

Improving Rural Women's Health in China: Cooking With Clean Energy

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Abstract

It is well known that women bear the greatest burden of health, time and labor supply due to gender disparity in many developing countries. In this study, we analyze the health inequality in rural China caused by indoor air pollution from traditional energy use. Specifically, we study the effect of clean energy access on woman health outcome by exploiting a nationwide rollout of clean cooking fuel program in 2014. Based on interviews with rural women in 2014 and 2016, this study analyzes the impact of clean energy use on women's health by using the Propensity Score Matching method with the Difference-in-Differences model (PSM-DID). We also analyze the heterogeneous health effects of clean energy uptake on rural women with different characteristics. The results show that clean energy applications can significantly improve the health of rural women. The positive health effects are substantial for middle-aged and older women, illiterate women and those women lived in northeastern China. The results highlight the role of clean energy in reducing gender disparities in health inequality. Therefore, the government in developing countries should do more to educate the people on the uses of clean energy and its benefits for women's health, provide technical and economic support for clean energy applications, and optimize clean energy promotion strategies.

1. Introduction

One of the main sources of gender disparity is traditional gender norms in the types of jobs assigned to men and women (Imelda and Verma, 2019). In the vast majority of developing countries, as women do more housework (Duflou, 2012), they have to bear excessive exposure to indoor air pollution caused by the use of traditional household energy that is polluting and harmful to health. Long-term exposure to indoor air pollution will have a significant negative impact on people's health (Kumar and Viswanathan, 2007). Meanwhile, indoor air pollution is the leading environmental health risk factor for women in less developed countries, and is a major cause of stroke, chronic obstructive pulmonary disease, lung cancer, heart disease and other non-communicable diseases (Imelda and Verma, 2019; Malla et al., 2011). According to WHO (2018), women and children accounted for more than 60 percent of all premature deaths caused by indoor air pollution. This is not just a health issue, but a serious gender disparity that requires global attention.

In our study, we focus on an issue of inequality that is often overlooked, namely the health burden associated with unclean cooking fuels. In most developing countries, cooking is not only typically classified as a female responsibility, but women also have little power to choose the type of cooking fuel. With unclean cooking fuel emitting a large number of harmful pollutants, biased gender roles and low bargaining power of women impose a disproportionately higher health cost on women than men (Imelda and Verma, 2019). Especially in the traditional rural areas of China, this phenomenon is more prominent. But the good news is that Chinese policy in recent years has recognized the importance of this problem and taken steps to address it. At the 19th National Congress of the Communist Party of China (CPC) in October 2017, General Secretary Xi Jinping stressed that the health of China's people is an important indicator of the country's prosperity and strength, and comprehensively initiated the "Healthy China" strategy. Meanwhile, the CPC Central Committee approved the *Outline of Healthy China 2030* and *Healthy China (2019–2030)*, highlighting the importance of women's and children's health and making it clearer that solving their health problems should be given the highest priority.

With China's rising standard of material living, it is clear that health, especially that of women and vulnerable groups, is a major concern (Zhang and Zhang, 2020a). According to data from the National Bureau of Statistics, there were 682 million women in China at the end of 2018, of which rural women made up about 40.42%. Existing studies have shown that rural women's physical and psychological health needs to be improved (Chen et al., 2018; Qian et al., 2017). Therefore, the "Healthy China" strategy, which focuses on improving the health of rural women addresses an urgent challenge.

The existing literature has found that the health of the rural population is significantly affected by multiple social and environmental factors, such as marriage (Stark, 2019), child-bearing (Amjad et al., 2018), age (Tong et al., 2018), water quality (Zhang, 2012), air quality (Al-Kindi et al., 2020; Lelieveld et al., 2015; Shen et al., 2019; Zhao et al., 2019), and medical security (Bairoliya et al., 2018). Regarding air quality, some scholars have proved that it is adversely affected by the use of traditional solid fuel, potentially creating health hazards and raising the risk of cancer (Chen et al., 2018; Du et al., 2018; Quansah et al., 2017). Owing to the combustion of solid fuel in cooking, WHO data also shows that indoor air pollution causes nearly 4.3 million premature deaths every year in China, the majority of which are women. For countless generations, solid energy has been the main fuel for domestic cooking and heating in rural areas; since women do most of the cooking, they are more likely to suffer from health problems caused by such traditional forms of cooking. While the image of rural women cooking in the traditional way in a modest, smoky, kitchen may have a certain charm, it is unlikely that these women, who must cook for their family three times a day, are enjoying the chore— it is more likely that they feel

irritation and physical discomfort. For these reasons, it is now more important than ever before to promote clean energy use in rural domestic cooking.

China has already issued a number of policies to promote clean energy use in rural areas. For example, *Several Opinions of the State Council on Promoting the Construction of a New Socialist Countryside*, announced in February 2006, clearly stated the need for promoting clean energy technologies in suitable rural areas. Because of the emphasis that the 19th National Congress has placed on building a clean, low-carbon, safe, and efficient energy system, and the urgent need to transform rural energy use to revitalize rural areas to build the new socialist countryside, the pace of the transition to clean energy in rural areas has gradually increased (Zhang and Zhang, 2020b). According to Liao et al. (2016), nearly 50% rural households are now using gas as energy for cooking and heating, which has positively impacted their health. The question that arises is: Are women, who actually do all the cooking, benefiting from these health improvements? Experimental studies have shown that solid fuel combustion generates indoor pollution and damages people's health in various ways, affecting their respiratory tract (Acharya et al., 2015), eyes (Chan et al., 2019), and cardiovascular system (Lee et al., 2012; McCracken et al., 2012), and even raising their risk of lung cancer (Lin et al., 2008; Lissowska et al., 2005). In such smoky kitchens, therefore, rural women who need to cook for their family three times a day are unlikely to feel their situation as one inspiring poetry; more likely, they will feel only physical and psychological discomfort.

This study is therefore based on rural women's perception of their own health, and begins by examining their self-assessments before and after using clean energy for cooking. It then examines whether the change in energy use has a positive impact on their health. We also analyzed the varying effects of such a change on the health of rural women who have different characteristics. Our goal is to provide new analytical insights into the transformation and upgrade of rural households' energy use. Meanwhile, instead of experimental or medical test methods, we innovatively choose to conduct our analysis by combining the Propensity Score Matching (PSM) method with Differences-in-Differences (DID) model of causality inference. This is because the use of PSM-DID can effectively solve endogeneity problems in the model, and ensure the reliability of the benchmark regression results.

