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The effect of Internet use on males' body mass index and overweight: evidence from China

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Abstract

The effects of increasing Internet use in developing economies have attracted various attention from politicians and academic researchers, while the literature investigating the effects of Internet use on nutrition and health is insufficient. In particular, research on China, with its large overweight population, is still not clear and complete. This study aims to evaluate the effect of Internet use on body mass index (BMI) and overweight for males in China and shed light on the underlying mechanisms of the effect. To address the non-random distribution problem of Internet use and control for unobservable factors that might bias the estimates we are interested in, an endogenous switching regression model is applied, an econometric method in which counterfactual analysis is used to obtain the average treatment effect of Internet use on BMI and overweight. The study sample is chosen from longitudinal research data from the China Health and Nutrition Survey, with 12,846 observations covering 5 waves. Estimation results indicate that Internet use could reduce BMI and the probability of being overweight by 3.626% and 33.963%, respectively. Heterogeneity analysis shows that Internet use has a greater effect on males living in urban areas and those with higher education. We also reveal that reducing total energy intake and macronutrient intake and increasing dietary knowledge levels and the time spent on exercising serve as important mechanisms through which Internet use can have an effect on BMI and overweight. This study shows that Internet use has a beneficial effect on BMI and overweight of males in China. Therefore, internet platforms may be an effective way to regulate males' macronutrient intake and BMI and overweight. More importantly, using Internet platforms to circulate information about healthy diets may contribute to improving dietary knowledge and the prevalence of overweight.

Keywords

Internet use; Males; BMI; Overweight; Macronutrient intake

1. Introduction

Over the past two decades, the widespread use and development of the Internet worldwide have undergone significant changes, which have profoundly affected people's lifestyles. According to the latest World Bank statistics, the proportion of individual Internet users to the total population worldwide has increased dramatically from 1.32% in 1996 to approximately 60% by 2020. Of these, 29 countries have an Internet population of over 90% of the total population [1], and some articles now suggest that the number of Internet users could potentially reach 2.7 billion [2]. The Internet has contributed to the reform of government services and the rapid development of e-government, which allows citizens to participate in state affairs through e-government platforms [3, 4]. The Internet has led to the growth of e-commerce, reducing the cost of customer acquisition and making millennials primarily online shoppers [5–7]. The Internet has facilitated a shift in the media industry, with online media becoming the focus of attention, and a decline in the use of traditional media [8]. The Internet has transformed the way people socialise, with online interaction making distance a less barrier to communication. All these changes mean that modern people are increasingly inseparable from the Internet, with it playing a greater role in their lives in general and in their daily work in particular, where they rely on the Internet to access information and communicate [9, 10].

Extensive research has investigated the impact of Internet use on the economic outcomes and well-being of its users. In contrast, little attention has been paid to its impact on nutrition-related health. Li and Zhou [11] find that Internet use enhances parent-child contact and increases subjective well-being among older adults; Hong and Chang [12] find that the Internet increases the incomes of forestry growers and thus increases farmers' subjective well-being. At the same time, studies have clearly shown that Internet use significantly increases the non-farm incomes of farming households in rural areas of developing countries [13, 14]. More recently, it has been found that Internet use may be associated with nutritional outcomes, but conclusions about the relationship between Internet use and BMI are inconsistent. Many studies indicate that Internet use has either no significant effect or a positive effect on overweight and obesity [15–17]. For instance, Beleigoli *et al*. [18] find that each additional hour of Internet use is associated with an 8% increase in the odds of being overweight or obese. Another study suggests that Internet use significantly improves dietary habits regarding healthy foods, such as fruits and vegetables [19], and increases contact with sources of health information, which could consistently improve people's health status [17, 20–22]. For instance, an empirical study in Serbia, a developing country, shows that more frequent Internet access is likely to result in BMI decrease [23].

Whether the above findings hold true in the transitional economy of China, especially for males, is still unclear. Therefore, this study aims to assess how and to what extent Internet use contributes to the nutritional outcomes of males in China. In China, food consumption has shifted from a situation of national poverty and hunger to one of overweight and obesity caused by excessive macronutrient intakes [24, 25]. According to the China Nutrition and Chronic Disease Report in 2012, the overweight and obesity rates among adults were 22.8% and 7.1%, respectively, while the latest survey results in 2020 show that the overweight and obesity rates have reached 34.3% and 16.4%, respectively [26]. Extensive studies have revealed that the increasing prevalence of overweight and obesity is a major cause of noncommunicable diseases, such as diabetes, cardiovascular diseases and hypertension; it also increases the risk of kidney and colon cancers [27–29]. This is a significant risk to individual and public health. Thus, understanding the impact of Internet use and its underlying mechanisms on nutritional outcomes has far-reaching implications for policy-makers looking to intervene in the prevalence of overweight and obesity in developing countries like China.

More importantly, the effects of Internet use on nutritional outcomes are inconsistent across genders, since males are more likely to be affected by Internet addiction [30–32] and experience more changes in their nutritional outcomes. According to the available data, the proportion of male Internet users is 2.4% higher than that of females [33]; regarding nutritional outcomes, it is estimated that males are more likely to be overweight and obese in recent years. In 2004, the average BMI and obesity rate of males were lower than those of females, but by 2018, there were 48 million obese adult males and 37 million obese females aged 18 to 69, meaning there were 11 million more obese males than females. The average BMI of males in China increased from 22.5 in 2004 to 24.7 in 2018, and the rate of overweight people increased from 20.9% in 2004 to 45% in 2018 [34]. As a large country with a population of over 1.4 billion, the issue of overweight and obese males in China deserves to be more fully studied and discussed. Changes in people's income levels and lifestyles are a major cause of this phenomenon. However, the Internet plays a huge role in changing people's lifestyles. Therefore, this study intends to demonstrate the gender-specific effect of the Internet use on males.

