Body Weight and Depression: A Simultaneous Equation Approach

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Abstract

Obesity and depression are two major public health concerns that involving a huge population around the world. This study investigates the mutual causality relation between obesity and depression for both males and females. Data for this study are drawn from the 2013 Behavioral Risk Factor Surveillance System (BRFSS), and an ordered probability simultaneous equation system is developed to accommodate the ordinal nature of body weight categories and its relation to depression. Results suggest body weight is positively associated with the risk to be depressed while depression in return, has positive effects on body weight for both males and females, and females are more sensible to the effects of depression on body weight. In addition, socio-demographic factors are found to vary significantly between gender, and factors of age, income, race, education, employment, marriage and health status play important roles in affecting body weight.

Introduction

Obesity and depression are two major public health concerns that involving a huge population around the world. According to the World Health Organization (WHO), over 350 million people of all ages suffered from depression during 2012 in all regions of the world (WHO 2012), and it is estimated that 1 out of 20 people reported having an episode of depression in the previous year worldwide (Kessler et al. 2008). Obesity is a pressing public health concern because it raises the risk of a series of diseases such as, hypertension, dyslipidemia, type 2 diabetes, coronary heart disease, stroke, gallbladder disease, osteoarthritis, sleep apnea and respiratory problems, and endometrial, breast, prostate, and colon cancers (National Institute of Health 1998). In 2014, more than 1.9 billion adults were overweight all over the world and over 600 million of these were obese (WHO 2015). In the U.S., more than one-third of adults and 17% of children were obese during 2011–2012 (Ogden et al. 2014).

Obesity is found to associate with not only physical diseases but also mental disorders, such as mood disorder, major depressive disorder and anxiety disorder (Scott et al. 2008). The nature of how obesity impact mental disorders in the general population is not well understood, but some studies suggest depressive symptoms may be caused by negative body image which is the result of obesity (e.g. Ross 1994; Roberts et al. 2003). Considering depression, previous studies suggest that depression may impact body weight, for instance through changing eating patterns or physical activity level (e.g. Richardson et al. 2003). Although obesity and depression problems are fully studied separately around the world, most existing studies either concentrate on clinic research with limited samples or exclude important socio-demographic factors. More importantly, few studies have taken consideration of the mutual causality relation between obesity and depression.

Previous studies suggest obesity is associated with mental problems and evidence has been found that obese people are more likely to be depressed (e.g. Onyike et al. 2003; Simon et al. 2008; Scott et al. 2008; Jokela et al. 2012). Onyike et al. (2003) find that the prevalence of depression is highest among persons with sever obesity with data from the Third National Health and Nutrition Examination Survey. Jokela et al. (2012) apply an instrumental variable regression to examine the association of adolescent and adult body mass index (BMI) with

adult depressive symptoms. Their results suggest a strong association between depression and obesity is increasing the risks of depressive symptoms. With national representative data from New Zealand, Scott et al. (2008) use moderators of ethnicity, age, gender and education to study the association between mental disorders and obesity in general population. They find obesity prevalence does not differ a lot across gender and obesity is related to depressive disorder.

In addition to the effects of obesity on depression, previous research also provides evidence that depression may impact obesity. Barefoot et al. (1998) use the 20-year follow-up data to examine the effect of depression on the weight changes in the future. With results from multiple regression models they find depressed people gained less weight than their non-depressed counterparts if they were initially lean, but more if they were initially heavy. Blaine (2008) uses a similar longitudinal approach to test the effect of depression on adults' and adolescents' follow-up body weight. The results suggest compared with non-depressed counterparts, depressed individuals are at higher risk for developing obesity, and the risk is particularly high for adolescent females.

Gender difference has significant effect on body weight and depression, and previous literature has provided strong evidence that women are more likely to be depressed than men (e.g. Kessler et al. 1993; Zhang and Yen 2015), and obesity more likely to be associated with depression in women than men (e.g. Onyike et al. 2003; Carpenter et al. 2000; Wit et al. 2010). Wit et al. (2010) conduct a meta-analysis of cross-sectional studies in a large population to investigate the effects of underlying socio-demographic factors on obesity and depression. They find a significant positive association between depression and obesity in general population and a stronger association among women. Focusing on middle-aged women in the U.S., Simon et al. (2008) find that the prevalence of depression is more than twice as great among women with BMI of 30 or more compared to those with BMI less than 30. In addition, they find a mutual causality relation between depression and obesity: increasing severity of depression is strongly associated with higher risk of obesity and increasing BMI is strongly associated with higher risk of depression.

