to individual EPOV. Meanwhile, residents' CMH status is usually influenced by personal or family factors (Ang, 2021) and has an inappreciable relation with the provincial average of EPOV at the macro level.

Results

Descriptive statistics. As shown in Table 2, the average scores of CH and MH of the middle-aged and older adults in our sample are 2.975 and 3.410, respectively. The proportion of the sample in EPOV ranges from 24.3% to 27.8%, according to different measures of EPOV. In terms of the demographics, the average age of the sample is 60.133, and the proportion of men and women is balanced (men account for 49.5%). In terms of the highest level of education received by the sample, primary school is the most (33.3%), followed by middle school (23.3%), and then high school (19.3%). 13.5% of the sample are illiterate. Those with the highest degrees in vocational school and university or higher are the least, 8.2% and 2.4%, respectively. On average, respondents exercise 2.57 times per week. In the total sample, 60.4% of the respondents

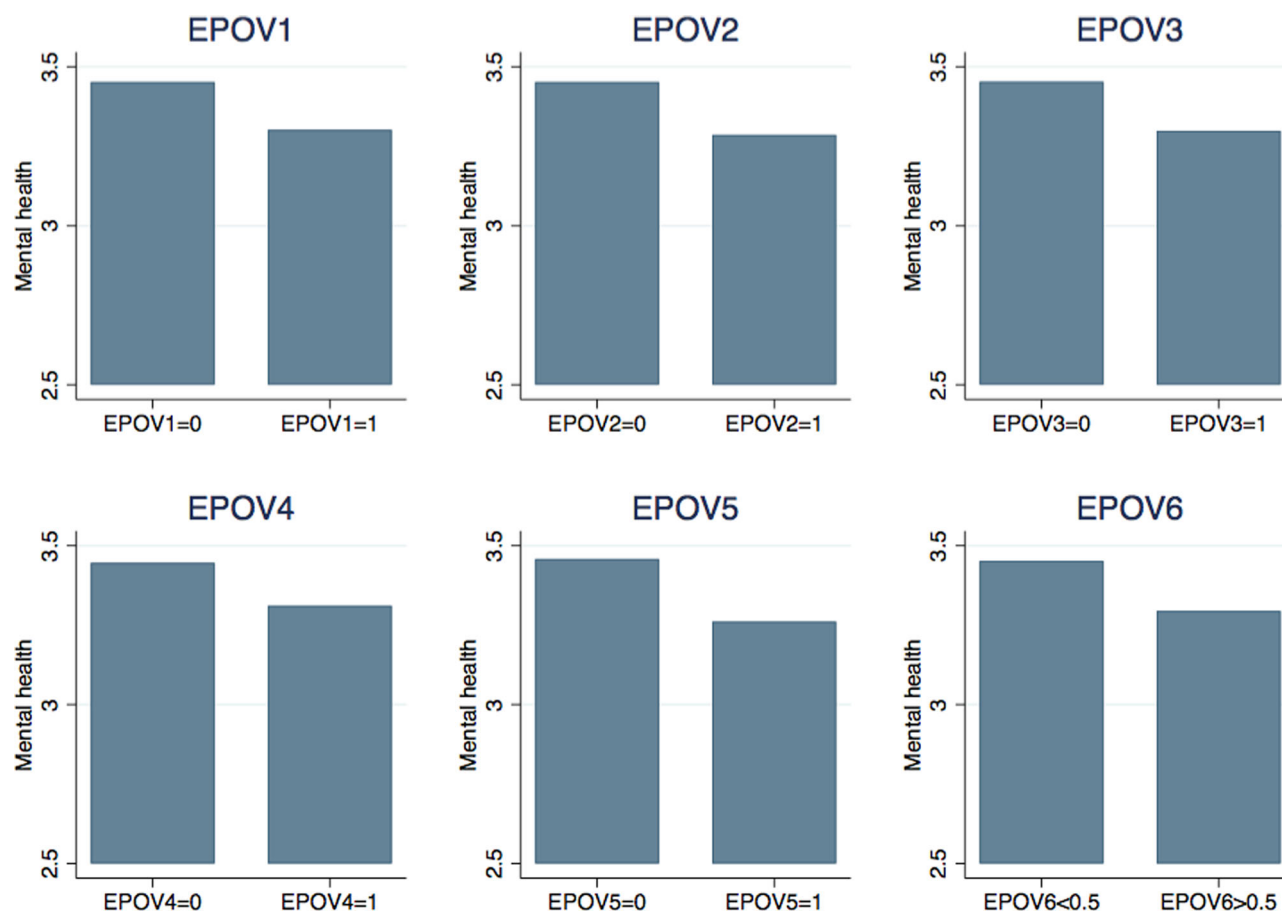


Fig. 4 Different measures of EPOV and MH. EPOV1-EPOV6 represent six different EPOV measures. Higher scores represent better MH status.

are employed, 86.7% are married, and 46% have urban hukou. The average self-reported score of respondents on their current social status is 3.083, which is at a relatively medium level.

The spatial distribution of EPOV in 2014, 2016, and 2018 is shown in Fig. 2. Overall, EPOV shows a downward trend year by year. In 2014 and 2016, the EPOV in the eastern provinces is lower than that in the central and western regions, especially in the Yangtze River Delta (i.e., Shanghai, Zhejiang, Jiangsu, and Anhui). The possible reason for this is that the socioeconomic conditions of the provinces in the Yangtze River Delta are more prosperous than in other provinces. In 2018, EPOV has been better improved nationwide. Among the 25 provincial administrative units included in the statistics, 18 provinces have EPOV lower than 25%, accounting for 72% of the total.

Figures 3 and 4 show the average CH and MH scores of samples with and without EPOV under six different EPOV measures, respectively. It can be seen that from EPOV1 to EPOV5, the samples living in EPOV scored lower than those not living in, regardless of MH and CH.