The main aim of this study is to investigate the effect of Internet use on BMI and overweight. The hypothesis of this study is that the Internet, as a medium of information dissemination, enables people who are online to receive more information. Information about healthy eating and health-related information can influence numerous behaviours that can lead to a reduction in people's BMI and a lower likelihood of being overweight. This is reflected in changes in energy intake, macronutrient intake, improved dietary knowledge and increased time spent exercising. The main research method used in this study is an econometric model, the endogenous switching regression (ESR) model. The main function of this model is that it reduces estimation bias due to unobservable factors and allows for average treatment effects to be derived from counterfactual analysis.

The remainder of the paper will be organised in the following manner. The second section addresses the methods, data, the econometric methods and the sample used in this study. The third section contains the results and discussion, the determinants of Internet use, the impact of Internet use on BMI and overweight, the heterogeneity analysis, and the mechanism analysis. The final section concludes the study.

2. Methods and data

2.1 Method

2.1.1 Endogenous switching regression model

This study focuses on analysing the effect of Internet use on males' nutritional outcomes. Still, Internet use as a self-determined behaviour does not occur randomly. It might be influenced by subjective and objective factors, some of which cannot be observed and controlled for. These unobservable factors may be related to the outcome variable, leading to the endogeneity problem of Internet use. Thus, ESR model is applied to control for both observable and unobservable characteristics and it allows counterfactual analysis to calculate the average treatment effects. An instrumental variable should be selected when using the ESR model. The availability of Internet cafes in the community is a potential instrumental variable for Internet use. A valid instrumental variable has to satisfy both relevance and exogeneity. First, the number of internet cafes in the community is highly correlated with whether males use the Internet. Second, the number of Internet cafes in the community is not necessarily associated with males who have elevated BMI or who are overweight.

The ESR model generally consists of two stages. In the first stage, a probit or logit model is used to estimate a decision equation for Internet use among males. In the second stage, outcome equations for BMI, overweight and dietary knowledge are developed separately for males to estimate the determinants of the outcome variables. Thus, the ESR model involves the following three equations:

The decision equation regarding whether to use the Internet or not:

$$D_i^* = \gamma Z_i + \pi I_i + \mu_i, \;\; D_i = \begin{cases} 1 \; if \; D_i^* > 0 \\ 0 \; otherwise \end{cases} \tag{1}$$

The outcome equation for males using the Internet:

$$Y_{ni} = \beta_n X_{ni} + \epsilon_{ni} \; if \; D_i = 1 \quad (2)$$

The outcome equation for males who do not use the Internet:

$$Y_{ui} = \beta_u X_{ui} + \epsilon_{ui} \; if \; D_i = 0 \quad (3)$$

In Eqn. 1, D_i represents the binary choice variable of whether males use the Internet, Z_i is the set of vectors that affect whether the Internet is used, I_i represents the vector set of the instrumental variables, and μ_i is the error term. Eqn. 2 represents the outcome variable equation for males who use the Internet. Y_{ni} represents BMI or overweight or dietary knowledge. X_{ni} represents the variable of interest affecting the outcome variable. ϵ_{ni} represents the error term of the equation. The variables in Eqn. 3 have the same meanings as those in Eqn. 2, with the difference that Eqn. 3 represents the decision equation for the outcome variables for males who do not use the Internet.

2.1.2 Estimating treatment effects

The average treatment effect can be further calculated with the help of ESR model. The observed and unobserved counterfactual outcomes of using the Internet are presented below [35, 36]:

The expectations of the outcome variables for males using the Internet (observed):

$$E\left[Y_{ni} \mid D_i = 1\right] = \beta_n X_{ni} + \sigma_{\mu n} \lambda_{ni} \quad (4)$$

The expectations of the outcome variables for males who use the Internet in the absence of Internet use (counterfactual):

$$E\left[Y_{ui} \mid D_i = 1\right] = \beta_u X_{ni} + \sigma_{\mu u} \lambda_{ni} \quad (5)$$

The average treatment effect on the treated is shown below:

$$ATT_i = E\left[Y_{ni} \mid D_i = 1\right] - E\left[Y_{ui} \mid D_i = 1\right] \quad (6)$$

2.2 Data

2.2.1 The sample

The sample used in this study is from the China Health and Nutrition Survey (CHNS), a collaborative project between the University of North Carolina and the Chinese Centre for Disease Control and Prevention. The data set includes 12 provinces and 3 municipalities: Liaoning, Heilongjiang, Jiangsu, Shandong, Henan, Hubei, Hunan, Guangxi, Guizhou, Yunnan, Zhejiang, Shaanxi, Beijing, Shanghai and Chongqing. 10 periods of data collection are conducted in the survey of 7200 families with more than 30,000 individuals: 1989, 1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011 and 2015.