This paper departs from the existing literature in three important ways. First, existing literature on health inequality caused by the environment have mainly focused on outdoor air pollution (Morelli et al., 2019; Zhao et al., 2019), such as the topic about air pollution and public health (Dedoussi et al., 2020; Lelieveld et al., 2015). However, much less is known of the impact of indoor air pollution on the gender disparity in developing countries, especially in China, which has the largest rural female population in the world. Second, Our paper adds to the literature on gender disparity, showing that policies that promote the use of clean energy can better mitigate health inequalities, empowering women can have benefits for the environment (Li et al., 2019). Besides, previous studies on the negative health effects of indoor air pollution were mostly based on the analysis of infant mortality rate (Imelda, 2020) and mostly medical literature (Ezzati, 2005; Gordon et al., 2017), without analyzing the impact of clean energy application on health from the perspective of causality inference. Given that these problems are not unique to China, but are common to most developing countries and poor regions in the world, our findings could provide more empirical evidence for these countries to make clean energy policies and contributes to gender equality in terms of health. Third, this study provides new empirical evidence for the heterogeneous health effects of indoor air pollution on rural women. we test the existence of heterogeneous effects by classifying the interviewees based on their age, education level, and residential location. The results show that rural woman in China exhibit varying health improvement levels of response to clean energy using in the process of cooking.

The rest of this paper is organized as follows. Section 2 introduces the theoretical basis and reviews the literature on the relationship between clean energy use and women's health. Section 3 presents the research design from three perspectives: data source, research strategy, and variable setting. The fourth section analyzes the empirical results, including a "before" and "after" comparison of rural women's health, a balancing test after application of the PSM, the impact of rural clean energy use on women's health, and a placebo test. Section 5 presents the heterogeneity analysis. The sixth and final section presents the study's conclusions and policy implications.

2. Theoretical Basis And Literature Review

2.1. Theoretical basis

Studies have shown that the combustion of wood, coal, and other traditional fuels will generate airborne pollutants (Ou et al., 2020; Zhao et al., 2019), such as carbon monoxide, airborne particulates, and toxic elements, all of which adversely affect indoor air quality and cause health problems (Fajersztajn et al., 2013; Simkovich et al., 2019). Environmental Stress Theory considers that the cause of

these health problems lies in individuals' adaptive responses to the pollutants, and affects people physiology, psychology, and behavior(Martin et al., 1996; Zhang and Tielbörger, 2020).

The physiological responses occur in three stages: the short and rapid abstinence response stage under sympathetic action; the adaptive stage under parasympathetic action, which reassesses the stimulus and prepares to address the danger it poses; and the exhaustion stage, which is a result of the stress caused by the large amounts of the body's energy used to deal with the pollutants, which can exceed the body's endurance limit. Therefore, when using traditional energy, we argue that although our body can resist the effects of limited amounts of pollution on health in the initial stage, in the long term the pollutants can cause an irreversible decline in people's physiological health. There is also a psychological response: facing the threat of pollution caused by poor air quality, individuals will have a negative evaluation of their health, according to their individual cognitive capabilities(Ellis et al., 2009), meanwhile, Behavioral Constraint Theory (Prosser et al., 2007) provides further evidence. When fuel combustion adversely affects indoor air quality and individuals' health, their first reaction will be psychological resistance; they will try their best to improve the indoor air quality. This can be achieved in two ways: changing their own behavior or alleviating their unhealthy surroundings. From this perspective, the act of replacing traditional energy sources with clean energy becomes an effective way of alleviating an unfavorable environment by checking the sources of pollution and also improving their sense of control over the air they breathe.

Therefore, based on the Environmental Stress Theory and the Behavioral Constraint Theory, and the responses to physiological and psychological stress, this study considers that when individuals use clean energy to replace traditional energy, it will reduce adverse impacts on their physiological health, enhance their sense of psychological well-being, and their sense of control over the air they breathe, resulting in an overall improvement of their health.

2.2. Literature review

The existing literature discussing energy use in rural households has mainly focused on analyzing its influencing factors and how to make it greener(Chen et al., 2016; Tao et al., 2018). Ravindra et al. (2019)found five major factors that influence households' use of clean energy: household characteristics, energy costs, cognitive level, government policy, and external conditions. Deng et al. (2020)revealed that families with elderly people are more willing to use clean energy. Environmental values, marital status, the influence of others, demonstration of the alternatives, and the perception of utility improvements significantly affect people's willingness to use clean energy. Dong (2017) analyzed solar energy and found that economic considerations and rural households' awareness of the benefits of low carbon emissions were the main factors affecting the uptake of solar energy. Li et al. (further investigated the influence of national subsidies and the peer effect on rural green energy transformation, then put forward more specific suggestions to promote clean energy use. These include: financial incentives, expanding the demonstration effect, generating new sources of income for farmers, and cultivating awareness of the need to conserve energy. It is clear that rural households' standard of living, their awareness of energy use, government promotion, neighborhood behavior, and other factors are all key influences on rural households' clean energy use.

From scholars' investigation of how China's energy consumption has developed, it can be observed that the use of clean energy in China is still at a low level(Carter et al., 2020), the main reason being rural households' lack of understanding of the risks posed by the use of traditional energy sources(Elie et al., 2019; Wang et al., 2019). Current research into the relationship between clean energy and health mainly focuses on analyzing the impact of air pollution on public health(Fann et al., 2013; Nel, 2005; Shaddick et al., 2020; Sofiev et al., 2018). Some scholars have looked at physiological data in their investigation of the relationship between energy substitution and middle-aged and elderly rural residents' health(Liu et al., 2018). However, overall, there have been few studies on this topic in China, with most of the research having been conducted in other countries. For example, Sattler et al. (2018)found that replacing coal-fired power plants with clean energy in Illinois could improve the residents' health. Baumgartner et al. (2011)found that air pollution resulting from traditional energy use may raise the risk of hypertension and cardiovascular diseases. Haines et al. (2007) pointed out that the current pattern of fossil fuel using causes substantial health problems. Therefore, a comprehensive clean energy application plan should strongly emphasize the health benefits of improved air quality.