Baseline results. The baseline results of EPOV6 on CMH are shown in Table 3. We first use ordinary least squares (OLS) estimators to examine the relationship between EPOV6 and CMH. As reported in columns (1) and (4), the coefficients of EPOV6 are both significant at magnitudes of -0.213 and -0.146 , denoting that EPOV significantly negatively affects CMH. Then we add various control variables in columns (2) and (5). The inclusion of provincial and year dummies decreases the effects of EPOV but remains consistent with the results in columns (1) and (4). The results of FE estimators are shown in

columns (3) and (6). Comparing the results of these six columns makes it not difficult to find that the FE estimate of EPOV6-associated effects on CMH is smaller than the OLS estimate. The difference in results may be because the FE estimators control the time-invariant individual fixed effects, alleviating part of the endogeneity of EPOV caused by ignoring unobserved factors. Overall, all regression results of baseline regression display that EPOV is related to low CMH scores. Our results are consistent with previous studies (Lin and Okyere, 2020; Mohan, 2022; Zhang et al., 2021b).

Endogeneity corrected results. Considering that the endogeneity of EPOV6 may lead to deviation in the analysis results, we take the provincial average of EPOV6 as the instrumental variable and use the 2SLS method for robustness tests. Table 4 displays the estimates of 2SLS and the related first-stage diagnostic test results. The F -statistics calculated in the first stage are larger than 10 in all regression, suggesting that the IV is not weakly associated with EPOV6 (Stock and Yogo, 2005). After correcting for endogeneity, we find that the relationship between EPOV6 and CMH is still significantly negative. Further, we employ FE-IV estimators for robustness tests and get a similar consequence. Admittedly, the bias-corrected estimates from both 2SLS and FE-IV models are larger than the baseline estimates across CH and MH, indicating that the baseline estimates are downward biased. This is consistent with Prakash and Munyanyi (2021) results on the impact of EPOV on obesity using Australian data. Earlier studies from China also report that the bias-corrected estimates are higher than the baseline results when detecting the impacts of EPOV on health and subjective wellbeing (Nie et al., 2021; Zhang et al.,

Table 3 Baseline results.