Data

Our data are drawn from the latest 2013 Behavioral Risk Factor Surveillance System (BRFSS) collected by state health departments in collaboration with the Centers for Disease Control (CDC). The BRFSS is a state-based system of health surveys that collects information on health risk behaviors. In the 2013 BRFSS, no indicators for current depressive symptoms are provided, so we combine two questionnaire items and create a proxy to indicate current depressive symptoms indirectly. These items are '(Ever told) you that you have depression?', and 'How many days during the past 30 days was your mental health not good?' According to the responses from these two questions, we create a binary proxy to indicate current depression. The value of depression equals 1 if individual responds 'Yes' to the first question and '> 0' to the second question; the value of depression equals 0 if individual responds 'No' to the first question and '0' to the second question. The Body Mass Index (BMI) is considered an ideal measure for body weight, and to investigate the different effects of depression on underweight, normal weight, overweight and obese individuals, we use the four-categories of BMI provided by the survey, with values ranging from 1 (underweight) to 4 (obese). After removing missing values for important variables, the study sample is restricted to individuals age >18 with a sample size of 44,502, which includes 20,457 males and 24,045 females. The frequency distribution of depression and body weight across gender is presented in table 1.

Table 2 presents definitions and sample statistics of explanatory variables used in this paper. Socio-demographic variables include age, income, race, education, number of children, and dummy variables indicating home ownership, employment status, and marital status. In addition, individual's health status is posited to affect depression. Three dummy variables indicating 'very good or excellent', 'good' and 'poor' self-reported health status taken as factors that affect depression but not body weight. In terms of body weight, drinking frequency of sugar-sweetened beverages and previous high blood pressure record are assumed to contribute[1]. The measurement for drinking frequency of sugar-sweetened beverages is coded from the BRFSS questionnaire 'During past 30 days, how often did you have sugar-sweetened

[1]Obese people usually have high blood pressure, thus if the individual has high blood pressure record it is very likely that the individual was obese in the past. Here we assume past body weight correlates with current body weight, and high blood pressure record can be taken as a proxy for past body weight.

drinks?' and the measurement for high blood pressure is a dummy variable which equals 1 if the individual has ever been told to have high blood pressure by a doctor, nurse or health professional in the past. Physical activity is generally believed to affect body weight and alleviate depressive symptoms. A dummy variable is used to differentiate regular exercisers and seldom exercisers (individuals who do physical activity no less than 15 times during last 30 days are regarded as regular exercisers), which is consistent with Zhang and Yen (2015).

Econometric Procedure

A two-equation simultaneous system is developed to deal with the mutual effects of ordinal body weight category (y_1) and binary depression (y_2). The model is characterized by two structural equations for corresponding latent variables y_1^* and y_2^*

$$y_1^* = \gamma_1 y_2^* + x'\alpha_1 + z'\alpha_2 + u_1 \tag{1}$$

$$y_2^* = \gamma_2 y_1^* + x'\beta_1 + w'\beta_2 + u_2 \tag{2}$$

where x, z and w are vectors of exogenous variables with conformable parameters of α_1, β_1, α_2 and β_2; γ_1 and γ_2 are scalar parameters, and the error terms are assumed to be bivariate normal distributed with zeros means and unitary variances, correlation ρ and covariance matrix:

$$\begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \sim \mathcal{N}\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & \rho \\ \rho & 1 \end{bmatrix} \right) \tag{3}$$

The variance of u_1 and u_2 are assumed to be unitary because y_1 is ordinal outcome with only unit increment in each category and y_2 is a binary variable. The reduced-form equations are

$$y_1^* = x'\Pi_{11} + z'\Pi_{12} + w'\Pi_{13} + v_1 \tag{4}$$

$$y_2^* = x'\Pi_{21} + z'\Pi_{22} + w'\Pi_{23} + v_2 \tag{5}$$

where Π_{11}, Π_{12}, Π_{13}, Π_{21}, Π_{22} and Π_{23} are functions of the structural parameters in equation (4) and (5), and the composite error vector $v = [v_1, v_2]'$ is distributed as a bivariate normal with zero

means, correlation τ, standard deviations ω_1 and ω_2, and covariance matrix:

$$\begin{bmatrix} v_1 \\ v_2 \end{bmatrix} \sim \mathcal{N}\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \omega_1^2 & \omega_1\omega_2\tau \\ \omega_1\omega_2\tau & \omega_2^2 \end{bmatrix} \right) \tag{6}$$