The data used in this study are longitudinal data from the years 2004 to 2015. The sample for this study focuses on a group of males aged 25–60 years old. The final sample size, after excluding missing values and outliers, is 12,846. As the CHNS information on energy intake and macronutrient intake is only updated in 2011, a sample size of 10,256 is used in the analysis of the channels of the role of the Internet on BMI and overweight. All of the following data analyses are carried out using STATA version 17 (StataCorp, College Station, TX, USA).

2.2.2 Variables

All the relevant variables are defined in Table 1. The treatment variable is whether one uses the Internet. It is defined in the questionnaire as “Can you access the Internet?”. Based on all the samples, the proportion of Internet use is 28.3%, and according to the most recent data from 2015, the proportion of Internet use reaches 45.7%. The ratio of Internet use shows an increasing trend over the years. The nutritional outcomes comprise two variables: body mass index (BMI, kg/m^2) and overweight. BMI is calculated using body weight divided by height squared and is a commonly used measure of physical health. According to the Asian population criteria proposed by the World Health Organization and the Chinese criteria proposed by the National Health and Family Planning Commission of the People’s Republic of China [37, 38], a person with a BMI equal to or greater than 24 is defined as overweight.

Table 1 shows a significant difference in BMI and overweight between males who use the Internet and those who do not at the 1% statistical level. This indicates that there may be significant effects of Internet use on the BMI and overweight of males, and these differences may be caused by a combination of observable and unobservable factors, so further work needs to be done to estimate the effects of Internet use on the level of the nutritional health of males. Looking at the distribution of the BMI sample values, as shown in Fig. 1, the kernel density plot for all the years in the sample indicates that the proportion of overweight individuals has reached 45% and the ratio of obese people has exceeded 10.8%. Not only is the overall percentage of overweight individuals alarming, but the rate of BMI growth among Chinese males is also very noteworthy. As shown in Fig. 2, the BMI of urban males is higher than the overall average, while the average BMI of rural males is lower than the overall average and much lower than that of urban males. The mean BMI shows an upward trend overall, whether observing the entire sample or the urban and rural samples separately.

The channel variable consists of four components, the first of which is energy intake. This is the average of the three-day energy intake of the respondents. In terms of total energy intake, internet users intake less energy. The second is macronutrient intake, including carbohydrates, proteins and fats. In CHNS, food consumption records of the participants are taken with the food consumption record form for 3 days and nutrient intakes are evaluated as a result of the average of these 3 days. High-quality protein intake has an effect on appetite suppression, as does simple carbohydrate-rich (such as sugar-sweetened beverages) increases the likelihood of obesity, and a high intake of low-quality fat may also lead to obesity [39]. Carbohydrate and fat are considered to be two

TABLE 1. Descriptive statistics of the variables.

Variables	Definitions	Obs.	All	Internet users	Non-Internet users	Difference
Treatment variables						
Internet use	1 if use Internet, 0 otherwise	12,846	0.283 (0.450)			
Nutritional outcomes						
BMI	Body mass index (kg/m^2)	12,846	23.839 (3.300)	24.396 (3.307)	23.619 (3.272)	0.777***
Overweight	1 if BMI $\geq$24, 0 otherwise	12,846	0.453 (0.498)	0.528 (0.499)	0.423 (0.494)	0.105***
Channel variables						
Energy intake	Natural logarithm of 3-day ave: Energy (kcal)	10,256	7.727 (0.314)	7.674 (0.339)	7.744 (0.304)	−0.070***
Carbohydrate	Natural logarithm of 3-day ave: Carbohydrate (g)	10,256	5.721 (0.375)	5.573 (0.378)	5.767 (0.362)	−0.194***
Protein	Natural logarithm of 3-day ave: Protein (g)	10,256	4.264 (0.333)	4.305 (0.331)	4.251 (0.332)	0.055***
Fat	Natural logarithm of 3-day ave: Fat (g)	10,256	4.269 (0.547)	4.360 (0.525)	4.239 (0.551)	0.121***
Dietary knowledge	Dietary knowledge index[a]	12,846	7.180 (4.146)	8.934 (3.887)	6.489 (4.040)	2.445***
Exercise	Exercise time per day (hours)	12,846	0.255 (1.022)	0.520 (1.366)	0.151 (0.826)	0.369***
Control variables						
Age	Years	12,846	45.262 (9.509)	41.321 (9.660)	46.814 (8.987)	−5.493***
Age squared	Natural logarithm of age squared	12,846	7.577 (0.452)	7.387 (0.483)	7.652 (0.415)	−0.265***
Education	Years of education	12,846	10.059 (4.268)	13.286 (4.215)	8.788 (3.560)	4.498***
Marital status	1 if the head of the household is married, 0 otherwise	12,846	0.927 (0.260)	0.898 (0.302)	0.938 (0.240)	−0.040***
Work	1 if currently has a job, 0 otherwise	12,846	0.885 (0.319)	0.936 (0.244)	0.865 (0.342)	0.071***
Urban	1 if living in an urban area, 0 otherwise	12,846	0.340 (0.474)	0.605 (0.489)	0.236 (0.425)	0.369***
Household size	Household size	12,846	3.185 (1.342)	3.294 (1.297)	3.142 (1.357)	0.152***
Income	Natural logarithm of the per capita household income (yuan) inflated to 2015 value	12,846	9.560 (1.347)	10.194 (1.006)	9.311 (1.382)	0.883***
Instrumental variable						
Internet café	Number of internet cafés in the community.	12,846	1.867 (4.873)	2.582 (5.125)	1.586 (4.740)	0.996***

*Source: Author's calculations using the CHNS data (2004–2015). Standard errors are presented in parentheses. ***$p < 0.010$.*
[a] Calculating by scoring 12 dietary knowledge questions. Using a 5-point scale to distinguish the level of accuracy in responding to each question. The higher the score, the higher the level of dietary knowledge.
BMI: body mass index.