More recently, the relationship between clean energy use and health and, in particular, the impact of kitchen fuel on health, is beginning to attract academic attention(Imelda, 2020; Yun et al., 2020). For example, Yun et al. (2020)has confirmed that ultra-fine particulate matter produced by the combustion of solid fuel poses potential health risks to people. Alexander et al. (2017)having conducted a randomized trial in Nigeria, concluded that replacing the solid fuel used in household stoves by ethanol may reduce pregnant women's diastolic blood pressure and hypertension: the use of clean cooking fuels may, therefore, reduce the overall harmful health effects

caused by household air pollution. Imelda (2020) estimated the carcinogenic risk of hetero-cyclic amines inhaled by women under different cooking conditions by simulating the process of typical household solid fuel combustion. The results showed that when the smoke could not be effectively discharged, women had higher health risks when bituminous coal, straw, and wood were used. Most scholars, therefore, have found that the type of fuel used for cooking has a significant impact on health. Along with scholars, the general public is also now beginning to pay more attention to health issues, Khandelwal et al. (2017) found that improved stoves that reduce negative impacts on health and the environment are receiving considerable attention in India.

However, studies of this issue have reached different conclusions. For example, Rosenthal et al. (2018) argued that improved biomass stoves could only incrementally improve air quality and provide few health benefits. Having followed the progress of 10,750 children in rural Malawi, Mortimer et al. (2017) also found no evidence that cleaner fuel stoves were effective in reducing their risk of contracting pneumonia.

It is clear, then, that scholars have different views on the health effects of clean energy use in the kitchen. However, when studies on the impacts of the wider environment are focused on the health of women, the evidence of adverse health impacts of poor air quality is more conclusive. These include the impacts on blood pressure problems during pregnancy; the risk of cancer caused by hetero-cyclic amines; certain physiological diseases including those of the respiratory tract, eyes; lung cancer; and others. From these studies, therefore, it can be safely inferred that the use of traditional energy sources for cooking has a negative impact on women's health.

To sum up, scholars have confirmed that there is likely to be a positive relationship between the use of clean energy and health, but when the health benefits of clean energy use in kitchen are specifically examined, the matter is unsettled. Chinese scholars mainly focus on verifying whether the particulate matter and soot produced by fuel combustion has negative effects on health from the perspective of environmental science. Other countries' scholars have focused more on the effects of stoves using different fuels on air quality and health. However, owing to different sample populations, the analyses have reached different conclusions and, while most studies investigating the environment and medicine use objective data, there has been little analysis of women's subjective view of their own health. In other words, there is still a lack of quantitative research into the health effects of women's cooking energy choices outside the environmental and medical fields; in China, in particular, such research simply does not exist.

Therefore, considering that the vast majority of people cooking for Chinese rural families are women, and considering rural women's health as its research object, this paper innovatively investigates changes in rural women's self-evaluation of their health following the replacement of traditional energy by clean energy in their households. At the same time, through heterogeneity analysis, this study examines the health differences between rural women with different characteristics following their uptake of clean energy, filling the research gap that exists due to the absence of studies that focus solely on the relationship between energy substitution and women's health in China. In doing so, this study attempts to include the female perspective into the debate among scholars regarding energy use in the kitchen and women's health.

This study therefore proposes two hypotheses:

Hypothesis 1

The use of clean energy in rural areas will affect women's health, but whether this impact is positive or negative is not yet known.

Hypothesis 2

Women with different characteristics may experience different health effects following their uptake of clean energy.

3. Methodology

3.1. Data source

The data used in this study are all from the China Family Panel Study (CFPS), which is funded by Peking University and the National Natural Science Foundation of China, and conducted by the Institute of Social Science Survey, Peking University. The data are obtained by sampling the entire country at the individual, family, and community levels. They can therefore effectively represent Chinese social, economic, demographic, educational, and health changes, covering the 25 provinces and autonomous regions of the country, so that this study can effectively avoid the limitations caused by geographical constraints.

To be specific, this paper chooses rural adult subjects from CFPS2014 and CFPS2016. The first step is to eliminate all the males and non-rural residents from the analysis. Second, people who were already using clean energy to cook in 2014 are removed, according to the DID model requirements. Then, the dummy variable of "cooking fuel" is defined based on whether the solid fuel used in the household generates airborne particulates. If the subject uses firewood or coal, and no clean energy, it is considered that the sample uses traditional energy for cooking, and the dummy variable is assigned the value 0. However, if the sample uses natural gas, liquefied gas, solar energy, biogas, or electricity, it is considered that the sample uses clean energy for cooking, and the dummy variable is assigned the value 1. Next, this paper constructs the control group using the subjects' IDs. Then, the outliers and subjects supplying invalid responses (such as "not applicable" and "refuse to answer") are eliminated from the sample. The final total number of subjects analyzed in the study is 6016; that is, 3008 rural female interviewees over each of the two years of the analysis.

The survey did not include questions concerning smoke extraction in the subjects' kitchen or the households' cooking method, so it is impossible to judge whether the research results will be affected by smoke extraction in the kitchen or households' different dining habits. However, given that these samples are all from rural China, either a traditional chimney or a new-style range hood will effectively remove smoke from the kitchen. Moreover, compared with urban kitchens, rural kitchens have more natural ventilation, which leads to better air quality. Meanwhile, unlike certain western dishes that are served cold, Chinese meals are largely "fried, boiled, or stewed," and the use of hot oil cannot be avoided. Therefore, this study assumes that the female subjects in this survey are consistent in their methods of cooking and smoke extraction.

3.2. Research strategy

To solve new problems, meet the challenge of Chinese energy development, and build a clean, efficient, safe, and sustainable modern energy system, the State Council issued the *Notice of the State Council General Office on Issuance of the Strategic Action Plan for Energy Development (2014–2020)* in 2014 (hereinafter referred to as the "Notice"). The Notice clearly proposed that China should implement a "Green and Low-carbon Strategy," optimize its energy structure, develop mainly clean and low-carbon energy when restructuring energy sources, stress the importance of transforming rural energy supplies, and strengthen energy conservation in rural areas. Therefore, this policy provides an excellent quasi-natural experimental background for this study's research. Then, in order to better analyze the health effects of rural clean energy uptake following the implementation of policies outlined in the Notice, the DID model is mainly used. However, in practice, there may be significant differences in the sample characteristics of the rural women who are affected by the policies. For example, rural women with higher levels of income and education are more likely to use cleaner energy to cook, but such cross-sectional heterogeneity could bias the DID model results. In order to effectively solve this problem, this study uses Propensity Score Matching and Differences-in-Differences (PSM-DID) to analyze the health impact of clean energy on rural women who engage in cooking, to generate a more reliable result (Heckman et al., 1998). In particular, we can find a sample i of subjects who do not use clean energy for cooking in the control group, and another sample j , who have similar characteristics and use clean energy for cooking in the treatment group, which can effectively account for the differences in observable characteristics between the two groups, satisfying the "conditional independence hypothesis" as far as possible. This effectively avoids both the endogeneity problem in rural women's clean energy use and the non-random grouping bias in the DID model. Based on this analysis, the DID model result shows the net effect of rural women using clean energy for cooking.