Be more specific, we have $\omega_1^2 = (1+\gamma_1^2+2\rho\gamma_1)/(1-\gamma_1\gamma_2)^2$, $\omega_2^2 = (1+\gamma_2^2+2\rho\gamma_2)/(1-\gamma_1\gamma_2)^2$ and $\tau = [\gamma_1+\gamma_2+(1+\gamma_1\gamma_2)\rho] \Big/ \sqrt{(1+\gamma_1^2+2\rho\gamma_1)(1+\gamma_2^2+2\rho\gamma_2)}$.

Based on the reduced form of equation (4) and (5), the model with ordinal outcome y_1 and binary outcome y_2 is characterized as

$$y_1 = k \quad \text{if} \quad \xi_{k-1} < y_1^* < \xi_k, \quad k = 0 \ldots K \tag{7}$$

$$\begin{aligned} y_2 &= 1 \quad \text{if} \quad y_2^* > 0 \\ &= 0 \quad \text{if} \quad y_2^* \le 0 \end{aligned} \tag{8}$$

where ξ_k is threshold parameter such that $\xi_0 = -\infty, \xi_1 = 0, \xi_K = \infty$, and $\xi_2 \ldots \xi_{K-1}$ are estimable.

Maddala (1983) suggests a two-step estimation of such simultaneous equation system. Although estimates of the two-step procedure are consistent, efficiency cannot be guaranteed. To overcome the shortcoming of two-step estimator, we develop a more efficient full information maximum-likelihood (FIML) procedure.

Before constructing the likelihood contribution for the sample observation, first define $\psi\Pi_1 = x'\Pi_{11} + z'\Pi_{12} + w'\Pi_{13}$ and $\psi\Pi_2 = x'\Pi_{21} + z'\Pi_{22} + w'\Pi_{23}$, where $\psi = [x', z', w']$. Given

$$\begin{aligned} \Pr(y_1 = k, y_2 = 0) &= \int_{-\infty}^{-\psi\Pi_2} \int_{\xi_{k-1}-\psi\Pi_1}^{\xi_k - \psi\Pi_1} f(v_1, v_2)\, dv_1 dv_2 \\ \Pr(y_1 = k, y_2 = 1) &= \int_{-\psi\Pi_2}^{\infty} \int_{\xi_{k-1}-\psi\Pi_1}^{\xi_k - \psi\Pi_1} f(v_1, v_2)\, dv_1 dv_2 \end{aligned}, \tag{9}$$

the joint probability of each body weight category and depression status is

$$\begin{aligned} \Pr(y_1 = k, y_2 = j) = &\Phi_2\left(\frac{\xi_k - \psi\Pi_1}{w_1}, \frac{(-1)^{j+1}\psi\Pi_2}{w_2}; (-1)^j \tau \right) \\ &- \Phi_2\left(\frac{\xi_{k-1} - \psi\Pi_1}{w_1}, \frac{(-1)^{j+1}\psi\Pi_2}{w_2}; (-1)^j \tau \right) \end{aligned}, \tag{10}$$

where $\Phi_2(x, y; \rho) = \Pr(X \le x, Y \le y)$ is a bivariate standard normal cumulative function (CDF)

with correlation ρ. The sample likelihood function for an independent sample is the product of (10) over the sample observations.

To facilitate interpretation of the effects on explanatory variables, marginal effects of explanatory variables on the probabilities of depression and body weight are calculated. Specially, for each individual, the probability to be depressed or non-depressed is

$$\Pr(y_2 = j) = \Phi_1\left(\frac{(-1)^{j+1}\psi\Pi_2}{w_2}\right), \quad j = 0,1 \tag{11}$$

where $\Phi_1(\cdot)$ is a standard normal cumulative function (CDF). Marginal effects of each continuous (binary) explanatory variable can be derived by differentiating (differencing) equations (10)–(11). In addition, to better gauge the effect of depression on each body weight category, we also estimate the average treatment effect of depression, which is

$$TE_k = \Pr(y_1 = k \,|\, y_2 = 1) - \Pr(y_1 = k \,|\, y_2 = 0), \qquad k = 1,...,K \tag{12}$$

For statistical inference, standard errors of the marginal and treatment effects can be derived by the delta method.