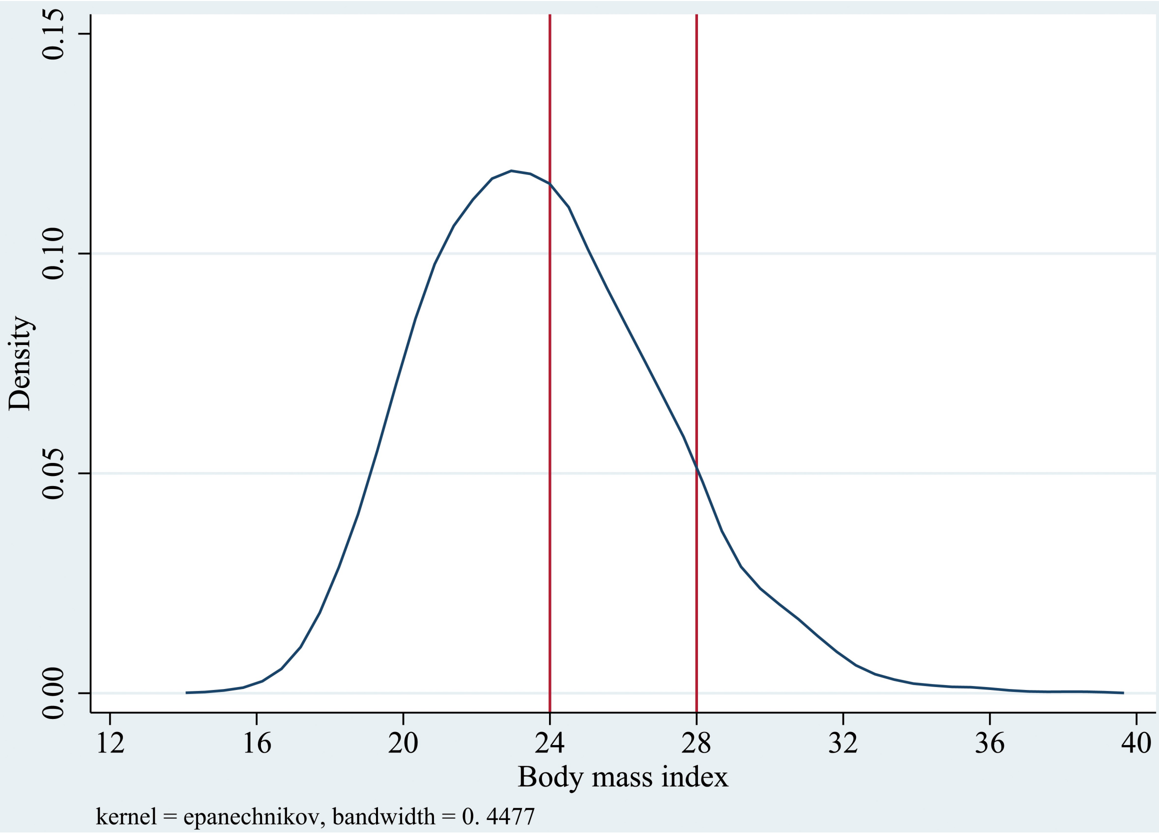

FIGURE 1. Distribution of body mass index (BMI). Note: A body mass index equal to 24 or above is defined as overweight. A body mass index equivalent to 28 or above is defined as obesity. Source: CHNS 2004, 2006, 2009, 2011 and 2015.