Therefore, against the quasi-natural experimental background, the main research design of this study is as follows: based on the 2014 and 2016 CFPS balance panel data, and investigating the change in cooking fuel of rural women before and after implementing the Notice, this study investigates whether rural women replace traditional energy with clean energy, and then collects reliable samples of the treatment group and control group. Specifically, we set 2014 as the initial period of the policy, but owing to limited data, we choose 2016 as the tracking period (based on the survey data, 22.97% of the subjects started to use clean energy in 2016, so it is considered that the analysis and tracking period setting is reliable). The treatment group includes rural women who did not use clean energy for cooking in 2014 but did in 2016. The control group includes rural women who did not use clean energy for cooking in both 2014 and 2016. The specific research steps are divided into three steps:

The first step, is to estimate the probability that subjects use clean energy for cooking in 2016 by their examining their initial characteristics. Characteristic variables include individual age, marital status, education level, income and consumption level, family size, housing type, individual health habits (whether or not they smoke), as well as local medical resources, and whether the subjects have health insurance. The logit model is used to clarify the relationship between clean energy use and these above initial characteristic variables, and we obtain the propensity score of subjects using clean energy for cooking by examining the estimation results. The logit model is constructed as follows:

$$\Pr(D_i = 1,16 | X_i, 14) = F(\alpha_0 + \alpha_i X_i, 14) \quad (1)$$

where $D_i=1,16$ represents sample i cook with clean energy in 2016; $X_i,14$ represents the initial characteristic variable of sample i in 2014, which is also the variable matched by the PSM method in this paper; $F(\cdot)$ stands for the logit distribution function; and α_i represents the coefficient of the characteristic variables. Therefore, according to the results generated, we can rematch the treatment group and the control group, making the two groups have more similar characteristics, so as to more effectively address the non-random grouping problem. Owing to the identical propensity scores, the balancing test is a necessary prerequisite for matching so, after the above calculation, this study conducts Radius Nearest Neighbor Matching to perform an balancing test (details are given in Sect. 4.2, below), which ensures grouping randomness between the treatment group and the control group.

In the second step, after grouping of the treatment group and control group by the PSM, eliminating samples that do not meet the "common area assumption," and through controlling the time and individual fixed effects in the DID model, we can eliminate the impact of time and individual unobserved heterogeneity. These do not change with the individual or over time and include such attributes as the resource endowment, or the energy-use environment, etc. Doing so allows us to further avoid the possibility of endogeneity problems in the model, so that we can accurately capture the relative health differences between the treatment group and the control group before and after using clean energy for cooking. This better reflects the effect of the policy on rural energy use. The specific model is constructed as follows:

$$Y_{it} = \beta_0 + \beta_1(D_i \times T_i) + \beta_2 X_{it} + c_i + year_t + u_{it} \quad (2)$$

In formula (2), Y_{it} represents dependent variables of this paper, which is the health status of sample i (comprising the results of health self-assessment, and the response to "whether physical discomfort was felt during the last two weeks"); D_i represents the dummy variable indicating whether sample i uses clean energy for cooking ($D_i=1$ refers to use of clean energy; otherwise $D_i=0$); T_i represents time ($T_i=1$ refers to tracking period of 2016, and $T_i=0$ refers to initial period of 2014); β_1 represents the estimated treatment effect of rural clean energy use on women's health; and X_{it} represents a series of covariables. It should be pointed out that the control group and the treatment group samples will have similar individual characteristics after PSM, so it is unnecessary to further control the covariables in the DID model. c_i represents the individual fixed effect; $year_t$ represents the time-fixed effect; and u_i is the random error term. After constructing the model, this study uses the Kernel Matching Method and direct OLS regression to calculate and compare the model's results, so as to ensure the robustness of the conclusions.

Third, in order to further study the impact of clean energy use for cooking on women's health in rural areas, this study attempts to examine whether there are differences in the health effects between women with different characteristics, such as age, education level, and region through heterogeneity analysis. Therefore, the subjects are grouped again, according to their different characteristics, and the results are analyzed using the PSM-DID method.

3.3. Variable setting

3.3.1. Independent variable

The interaction term between cooking fuel used by rural women and time is an important independent variable in this study, and is mainly used to reflect the changes in fuel used by sample women between the initial period and the tracking period. According to the above definitions of D_i and T_i , if the sample i is in the treatment group, the value of this independent variable is equal to 0 in 2014 and 1 in 2016; otherwise, if the subject is in the control group, both values are 0. Of the 6016 samples, 1382 (22.97%) are in the treatment group and 4634 (77.03%) are in the control group.

3.3.2 Dependent variables

The health self-assessment result of rural women is the key dependent variable in this study. From the perspective of time, this study chooses two health indicators related to subjects' health in the CFPS questionnaire as the dependent variables. They comprise: "health self-assessment" (*healthsub*) and "whether I have felt physical discomfort during the last two weeks" (*unhealth*, hereinafter "physical discomfort"). Among indicators, "health self-assessment" has been taken as an indicator of health measurement by a large number of

scholars, because it can reflect a person's overall health assessment and incorporates both subjective and objective health information. On the one hand, the subjective evaluation of a person's health can reflect private health information that is only known only to that person, and it can include aspects of health that cannot be quantified by objective indicators. On the other hand, there is a significant correlation between this indicator and objective indicators of morbidity, mortality, and so on, and it also contains aspects of non-private information, such as current and past disease and health status. Therefore, this study considers that the "health self-assessment" indicator can effectively reflect the health status of subjects. In the CFPS data, the values of this variable ranges from 1 to 5, where larger values indicate poorer health.

In addition, "physical discomfort" (*unhealth*) is also treated as the dependent variable in further testing. Specifically, this indicator is a binary dummy variable in the questionnaire: its value equals 1 when the sample has recently felt physical discomfort, and 0 otherwise.

3.3.3 Matching variables

As mentioned in Sect. 3.2, the matching variables of this study include individual basic conditions (age, region, and marital status), individual socioeconomic conditions (education level, economic level), individual family conditions (family size, housing type), individual daily habits (smoking or non-smoking), and local medical conditions. The meaning and descriptive statistical characteristics of each matching variable are shown in Table 1. Importantly, there are a large number of outliers in both CFPS2014 and CFPS2016 when measuring economic level by income, so we choose to measure the economic level of subjects using relatively stable indicators such as "household cash," "household total deposit," and "household consumption expenditure." As well, in order to better distinguish whether the subject has medical insurance, we construct a binary dummy variable: regardless of the type of medical insurance (public medical treatment, urban workers' medical treatment, urban residents' medical treatment, supplementary medical treatment, new rural cooperative medical insurance), if a subject has any type, the value of the dummy variable is 1; otherwise it is 0.