	CH			MH		
	(1)	(2)	(3)	(4)	(5)	(6)
EPOV6	−0.213*** (0.015)	−0.180*** (0.015)	−0.061*** (0.020)	−0.146*** (0.008)	−0.130*** (0.008)	−0.042*** (0.009)
Age	−0.015*** (0.001)	−0.013*** (0.001)	0.025 (0.023)	−0.000 (0.000)	−0.000 (0.000)	−0.011 (0.011)
Gender	0.253*** (0.013)	0.222*** (0.012)	−0.660 (0.734)	0.136*** (0.006)	0.135*** (0.006)	0.135 (0.156)
Primary school	0.088*** (0.019)	0.296*** (0.022)	0.004 (0.044)	−0.003 (0.009)	0.039*** (0.010)	0.005 (0.019)
Middle school	0.300*** (0.021)	0.516*** (0.023)	−0.067 (0.081)	0.082*** (0.010)	0.111*** (0.010)	0.031 (0.034)
High school	0.471*** (0.022)	0.740*** (0.025)	−0.124 (0.121)	0.110*** (0.010)	0.150*** (0.011)	0.045 (0.050)
Vocational school	0.675*** (0.026)	0.990*** (0.030)	−0.159 (0.162)	0.129*** (0.012)	0.185*** (0.013)	0.077 (0.068)
University or higher	0.900*** (0.036)	1.184*** (0.039)	−0.112 (0.208)	0.116*** (0.017)	0.162*** (0.018)	0.121 (0.087)
Currently employed	0.005 (0.014)	0.026* (0.014)	0.067*** (0.020)	0.046*** (0.007)	0.057*** (0.007)	0.023** (0.009)
Training	0.018*** (0.002)	0.023*** (0.002)	0.005 (0.003)	0.006*** (0.001)	0.007*** (0.001)	−0.001 (0.001)
Social status	0.055*** (0.006)	0.073*** (0.006)	0.037*** (0.008)	0.042*** (0.003)	0.048*** (0.003)	0.010*** (0.004)
Married	0.047** (0.019)	0.034* (0.018)	−0.003 (0.053)	0.173*** (0.010)	0.161*** (0.010)	0.223*** (0.029)
Hukou	0.222*** (0.013)	0.150*** (0.013)	−0.095** (0.037)	0.106*** (0.006)	0.070*** (0.006)	−0.012 (0.016)
Observations	44,981	44,981	44,981	44,981	44,981	44,981
Number of Individuals			19,664			19,664
Provincial FE	No	Yes	Yes	No	Yes	Yes
Yearly FE	No	Yes	Yes	No	Yes	Yes
Individual FE	No	No	Yes	No	No	Yes
Adj. R ²	0.092	0.124		0.075	0.102	

Note: ***, **, * represent significance at 1%, 5%, 10%, respectively.

Table 4 IV results.

	CH		MH	
	(1—2SLS)	(2—FE-IV)	(3—2SLS)	(4—FE-IV)
EPOV6	−1.176 *** (0.252)	−0.464* (0.263)	−0.910*** (0.127)	−0.637*** (0.127)
Other controls	Yes	Yes	Yes	Yes
Observations	44,981	40,661	44,981	40,661
Number of individuals		15,344		15,344
First stage				
Instrument:	0.817*** (0.061)	0.817*** (0.070)	0.817*** (0.061)	0.817*** (0.070)
Mean of EPOV6				
F-Statistics	>10	>10	>10	>10

Note: ***, **, * represent significance at 1%, 5%, 10%, respectively.

2021a; Zhang et al., 2021b). Hence, we conclude that EPOV has significant adverse effects on CMH.

Robustness checks. Considering the sensitivity of the research results, we examine a series of robust checks. Firstly, we test the robustness of the results under alternative EPOV measures, using EPOV1–EPOV5 to replace the EPOV6, respectively (see Table 5). Panel A is the results of the impacts of different EPOV measure standards on MH, and Panel B is the impacts on CH. The results

in Table 5 indicate the negative impacts of EPOV on CMH, which are consistent with the baseline estimates.