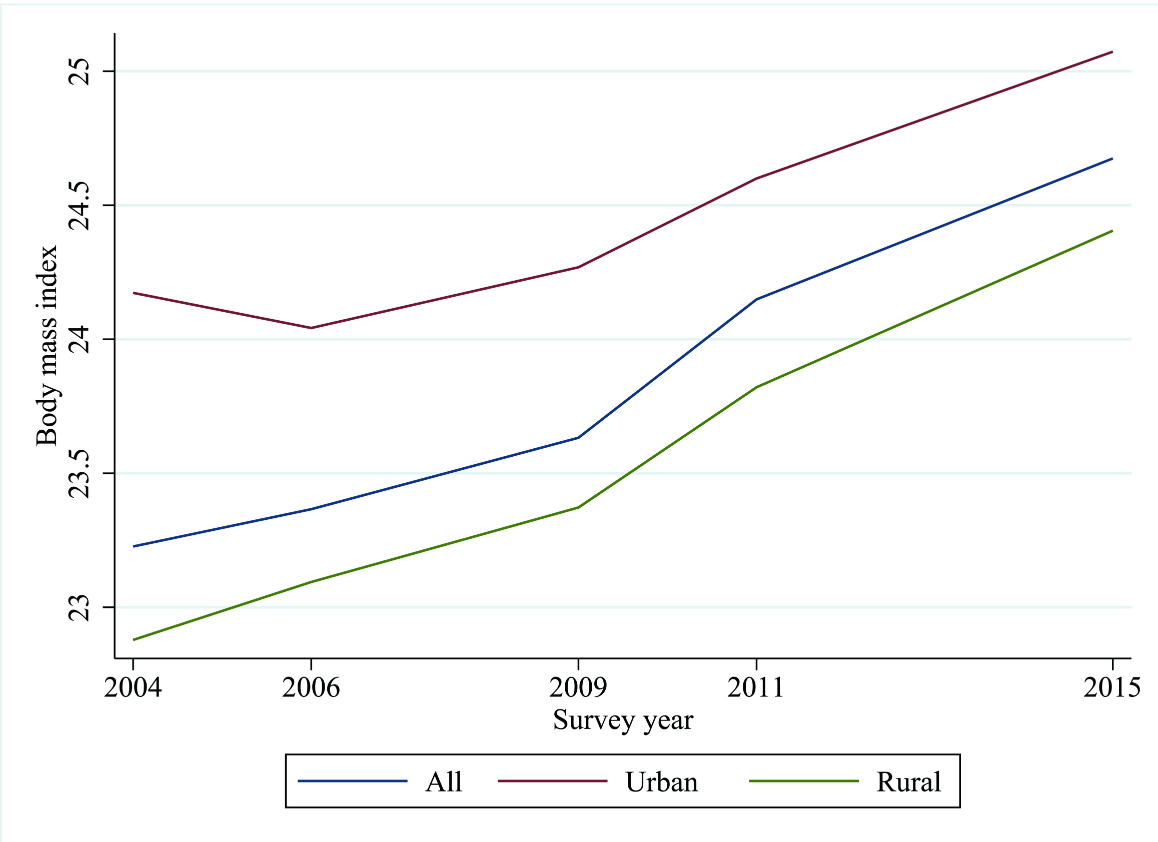

FIGURE 2. Average body mass index (BMI) changes in urban and rural areas in 2004–2015. Source: CHNS 2004, 2006, 2009, 2011 and 2015.

important macronutrients related to obesity, and the balance of intake of these two macronutrients is an important element of obesity in the male population [40]. Moreover, these three macronutrients have been shown to be important as part of people's daily intake, which is why we chose them as one of the channels [41]. Table 1 shows that the intakes of these three nutrients differ significantly between Internet users and non-users, so Internet use has an effect on macronutrient intake. The other two channel variables are the time spent exercising and dietary knowledge. Exercise time is defined as the amount of time spent exercising each day, including ball games, running and swimming. Dietary knowledge index is a synthetic indicator that is calculated by scoring respondents' answers to 12 questions related to dietary knowledge using a 5-point scale to distinguish the level of accuracy in responding to each question, ranging from correct to incorrect on a scale of 2 to −2. The final scores for all the questions are added up to obtain the variable of dietary knowledge. Thus, higher dietary knowledge scores indicate higher levels of dietary knowledge. The mean values of exercise time and dietary knowledge are higher for Internet users than those who do not use the Internet. The mean value of exercise time per day for Internet users is 0.520 hours, and the mean level of dietary knowledge is 8.934 points. This compares with an average of 0.151 hours of exercise and a dietary knowledge level of 6.489 points for males who do not use the internet.

Drawing on existing studies, the control variables are selected to include individual-level variables of interest (age, age squared, education, marital status and current employment) and household-level variables (residence location, household size and annual per capita household income) [41, 42]. The average age of the sample is approximately 45 years old, and the average number of years of education is about 10 years. More than 92% of the respondents are married, about 88% are currently working, 34% of the sample live in the city, and the average household size is about 3 persons—the covariates for males who use the Internet and males who do not are statistically significantly different. Specifically, males who use the Internet are younger, more educated, somewhat less prone to be married, more likely to be currently working and more inclined to be living in the city in a slightly larger household and with a somewhat higher income. The characteristics of males who use the Internet are not consistent and are significantly different from males who do not use the Internet, and such selectivity bias can lead to biased estimation results.

3. Results

This section begins with a correlation analysis of the key variables, confirming the existence of a correlation between internet use and both the outcome variable and the channel variable. In the second section, an analysis of the factors influencing internet use is conducted, which forms the basis of the ESR model. In the third section, the effects of BMI and overweight are estimated using the ERS model. The fourth section analyses urban-rural and educational attainment, two variables that can make a significant difference, to see the impact of Internet use on different samples. The fifth section conducts a mechanistic analysis in an attempt to find the channels through which the Internet acts on BMI and overweight.

3.1 Correlation analysis

Table 2 provides a Pearson correlation analysis of Internet use with the outcome variables as well as the channel variables. As shown in Table 2, Internet use is significant at the 1% level with both outcome variables and with all three sets of channel variables. Specific results are reported below. First, Internet use is positively correlated with BMI and overweight. Second, Internet use is not consistently correlated with the three nutrients in the same direction. It is negatively correlated with carbohydrate intake and is positively correlated with protein intake and fat intake. Third, Internet use is positively associated with dietary knowledge and is positively correlated with time spent exercising. This is only the correlation between the treatment, outcome, and channel variables. After adding relevant control variables and considering the endogenous problems, the relationship between Internet use and nutritional outcomes needs further analysis.