Table 1
Summary statistics of key variables.

Covariable name	Meaning	Mean	S.D.	Min	Max
age	The actually age value	51.526	15.312	18	94
marriage	current marital status(1 = unmarried;2 = married (with a spouse)3 = cohabitating4 = divorced5 = spouse deceased)	2.265	0.955	1	5
edutime	years of education	3.713	4.281	0	19
savings	total cash and deposits	14389.8	37288.5	0	800000
pce	consumption expenditure of residents	35570.8	41156.9	0	759240
familysize	people in the household	4.599	2.097	1	19
housingtype	1 = apartment;2 = bungalow3 = courtyard4 = villa5 = townhouse6 = small buildings; 7 = others	9.689	21.513	1	7
smoking	smoking or not(1 = yes;0 = no)	0.040	0.197	0	1
mt	level of medical treatment(1 = very good;2 = good3 = general4 = bad5 = very bad)	2.507	0.788	1	5
mtins	have medical insurance or not(1 = yes;0 = no)	0.938	0.241	0	1
Source: China Family Panel Studies 2014 and 2016.					

4. Empirical Results

4.1. Changes in rural women's health after using clean energy

Table 2 lists the descriptive statistics and DID model estimation results of the dependent variables for both the treatment group and the control group, in the initial period in 2014 and the tracking period in 2016. Owing to the uptake of clean energy, the results show that all the sample women of the treatment group had an improved self-evaluation of their health compared to the control group in both 2014 and 2016. Moreover, the improvement in the treatment group is greater than that in the control group. Specifically, the value of "health

self-assessment" (*healthsubj*), in the treatment group is 0.11 lower (indicating an improvement in their self-assessed health) than that of the control group in 2014, and the difference in mean value widens to 0.15 in 2016. Similarly, in the evaluation of "physical discomfort" (*unhealth*), the mean value of the treatment group is 0.014 lower than that of the control group in 2014, and the difference in mean value widens to 0.066 in 2016. Thus, it can be seen that the DID of the dependent variables are - 0.04 and - 0.052, respectively. These results indicate that the health level of sample women who replace their traditional cooking fuel with clean energy in 2016, will improve by 0.04 (*healthsubj*) and 0.052 (*unhealth*) compared to the sample women who use traditional fuel for cooking in both 2014 and 2016.

However, the results also show that for "health self-assessment," clean energy use does not result in a statistically significant improvement of health; while for "physical discomfort," the result is significant only at the 10% level. Therefore, this study uses the PSM for further analysis.

Table 2. Comparison of changes in rural women's health

Dependent variable	2014					2016					DID= (1)-(2)
	Control group N=2317		Treatment group N=691		Difference in means 1	Control group N=2317		Treatment group N=691		Difference in means 2	
	Mean	S.D.	Mean	S.D.		Mean	S.D.	Mean	S.D.		
healthsubj	3.379	1.341	3.269	1.383	0.110	3.480	1.306	3.330	1.285	0.150	-0.040
unhealth	0.435	0.496	0.421	0.494	0.014	0.424	0.494	0.358	0.480	0.066	-0.052*

Notes: The last column of this table shows the results of the DID analysis. * indicates significance levels of 10% level, respectively.

4.2. Balancing test after PSM matching

The regression results of the logit model used to estimate the propensity score, show that education, marriage, age, economic level (total cash and deposits, the consumption expenditure of residents), and other factors in 2014 (the initial period) have a significant impact on the probability of using clean energy for cooking in 2016 (the tracking period):

- If the subject has higher educational level, she is more likely to use clean energy;
- As the subject's marital status changes from unmarried to married, cohabitating, or "other," the probability that she will use clean energy rises significantly;
- The preference for clean energy is more obvious among older women who have been engaged in cooking for a long time;
- A rise in the individual's economic level may also promote the clean energy use.

Table 3 shows that there is a significant difference in nearly half of the variables' initial characteristics between the treatment group and the control group before matching. Therefore, if DID analysis were directly carried out by these samples without matching, the results would be unreliable, owing to the selectivity bias of the samples. However, given the characteristics of samples in the initial period, after adjusting the groupings through the radius nearest neighbor matching in PSM, it becomes clear that the variables' characteristic of the two groups will no longer be significantly different. In other words, the treatment group and the control group will have similar initial characteristics after PSM processing, and the results of the Kernel Matching Method also have similar characteristics. Thus, it is considered that the application of PSM-DID can effectively solve the non-randomness problem of the sample groupings and enhance the credibility of the analysis results.

Table 3
Balancing test

Variable	Before matching		After matching	
	Treatment group	Control group	Treatment group	Control group
age	50.215	49.770	50.214	50.937
marriage	2.261	2.182**	2.256	2.335
edutime	4.831	3.533***	4.824	4.581
savings	10728	12923	10745	9823
pce	36225	30787***	35878	35955
familysize	4.531	4.570	4.530	4.464
housingtype	9.376	11.318*	9.386	8.927
smoking	0.044	0.042	0.044	0.597
mt	2.496	2.496	2.495	2.460
mtins	0.918	0.933	0.918	0.930

Notes: Values in the table are means. *, **, and *** represent significant differences between the means of the treatment group and the control group before and after matching, at the 10%, 5% and 1% levels, respectively.

4.3. The effect of rural clean energy use on women's health

Table 4 shows that the PSM-DID (radius nearest neighbor matching, kernel matching) and OLS regression methods have a highly consistent influence on the significance and direction of the two dependent variables, indicating that the results of the estimations in this analysis have a high degree of robustness. Further, given that smaller values of the dependent variables represent better health conditions, we can observe that the negative coefficient of the independent variable has a positive effect on health.

The PSM-DID analysis of the radius nearest neighbor matching suggests that if the women in the sample replace traditional energy with clean energy for cooking during the tracking periods, their self-assessed level of health will improve by 0.1555, which implies that the change of energy source leads to a 4.64% improvement in their self-assessed health (*healthsubj*) and a 13.82% reduction in their "physical discomfort" (*unhealth*). Therefore, it can be seen that the uptake of clean energy in rural kitchens will have a significant positive impact on women's health, which is conducive to improving their self-assessed level of health.