Second, we measure CH and MH in alternative ways. Some researchers select standardized verbal tests and math tests from CFPS to measure CH (Gao et al., 2021; Zhang et al., 2018). Specifically, the test score depends on the most difficult question that the respondent can answer. The higher the test score, the better the CH of the respondent. Meanwhile, researchers use positive measures, such as happiness and life satisfaction, to represent MH (Awaworyi Churchill et al., 2020; Drucă et al., 2019; Nie et al., 2021; Zhang et al., 2021a). Life satisfaction and happiness show people's thoughts and feelings about life (Pénard et al., 2013), reflecting on their mental situation. The CFPS asks respondents "how happy are you" on a scale of 10 (not happy at all = 1, very happy = 10) and "are you satisfied with your life" with a 5-point scale (not satisfied at all = 1, very satisfied = 5). Therefore, we introduce four CMH proxies of happiness, satisfaction, mathematics test score, and verbal test score. Since the questionnaires of the above four variables are various in different survey waves, we only employ OLS estimators to test the robustness based on the data of 2018 CFPS. The results reported in Table 6 also support the conclusion that EPOV significantly negatively impacts CMH.

Mechanisms and further investigations. This section further explores whether PH is a channel through which EPOV affects CMH. To conduct this investigation, we introduce the indicator: self-reported health. In the CFPS, respondents need to answer

Table 5 Robustness checks (alternative measures of EPOV).

	(1)	(2)	(3)	(4)	(5)
Panel A: Using "CH" as a dependent variable					
EPOV1	−0.050*** (0.017)				
EPOV2		−0.046*** (0.018)			
EPOV3			−0.040** (0.017)		
EPOV4				−0.049*** (0.017)	
EPOV5					−0.052*** (0.019)
Other controls	Yes	Yes	Yes	Yes	Yes
Observations	44,981	44,981	44,981	44,981	44,981
Number of Individuals	19,664	19,664	19,664	19,664	19,664
Panel B: Using "MH" as a dependent variable					
EPOV1	−0.035*** (0.008)				
EPOV2		−0.035*** (0.008)			
EPOV3			−0.031*** (0.008)		
EPOV4				−0.032*** (0.008)	
EPOV5					−0.028*** (0.009)
Other controls	Yes	Yes	Yes	Yes	Yes
Observations	44,981	44,981	44,981	44,981	44,981
Number of Individuals	19,664	19,664	19,664	19,664	19,664

Note: ***, **, * represent significance at 1%, 5%, 10%, respectively. All estimators are presented as FE estimators.

Table 6 Robustness checks (alternative measures of CH and MH).

	Math test scores (1)	Verbal test scores (2)	Happiness (3)	Life satisfaction (4)
EPOV6	−0.280*** (0.071)	−0.629*** (0.192)	−0.368*** (0.054)	−0.091*** (0.022)
Other controls	Yes	Yes	Yes	Yes
Observations	12,632	13,844	13,844	13,844
Adj. R ²	0.511	0.365	0.104	0.141

Note: ***, **, * represent significance at 1%, 5%, 10%, respectively. All estimators are presented as OLS estimators.

Table 7 Channel analysis.

	CH (1)	SRH (2)	CH (3)	MH (4)	SRH (5)	MH (6)
EPOV6	−0.061*** (0.020)	−0.148*** (0.017)	−0.048** (0.020)	−0.042*** (0.009)	−0.148*** (0.017)	−0.032*** (0.009)
SRH			0.084*** (0.008)			0.065*** (0.003)
Other controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	44,981	44,981	44,981	44,981	44,981	44,981
Number of Individuals	19,664	19,664	19,664	19,664	19,664	19,664

Note: ***, **, * represent significance at 1%, 5%, 10%, respectively. All estimators are presented as FE estimators.

Table 8 Further investigation (effect of lagged EPOV on CMH).