3.2 Determinants of Internet use

The estimation results using ESR model are presented in Table 3. In the analysis of this paper, the instrumental variable corresponding to Internet use is used to better estimate the determinants of such use based on the presence of Internet cafes in the community. rho0 and rho1 indicate that there is a significant correlation between the determinants of the Internet use equations for BMI and overweight and the determinants of BMI and that there is endogeneity, which can be further calculated with the help of ESR model. The Wald test shows that Prob $>$ chi^2 = 0, a result that suggests that Internet use is not an exogenous variable. All the above descriptions suggest that ESR model used in this study can estimate males' health. Furthermore, the counterfactual analysis can calculate the mean treatment effect.

The second and fifth columns of Table 3 report the determinants of Internet use, which are calculated using Eqn. 1. The results show that the coefficient of the age-squared term is negative and significant, indicating an inverted u-shaped distribution of Internet use among males. The positive and significant coefficient of years of education shows that males with higher education are more likely to use the Internet, which is consistent with existing studies [43, 44]. The negative and statistically significant coefficient of marital status indicates that single people are more likely to use the Internet than married people, which may be because single people have a greater willingness to socialise. The Internet provides a broader platform for making friends. The coefficient of current work status is positive and significant, indicating that work increases the likelihood of using the Internet compared to those who do not work. In this information age, the Internet is an essential means of communication, and all kinds of work are becoming more and more closely related to the Internet. The coefficient of urban is positive and significant, indicating that males living in urban areas are more likely to use the Internet compared to those living in rural areas.

The third and fourth columns of Table 3 report the de-

TABLE 2. Correlation matrix for study variables.

	Internet	BMI	Overweight	Energy intake	Carbohydrate	Protein	Fat	Dietary knowledge	Exercise
Internet	1								
BMI	0.106***	1							
Overweight	0.095***	0.802***	1						
Energy intake	−0.095***	−0.003	0.007	1					
Carbohydrate	−0.221***	−0.075***	−0.065***	0.751***	1				
Protein	0.070***	0.069***	0.073***	0.728***	0.507***	1			
Fat	0.095***	0.082***	0.088***	0.628***	0.078***	0.455***	1		
Dietary knowledge	0.266***	0.117***	0.108***	−0.077***	−0.183***	0.028***	0.090***	1	
Exercise	0.162***	0.053***	0.060***	−0.028***	−0.078***	0.053***	0.043***	0.070***	1

*Note: Author's calculations using the CHNS data (2004–2015). ***$p < 0.010$. BMI: body mass index.*

terminants of BMI. The sixth and seventh columns report the determinants of overweight. The results show that the coefficients of age, age squared, education, urban and income are statistically significant for both Internet users and non-users. All the factors with significant coefficients show a positive effect on BMI, except for age, which has a u-shaped impact.

3.3 The effect of Internet use on BMI and overweight

The results in the second column of Table 4 are calculated using Eqn. 4 for the BMI and overweight expectations for males who use the Internet. The values in the third column of Table 4 are determined using Eqn. 5 to obtain estimates of the outcome variables for males who do not use the Internet. The results in the fourth column of Table 4 are calculated using Eqn. 6 for the outcome, the average treatment effect on the treated (ATT). The last column estimates the degree of variation in the outcome variable. The results in Table 3 show that the expectation of BMI for males using the Internet is 24.399, while the expectation of BMI for males not using the Internet is 25.316, with an ATT value of −0.917 and is statistically significant. Therefore, the expectation of BMI is reduced by 3.626% due to Internet use. For males using the Internet the expectation of being overweight is 0.528, while for males not using the Internet the expectation of being overweight is 0.800 and the ATT value is −0.272 and is statistically significant. Thus, the expectation of being overweight is reduced by 33.963% due to the use of the Internet.

3.4 Heterogeneous analysis

The results are estimated separately for the urban and rural samples because of the large differences in Internet infrastructure conditions and economic levels between urban and rural areas of China, which may have different effects on Internet use. The results in Table 5 show the ATT for the outcome variables. Urban males experience a 3.609% reduction in their BMI and a 28.109% decrease in the likelihood of being overweight after using the Internet. Rural males experience a 0.358% reduction in their BMI and a 15.400% decrease in the likelihood of being overweight after using the Internet. It is clear that the impact of Internet use is higher for urban males. Table 5 also reports the extent to which males who have completed nine years of compulsory education or not responded differently with regard to Internet use. Males who have completed 9 years of compulsory education experience a 3.401% reduction in their BMI and a 31.500% decrease in the likelihood of being overweight. In comparison, males who have not completed 9 years of compulsory education experience a 1.020% reduction in their BMI and a 16.410% decrease in the likelihood of being overweight after using the Internet. Internet use more greatly impacts males who have completed nine years of compulsory schooling.

3.5 Channel analysis

Table 6 reports the effects of Internet use on dietary knowledge, energy intake, macronutrient intake and the time spent exercising. These are the four channels used in this study to analyse the effects of Internet use on the nutritional health of males. The estimation results are still calculated using the ESR model and counterfactual analysis. First, the ATT value for dietary knowledge means a 3.068% increase in dietary knowledge for non-Internet users after using the Internet, as calculated by counterfactual analysis. Second, the ATT of energy intake for men indicates that non-Internet users have a 1.211% lower energy intake after using the Internet. Third, the results for macronutrient intake are statistically significant, with a 2.067% decrease in carbohydrate intake, a 2.685% decrease in protein intake and a 12.603% decrease in fat intake. Finally, the ATT of Internet use on exercise time in males is 0.198 and statistically significant, revealing a 61.649% increase in exercise time.