This could be explained by "the Syndrome of Drunk Oil" (van Wormer, 2007). As mentioned in Sect. 3.3.2, above, the health variables adopted in this paper can objectively reflect personal health information and also incorporate related information that is only known to the individuals concerned, so that their objective health level will be closely related to their self-assessed health level. The Syndrome of Drunk Oil shows that kitchen fumes is the most common cause of poor appetite among women who cook by traditional means since it contains harmful gases and particulate matter (such as CO, SO₂, CO₂, and NO compounds). We believe that these fumes released during cooking negatively impact the subjects' health. Thus, clean energy use can effectively reduce this effect, and significantly improve women's health.

Table 4
Treatment effect of rural clean energy use on women's health

Dependent variable	Radius Nearest Neighbor Matching		Kernel Matching		OLS	
	Coef.	S.D.	Coef.	S.D.	Coef.	S.D.
	healthsubj	-0.1555**	0.0602	-0.1562***	0.0601	-0.1499***
unhealth	-0.0596**	0.0230	-0.0599***	0.0230	-0.0663***	0.0221

Notes: In both "radius nearest neighbor matching" and "kernel matching" the number of samples that met the common area assumption was 5454 (there are differences between the matching samples); neighbor = 1, caliper = 0.05; OLS regression was directly performed on initial samples of 6016. *** and ** indicate significance at the 1% and 5% levels, respectively.

4.4. Placebo test

In order to ensure the reliability of this study's conclusions, we now conduct a placebo test, which aims to verify the impact of rural clean energy use on women's health. The research methods are as follows: ① Considering the samples of rural women after PSM; ② Randomly choose some women (the sample number is consistent with the original PSM-DID treatment group) as the treatment group in a new DID regression, and assume that the subjects in the group used clean energy for cooking in 2016; ③ Estimating the regression coefficient β_7 of the new, randomly chosen treatment group according to the original formula to run the model for 500 random simulations. Accordingly, we obtain a distribution of the coefficient β_7 . If the regression coefficient of the DID treatment group is always significant, and is consistent with the benchmark results, this would indicate that the empirical results presented above are not generated from clean energy use: they might merely have been caused by coincidence and unobserved variables. However, if it can be proved that the application of clean energy in rural areas does lead to a significant health improvement for rural women, this would further verify the reliability of the benchmark regression results.

We therefore perform a placebo test with samples that have already been matched by the radius nearest neighbor matching method. Figures 1 and 2 show the results of the placebo test for "health self-assessment" and "physical discomfort". From Table 4, we observe that the regression coefficients of the two dependent variables are -0.1555 and -0.0596, but in Figs. 1 and 2, after 500 random simulations, it can also be seen that more than 95% of the regression coefficients are distributed outside the benchmark regression results. The result suggests that artificial random selection samples of rural clean energy use do not have a significant impact on rural women's health, supporting the conclusion that the benchmark results of this study are not affected by unobserved factors.

4.5. Heterogeneity analysis

Based on the above empirical results, it can be seen that the uptake of clean energy in rural areas is conducive to improving women's health. The questions now arise are whether the uptake of clean energy has different health effects on rural women with different characteristics. In order to answer these questions, we now divide the sample women into different groups according to their age, education level, and regional characteristics, and further investigate the health effects of their clean energy use. Given that the results of the radius nearest neighbor matching and the kernel matching of samples in the PSM are consistent with each other, we now take the treatment group and control group that are already matched by the radius nearest neighbor matching as the basis of the heterogeneity analysis.

Following the age categories of the WHO, the sample women are divided into a young group and a middle-aged/older group. As shown in Table 5, middle-aged/older women who replace traditional energy with clean energy for cooking could experience a greater positive effect on their health than young women: their "health self-assessment" and "physical discomfort" are respectively reduced by 0.1736 and 0.0878, which means an increase of 5.18% and 20.35% in their health self-assessment. The possible reason is that, in Chinese rural families, most married middle-aged/older women do most of the cooking for the family, especially when their daughters-in-law go out to work with their husbands. When three generations of a family live in the same household, the grandmother will generally do all the home cooking. As a result, the health of middle-aged/older women shows the greatest improvement when traditional cooking fuel is replaced by clean energy.

Next, considering that education may make a difference to the women's understanding and acceptance of new things, and based on the fact that the sample women are generally less educated (about 50% are illiterate), this paper divides the samples into illiterate and non-illiterate groups. This analysis finds that the health of the illiterate groups improves significantly when clean energy is used for cooking, which is basically consistent with the existing literature (Imelda, 2020). The possible reason for this is that highly educated women are more aware of and pay more attention to their cooking environment and, realizing its significance, are more likely to reduce air pollution in their kitchens by purchasing a range hood or renovating their stoves, for example, and thereby reducing the damage to their health.

Finally, to investigate regional differences, the whole sample is divided into four groups according to which region of China they inhabit: eastern, central, western, or northeastern. It is found that northeastern women experience the most significant health improvement after using clean energy for cooking. The possible explanation for this could lie in the particular climate and resource endowment of the rural areas in northeastern China: their typical household has a Kang bed-stove, often of brick or concrete, which burns fuel (such as wood or straw) for both cooking and heating. Though an efficient use of resources, the Kang generates soot as well as heat, as it burns fuel. Therefore, northeastern women experience greater positive health effects after replacing traditional fuel with clean energy. Owing to such local cultural and natural conditions, if clean energy cooking is to be promoted in these regions, we need to find effective methods adapted to local circumstances that improve people's health while also synergizing with their lifestyles. In rural areas of the central region it is also found that clean energy use for cooking has a positive impact on women's health.