	CH				MH			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
EPOV6	−0.160*** (0.019)			−0.142*** (0.037)	−0.135*** (0.009)			−0.129*** (0.017)
EPOV6 _{t-1}		−0.119*** (0.023)		−0.105*** (0.035)		−0.100*** (0.010)		−0.060*** (0.015)
EPOV6 _{t-2}			−0.019 (0.033)	0.025 (0.034)			−0.091*** (0.014)	−0.057*** (0.015)
Other controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	29,919	19,946	9,973	9,973	29,919	19,946	9973	9973

Note: ***, **, * represent significance at 1%, 5%, 10%, respectively. To ensure the comparability of the coefficient, all estimators are presented as OLS estimators. EPOV6_{t-1} represents the EPOV6 in time $t-1$; EPOV6_{t-2} represents the EPOV6 in time $t-2$.

Table 9 Further investigation (heterogeneous effects across different groups).

	CH		MH	
	Middle-aged (1)	Older adults (2)	Middle-aged (3)	Older adults (4)
EPOV6	−0.052** (0.021)	−0.060*** (0.021)	−0.024** (0.010)	−0.060*** (0.011)
Different test (χ^2)	0.08		5.95**	
Other controls	Yes	Yes	Yes	Yes
Observations	24,448	20,533	24,448	20,533
Number of Individuals	11,478	10,254	11,478	10,254

Note: ***, **, * represent significance at 1%, 5%, 10%, respectively. All estimators are presented as FE estimators.

questions related to this: “how is your health” with a five-point scale (very unhealthy = 1, very healthy = 5). Self-reported health (SRH) has been widely used as a proxy variable for PH (Awaworyi Churchill and Smyth, 2021; Kahouli, 2020; Nie et al., 2021). We adopt a two-step procedure that is frequently used in earlier studies (Koomson and Danquah, 2021; Zhang et al., 2021a). The results are shown in Table 7.

In the first step, we examine whether potential channels are related to EPOV. The results of Panel A indicate that increased EPOV reduces the self-reported health level (see columns (2) and (5)). As expected, EPOV significantly negatively affects PH, suggesting that it is difficult for middle-aged and older adults with EPOV to have good PH. Our findings are well in accordance with those of Oliveras et al. (2020) for Spain, Zhang et al. (2019) for China, Oum (2019) for Lao PDR. After measuring the correlation between PH and EPOV, we included PH as an additional covariate in the baseline regression in the second step (see columns (3) and (6)). We find that self-reported health is positively related to both CH and MH, manifesting that PH has a significant positive impact on CMH. Moreover, after taking self-reported health as an additional covariate, the absolute values of EPOV coefficients on both CH and MH decrease, indicating that self-reported health is a mediator of EPOV affecting CMH. Overall, the results of this section suggest that PH is a channel through which EPOV affects CMH.

Considering that there may be a lag or delay in the impact of EPOV on CMH, we discuss the lagged effects of EPOV on CMH in Table 8. To conduct this investigation, we remove the samples with interruptions in the tracking survey and convert the

unbalanced panel data into balanced panel data. Column (1) shows the contemporary effect of EPOV6 on CH in time t , and columns (2) and (3) report the lagged effects in time $t-1$ and $t-2$. Our result suggests that EPOV6 significantly negatively impacts CH in time $t-1$, but not in time $t-2$. To capture the cumulative impact of EPOV6 on CH, we then include EPOV from time t to time $t-2$ in the same regression (see column (4)). The results show that the coefficients of EPOV6 in time t and $t-1$ are significantly negative. The above results indicate that EPOV not only has a negative impact on CH in the current period but also has a continuous impact. Similar consequences are found in MH, indicating that both current and periods EPOV status have significant negative impacts on MH. Obviously, the magnitudes of the total impacts of the current period and the previous periods are substantially greater than the effect estimated using the current period alone, indicating that earlier studies may underestimate the negative impacts of EPOV on CMH and even general health.