TABLE 3. The Determinants of internet use based on ESR model.

	BMI			Overweight		
Variables	Internet	Internet users	Non-users	Internet	Internet users	Non-users
Age	0.0013 (0.0140)	−0.2028*** (0.0537)	−0.1340*** (0.0337)	−0.0021 (0.0141)	−0.0511* (0.0203)	−0.0420** (0.0139)
Age squared	−1.0088*** (0.2897)	3.6226*** (1.0978)	2.7198*** (0.7345)	−0.9369*** (0.2921)	1.1848** (0.4078)	0.7931** (0.3096)
Education	0.1151*** (0.0054)	0.1348** (0.0505)	0.0931*** (0.0100)	0.1194*** (0.0046)	0.0132 (0.0132)	0.0503*** (0.0052)
Marital status	−0.1089* (0.0571)	0.1518 (0.2228)	0.3459** (0.1343)	−0.1196* (0.0571)	0.1061 (0.0807)	0.0758 (0.0585)
Work	0.1422** (0.0544)	0.3457 (0.2513)	−0.1339 (0.1020)	0.1335* (0.0548)	0.0657 (0.0956)	−0.0558 (0.0430)
Urban	0.5994*** (0.0339)	1.1056*** (0.2971)	0.7013*** (0.0877)	0.5993*** (0.0339)	0.2157** (0.0814)	0.3400*** (0.0382)
Household size	−0.0084 (0.0121)	−0.0005 (0.0505)	−0.0321 (0.0250)	−0.0085 (0.0122)	−0.0094 (0.0197)	0.0008 (0.0108)
Income	0.1583 (0.0172)	0.2292* (0.1018)	0.1512*** (0.0251)	0.1588*** (0.0171)	0.0252 (0.0315)	0.0653*** (0.0117)
Internet café	0.0089** (0.0029)			0.0088** (0.0030)		
Constant	3.3048* (1.5683)	−1.5988 (5.7484)	7.2321* (4.0498)	2.8924* (1.5796)	−7.3468*** (2.1548)	−5.4214** (1.7122)
Year	Yes	Yes	Yes	Yes	Yes	Yes
Province	Yes	Yes	Yes	Yes	Yes	Yes
rho1		0.6597** (0.2417)			0.1510 (0.1899)	
rho0			0.1514*** (0.0291)			0.4501*** (0.0896)
Log pseudolikelihood		−37,591.32		−13,070.13		
Wald test of indep. Eqn	chi^2 (2) = 35.57 Prob > chi^2 = 0			chi^2 (2) = 19.24 Prob > chi^2 = 0		
Obs.	12,846			12,846		

*Note: Author's calculations using the CHNS data (2004–2015). Standard errors are presented in parentheses. *p < 0.10, **p < 0.05, ***p < 0.010. BMI: body mass index.*

TABLE 4. The overall effects of Internet use on nutritional outcomes based on the ESR model.

	Internet users	Non-users	ATT	Change (%)
BMI	24.399 (0.017)	25.316 (0.018)	−0.917*** (0.025)	−3.626
Overweight	0.528 (0.002)	0.800 (0.002)	−0.272*** (0.001)	−33.963

Note: Author's calculations using the CHNS data (2004–2015).
*Standard errors are presented in parentheses. ***p < 0.010.*
ESR: endogenous switching regression model. ATT: average treatment effect on the treated. BMI: body mass index.

TABLE 5. The effect of heterogeneity on BMI and overweight.

Category	BMI				Overweight				
	Internet users	Non-users	ATT	Change (%)	Internet users	Non-users	ATT	Change (%)	Obs.
Urban	24.618 (0.015)	25.540 (0.020)	−0.922*** (0.025)	−3.609	0.562 (0.002)	0.782 (0.002)	−0.220* (0.001)	−28.109	2195
Rural	24.056 (0.035)	24.143 (0.031)	−0.086* (0.047)	−0.358	0.478 (0.004)	0.564 (0.004)	−0.087*** (0.003)	−15.400	1435
Compulsory education	24.618 (0.015)	25.540 (0.020)	−0.869*** (0.026)	−3.401	0.562 (0.002)	0.782 (0.002)	−0.246* (0.002)	−31.500	2587
Non-compulsory education	24.056 (0.035)	24.143 (0.031)	−0.246* (0.002)	−1.020	0.478 (0.004)	0.564 (0.004)	−0.093*** (0.003)	−16.410	1043

*Note: Author's calculations using the CHNS data (2004–2015). Standard errors are presented in parentheses. *p < 0.10, ***p < 0.010.*
BMI: body mass index. ATT: average treatment effect on the treated.

TABLE 6. The impact of Internet use on macronutrient intakes, exercise time and dietary diversity.

Variables	Internet users	Non-users	ATT	Change (%)
Dietary knowledge	8.927 (0.027)	8.661 (0.025)	0.266*** (0.037)	3.068
Energy intake	7.671 (0.002)	7.764 (0.003)	−0.094*** (0.004)	−1.211
Macronutrient intake				
Carbohydrate	5.573 (0.004)	5.691 (0.004)	−0.118*** −(0.005)	−2.067
Protein	4.305 (0.002)	4.424 (0.002)	−0.119*** (0.003)	−2.685
Fat	4.361 (0.002)	4.989 (0.003)	−0.629* (0.004)	−12.603
Exercise	0.520 (0.005)	0.322 (0.003)	0.198*** (0.006)	61.649

Note: Author's calculations using the CHNS data (2004–2015).
*Standard errors are presented in parentheses. *p < 0.10, ***p < 0.010.*
ATT: average treatment effect on the treated.