Table 5
Heterogenous results

Grouping		healthsubj			unhealth		
		N	Coef.	S.D.	N	Coef.	S.D.
Age	young	1736	-0.1130	0.1015	1693	0.0038	0.0384
	middle-elder	3718	-0.1736**	0.0697	3624	-0.0878***	0.0276
Education level	illiterate	2696	-0.1653*	0.0944	2619	-0.1038***	0.0369
	non-illiterate	2758	-0.0149	0.0762	2698	-0.0015	0.0293
Region	east	961	-0.0795	0.1265	945	-0.0504	0.0489
	center	1273	-0.2440**	0.1189	1239	-0.0660	0.0437
	west	2360	-0.0395	0.1070	2283	-0.0129	0.0439
	northeast	860	-0.2677*	0.1520	850	-0.1110**	0.0529

Notes: The matching method used for is the "Radius Nearest Neighbor Matching" method. Neighbor = 1, and Caliper = 0.05. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

5. Conclusions And Policy Implications

5.1. Conclusions

Using panel data for samples of rural women in CFPS2014 and CFPS2016, this study applies the Propensity Score Matching method and a Difference-in-Differences model (PSM-DID), and combines these with heterogeneity analysis to comprehensively analyze the impact on women's health of rural clean energy use. The conclusions are: (1) Clean energy use can significantly improve the health of rural women; and (2) When clean energy replaces traditional energy, the health improvement of rural women differs according to their age, education level, and region. Middle-aged, older, illiterate, and northeastern women experience greater positive health effects. Therefore, clean energy use should be promoted in rural areas as a means of equalizing, as well as improving, women's health outcomes. The analysis was shown to be robust under different analytical methods, including radius nearest neighbor matching, kernel matching, and OLS regression, and it also passed the placebo test. It is therefore believed that the conclusions are robust, and that it can be said with confidence that clean energy use in rural areas has a positive impact on women's health.

5.2. Policy implications

Based on the conclusions of this study, and in order to realize the doubly positive impact on "health efficiency" and "health equity" for women through clean energy use in rural areas, the following policy measures are proposed. First, improving education about clean energy, and raising women's awareness and knowledge about health issues. Currently in rural areas, traditional fuels are still used for cooking and women's health is paid little attention. Publicity campaigns could therefore usefully combine the promotion of clean energy with emphasis on women's health issues. The government could conduct such campaigns in model villages through television broadcasting or pamphlets, for example, specific cases could be used to highlight the potential risks to women's health of using traditional fuel. Local farmers could be encouraged to move to cleaner energy use and popularize clean energy based on their experience of its benefits(Zhang et al., 2018).

Second, the central government should provide support for clean energy technologies(Zhang et al., 2019). Our heterogeneity analysis shows that the health of middle-aged, older, and illiterate women benefits most from clean energy use in rural areas. However, these women are also more likely to encounter difficulties when they try to assess the pros and cons of new technologies and when they pay for converting their kitchens to clean energy use. Hence, these women are more inclined to continue to use traditional energy and so bear more health risks. To solve this problem, the central government should try to build a more perfect clean energy technology service system and economic support system, which aim at helping these women increase their willingness of clean energy use. For example, providing more efficient service guarantees for users by stationing technical stations and employing professional technologists to help households transform their kitchens to use clean energy. Besides, the government could promote the policy of "*Home Appliances to the Countryside*" to reduce the cost of purchasing clean energy equipment, and give official discounts to farmers who purchase the equipment at the first time. At the same time, the government also could give regular subsidies during using clean energy. These practical measures would both encourage rural women to pay more attention to clean energy and facilitate its uptake.

Third, promotion of clean energy should be optimized for local conditions. Women in different regions of China benefit to different degrees when they use clean energy. Therefore, when promoting clean energy in rural areas, the varying resource endowments and customs in the regions need to be considered, and the construction of the necessary energy infrastructure should be done sensitively. In particular, when promoting energy transformation in northeast China, we should respect the complementarity of local cooking and winter heating in the region, and ensure that clean energy performs at least as well as traditional energy.

Fourth, the government should carry out necessary preliminary investigations to understand the current situation of clean energy use in China's rural areas and their main existing problems. Specifically, the following process can serve as a reference: (1)The government could organize a field survey about local clean energy use before developing clean cooking energy, so as to understand the actual demand of local energy use; (2) According to the survey results and combining with the local actual resource situation, the local government should put forward different strategies to develop clean energy and give more suitable development guidance; (3) Regularly summarize the policies that have been formulated, and timely adjust the strategies that run counter to the local actual development.

Fifth, building a collaborative, mutually beneficial atmosphere for clean energy use in rural areas. For all we know, China's rural society is a society that attaches communication and interpersonal relations, so no matter what changes have taken place in their daily lives, they could easily impact on their relatives and neighbors, especially for the older and less educated groups. Therefore, we could infer that rural women are more likely to use clean energy if they are surrounded by those who have already used clean energy. Based on this objective phenomenon, the local government could try to hold "Clean Energy Experience Activities" with related enterprises in villages. For example, a clean energy theme day can be set as a regular day of celebration. In the theme day, local farmers can learn about clean energy from multiple perspectives, such as clean energy knowledge lectures, popular science videos and product experience etc. The theme day could help these women realize the unique charm and advanced nature of clean energy. Besides, it could encourage rural women who have already used clean energy for cooking to share their feelings with others, especially older and less educated women. The "clean energy theme day" maybe be good to reduce rural women's stickiness to traditional energy.

Lastly, owing to the theme of this paper is the improvement of clean energy use on women's health, we need to apply the theoretical results into real life. We suggest that everyone could more stand in the perspective of women and their health when appealing to promote rural clean energy. For instance, women consumers who have experienced the benefits of clean energy should be selected for those publicity campaigns. In addition, women should not be ignored when the government train rural clean energy technicians. And even in the related department of the rural government, women should be given more power to promote clean energy in rural areas. Because many rural female officials also experienced the health hazards of traditional energy in cooking, if they could advocate using

clean energy by themselves, it maybe have more power to persuade other rural women change their cooking energy. Therefore, giving women more participation and more executive power could better promote clean energy use in rural areas and improve women's health.

Declarations

Ethics approval and consent to participate:

Not applicable

Consent for publication:

Not applicable

Availability of data and materials:

The datasets used during the current study are available from the corresponding author on reasonable request.

Competing interests:

The authors declare that they have no competing interests.

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Authors' contributions:

NL: Writing, Methodology, Software; GLZ: Data curation, Writing-Original draft preparation; LGZ: Validation, Investigation. YHZ: Software, Validation. NZ: Writing- Reviewing and Editing.