Next, we further investigate the effects of EPOV on different sub-groups. Many studies have shown that EPOV has diversified effects on different age groups (Awaworyi Churchill and Smyth, 2021; Prakash and Munyanyi, 2021). Considering that the health of older adults is more vulnerable to external influence than the middle-aged (Liu et al., 2021), we divide the sample into the middle-aged group and the older adults group for in-depth analysis. According to the Law on the Protection of the Rights and Interests of older adults in China, all residents over the age of 60 belong to older adults. In Table 9, we explore the different effects of EPOV on CMH of respondents whether they are older than 60 years old. The results show that the impact of EPOV6 on CMH is a significant negative for both middle-aged and older adults. However, the magnitude of the EPOV6 coefficient of the middle-aged subgroup is relatively small. The seemingly unrelated estimation test is used to test for age differences in the coefficients between models using Wald chi-squared tests (Weesie, 2000). We find a significant difference between middle-aged and older adults for MH ($\chi^2 = 5.95$, $p = 0.01$), but no significant difference for CH ($\chi^2 = 0.08$, $p = 0.78$). This result indicates that the negative impact of EPOV on older adults is more severe, which is consistent with Nie et al. (2021) that the middle-aged generally have better socioeconomic status to address potential health challenges posed by EPOV.

Conclusion

Population aging is a global issue. Health promotion targeting middle-aged and older adults is a critical way to deal with aging, which requires a comprehensive understanding of the factors affecting the health of middle-aged and older adults. EPOV is a global problem in both developing and developed countries, and

is considered to have a significant impact on health. Although researchers have paid much attention to the detrimental effects of EPOV on health, there are few empirical studies on the effects of EPOV on CMH in middle-aged and older adults. We use nationally representative data from the 2014–2018 CFPS to provide insights into EPOV-CMH relations among middle-aged and older adults.

The analysis yields several key findings: First, the proportion of middle-aged and older adults living in EPOV in China ranges from 24.3% to 27.8%, according to different measures based on energy affordability, which indicates that there are still a large number of middle-aged and older adults facing the challenge of energy affordability. Second, EPOV has a significantly negative effect on CMH, and the effect is persistent. These results are robust to various robustness tests. PH is confirmed to be an important channel through which EPOV affects CMH. Finally, EPOV has greater negative impacts on older adults than on the middle-aged, which suggests the importance of preventing the influence of EPOV on CMH in health promotion. These findings provide incremental information for promoting healthy aging in China. Eliminating EPOV can not only improve the current CMH status of middle-aged and older adults, but also prevent them from CMH problems due to insufficient use of energy services.

The study's conclusion echoes previous studies and has important implications for policy. Although the problem of extreme poverty has been alleviated, China still faces the challenge of multidimensional poverty represented by EPOV. To solve the challenge of EPOV, policymakers should shift the focus from energy availability to energy affordability. Considering the differences in the incidence of EPOV across provinces, policymakers can implement differentiated policies based on local conditions. On the one hand, policymakers can develop local renewable energy sources, reducing the energy cost for residents. For example, solar and wind energy resources are rich in northwest China, and hydropower resources are abundant in southwest China. On the other hand, policymakers can reduce the incidence of EPOV by improving the housing structure, and reducing residents' electricity consumption of energy devices, such as air conditioners.

Moreover, the government can reduce energy prices through market-oriented reforms (Ren et al., 2022), and solve the problem of EPOV through accurate identification and targeted energy subsidies, especially for middle-aged and older adults who lack competitiveness in the labor market. Since solving EPOV is not an overnight solution, the government should pay attention to the changes in the CMH of middle-aged and older adults while improving their energy affordability, and take various measures to improve their CMH. For example, the government can conduct regular visits to households in EPOV to understand their CMH status, and provide appropriate assistance, such as financial assistance and psychological support, to those at risk of CMH deterioration. It is hoped that this study can inspire future researchers interested in EPOV, CMH, and aging. Future studies can further explore the different mechanisms of EPOV's impacts on CMH.

Data availability

All data generated or analyzed during this study are included in this published article.

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Ethical approval

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Correspondence and requests for materials should be addressed to Han Yang.

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