4. Discussion

This contribution of Internet use to dietary knowledge in males is consistent with the findings of existing studies. It has been shown that Internet use has a significant positive impact on the health of males in rural China, improving the quality of their diet [45, 46]. Some college students actively access health-related information on the Internet [47]. When Internet users have a higher level of dietary knowledge, they will, at the same time, pay more attention to the healthiness of their dietary practices. This healthy food intake is reflected in a healthier intake of macronutrients and less overconsumption. Existing studies focus on the fact that longer leisure-time Internet use leads to longer sedentary activities, which can lead to "sedentary disease", resulting in a higher BMI and the increased likelihood of being overweight [15, 48]. These studies have only focused on developed countries (*e.g.*, the United States and Australia) and not on populations in developing countries, especially not China. According to the available studies, leisure time and leisure time physical activity (LTPA) among the Chinese have not always been on the rise, with Nan noting that the average leisure time in some major Chinese cities fell to 2 hours in 1990, almost half the 1986 level [49]. Zou pointed out that the age-standardised LTPA prevalence among Chinese adults aged 18 and beyond increased from 7.13% in 2000 to 11.79% in 2011 and then declined to 7.33% in 2015 [50]. So, there is also no evidence that Internet use leads to an overall increase in leisure sedentary time among adults. In contrast, the results of this study show that adult men who use the Internet spend more time exercising than males who do not use the Internet, suggesting that increased exercise time is an important channel through which Internet use reduces BMI and overweight in males.

The main contributions are as follows. First, ESR model is applied to the topic of the impact of Internet use on nutritional outcomes to address the possible issues of the samples not being randomly distributed and of unobservable factors leading to biased estimates. Second, counterfactual analyses estimate that Internet use reduces BMI levels by approximately 3.6% and the likelihood of being overweight by about 34% in Chinese males. Third, for the first time, the impact of Internet use on nutritional outcomes is analysed in urban and rural areas and for males with different levels of education. The results reveal that urban areas are more affected than rural areas and that males with higher levels of education are more affected than males with lower levels of education. Fourth, the mechanisms through which Internet use reduces BMI and overweight are analysed for the first time.

The limitations of this study lie in two areas. On the one hand, it is due to the limitation of data timeliness, the sample only includes information up to 2015. From 2015 to the present, China's internet infrastructure has been greatly improved and the gradual rise of short-form video software has gradually lowered the threshold of internet use, allowing the internet to increase its level of influence on people. With recent research data, it would be possible to study the current impact of the internet on people in more detail and with greater accuracy. On the other hand, there are a large number of missing observations in the surveys of various types of internet use activities and the corresponding hours of use. Therefore, this study is unable to explore the effect of different uses and duration of the Internet use on BMI and overweight. Further exploration is needed in future studies.

5. Conclusions

This study estimates the effect of Internet use on males' health and dietary knowledge using data from the CHNS for the five periods of 2004, 2006, 2009, 2011 and 2015 and based on a total valid sample size of 12,846. This study applied the ESR model to address bias due to observable and unobservable factors while also grappling with the endogeneity of Internet use as a behaviour that causes the inconformity of the sample to a random distribution.

The results show that Internet use leads to a significant reduction in BMI and a significant decrease in the likelihood of being overweight in males. Regarding rural and urban differences, Internet use significantly reduces BMI levels for urban and rural males, with a somewhat larger effect for urban males. In terms of the completion of compulsory education, Internet use results in a significant reduction in BMI levels and the likelihood of being overweight in males, regardless of whether they completed nine years of compulsory education or not, but it has a greater impact on males who have completed nine years of compulsory schooling. The analysis of the mechanisms of Internet use on BMI and overweight in males through four channels shows that Internet use significantly increases dietary knowledge, reduces energy intake and macronutrient intake and increases the time spent exercising.

Overweight and obesity in males are increasingly becoming a significant part of public health expenditure, and the question of reducing BMI and promoting healthy eating in males has become a topical issue. This article can provide effective ways to reduce the expenditure by analysing the impact of Internet use on BMI and overweight in males. Studies have used the Internet to promote weight or waist circumference loss with good results by sending emails or targeting information about weight loss programmes through software [18, 51, 52]. The significance of this study is the confirmation of the role of this behaviour of Internet use on the increased dietary knowledge of adult males and the resulting reduction in energy intake and macronutrient intake, increase in exercise time. Efforts should be made to continue the positive and active role of the Internet in knowledge diffusion and information dissemination to disseminate correct dietary knowledge and healthy eating practices to a wider population through more effective methods.

AVAILABILITY OF DATA AND MATERIALS

The data presented in this study are available on reasonable request from the corresponding author.

More information, see https://www.cpc.unc.edu/projects/china.

AUTHOR CONTRIBUTIONS

YJR—Study Design. WGL—Data Analysis, Writing Original Draft. JL, YJR, JPL and WGL—Manuscript Review and Editing. All authors have read and agreed to the published version of the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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