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Figures

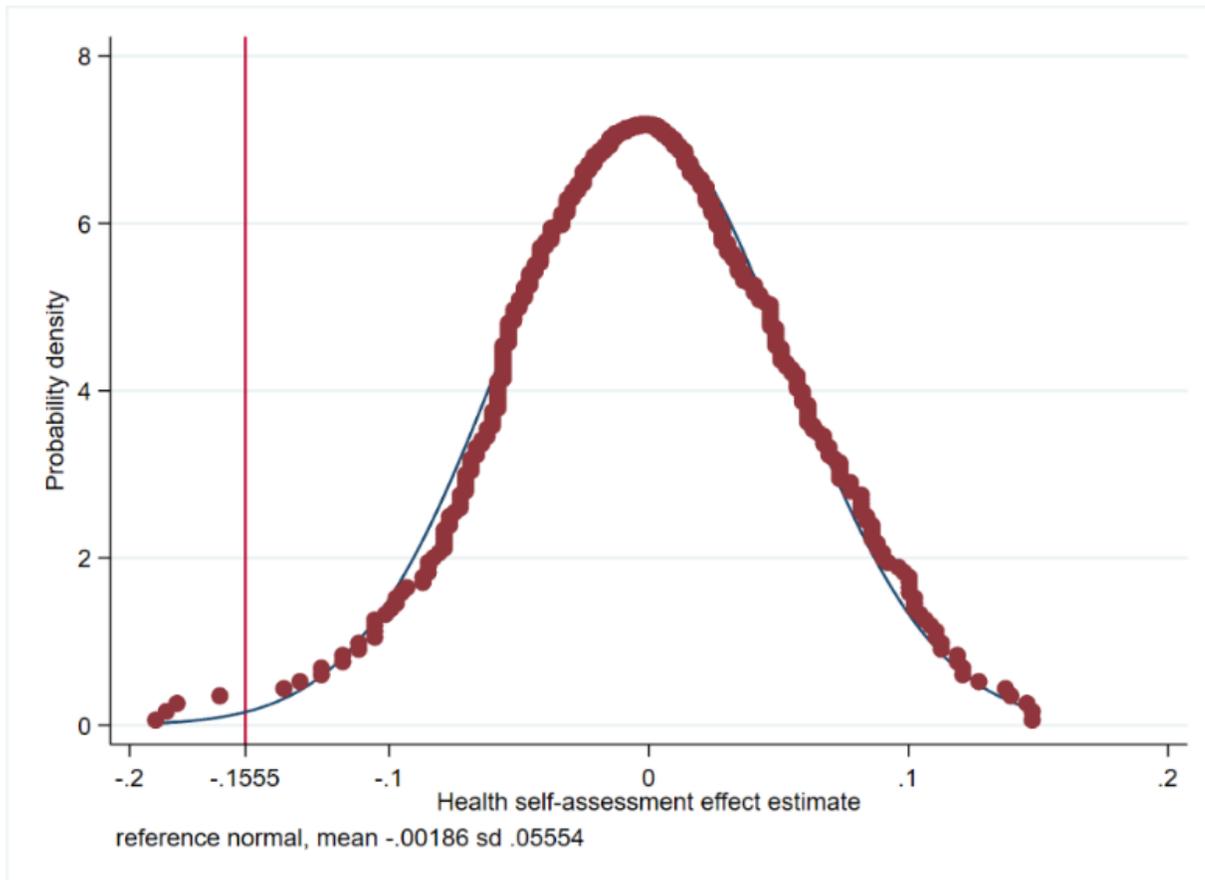


Figure 1

Distribution of new regression coefficients of placebo test with the health self-assessment as the explained variable

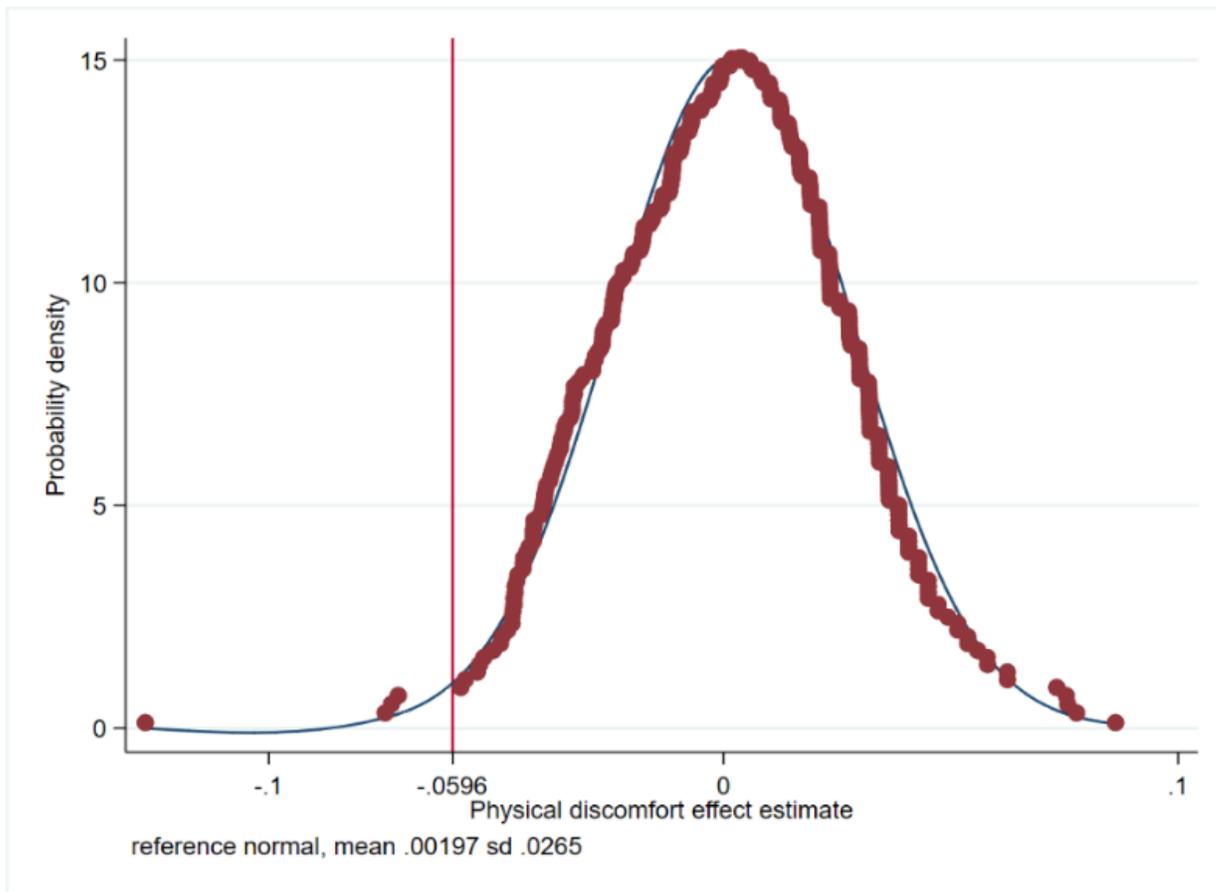


Figure 2

Distribution of new regression coefficients of placebo test with the physical discomfort as the explained variable