Results and Discussion

Before further discussion of the empirical results, statistical tests are performed to evaluate suitability of the gender equality, viz., that all parameters are equal between men and women. This is carried out with a Likelihood Ratio (LR) test, which is similar to Chow test in linear regression models. Specifically, define the log-likelihood values for the male, female, and pooled sample samples as $\log L_m, \log L_f$, and $\log L_p$, with corresponding numbers of parameters k_m, k_f, and k_p. Then, under the null hypothesis that parameters are equal across genders, the test statistics $LR = 2(\log L_m + \log L_f - \log L_p)$ is Chi-square distributed with $k_m + k_f - k_p$ degrees of freedom (*df*). For the simultaneous equation system, the hypothesis of equal slope coefficients between male and female samples is rejected (*LR* = 1235.5, *df* = 51, *p*-value < 0.001), which suggests separate estimation of the male and female samples. Since using a gender dummy variable alone cannot adequately accommodate the gender differences in

depression and body weight, further analyses are based on the gender separated samples.

The full information maximum likelihood estimates for male and female samples are presented in table 3. All threshold parameter estimates are positive and significant at the 1% level of significance or lower for both male and female samples, which suggest that the ordered probability simultaneous equation system is successful in delineating the body weight categories for depressed and non-depressed individuals. The error correlation estimates between the depression equation and body weight equation are both negative and significant at the 1% level or lower (–0.687 for men and –0.586 for women), which suggest the unobservable characteristics affect depression and body weight in the reverse direction. The negative error correlation estimate is consistent with Costa-Font and Gil (2006).

For both men and women, the endogenous depression has a positive and significant coefficient in the body weight equation (0.446 for men and 0.482 for women), while body weight also has a positive and significant coefficient in the depression equation (0.341 for men and 0.204 for women). These positive associations between depression and body weight suggest depressed individuals are more likely to be obese and obese people have higher risks to be depressed on average.

Of the 24 variables in the depression equation, 13 variables, excluding coefficient of body weight, are significant at the 10% level for males, while 20 variables are significant for females. Two dummy variables indicating health status are significant in the depression equation at the 1% level of significance in both male and female samples, rejecting the hypothesis of weak instrument and justifying use of the variable as an identification variable. Of the 24 variables in the body weight equation, excluding coefficient of depression, there are 15 variables significant at the 10% level for males and 20 variables significant for females. The dummy variable indication high blood pressure record is positive and significant both men and women justifying the use of identification. The estimates also differ greatly among men and women, in terms of signs, magnitudes, and statistical significance. To further exploit effects of depression and explanatory variables on different category of body weight, average treatment effects and marginal effects of explanatory variables are discussed below.

Average Treatment Effects of Depression on Body Weight

Since one of the primary purposes of this study is to investigate the effects of depression on different body weight categories, average treatment effects (ATE) are calculated to quantitatively describe such effects. ATE results for males and females are presented in table 4 and table 5 respectively. For males, none of these ATEs are significant, which suggest depression does not affect men's body weight. This finding is partially consistent with Onyike et al. (2003) and Carpenter et al. (2000), who find obesity is associated with depression in women but not men. In terms of females, ATEs are significant for all 4 body weight categories, which suggest depression indeed affect women's body weight statistically. According to the results of ATEs, for a randomly selected female individual, a depressed woman has 0.45% and 3.41% lower probabilities to be underweight and normal weight than a non-depressed woman. For a randomly selected female individual, a depressed woman has 0.68% and 3.18% higher probabilities to be overweight and obese than a non-depressed woman. In terms of body weight categories, depressed women are at highest risks of being obese, this finding is consistent with Blaine (2008).

Marginal Effects of Explanatory Variables for Males

Marginal effects on the joint probabilities of depression and body weight categories for males are presented in table 6. Age plays different roles in affecting body weight between non-depressed and depressed males. Among non-depressed males, a 10-year increase in age is associated with 0.13%, 2.88% and 1.15% increases in the probabilities to be underweight, normal weight and overweight, while among depressed males, a 10-year increase in age is associated with 0.02%, 0.41% and 0.86% decreases in the probabilities to be underweight, normal weight and overweight. As expected, income plays a role in affecting body weight for both non-depressed and depressed males. The marginal effects of income on the probabilities of all body weight categories are negative, which suggest that higher income decreases body weight of all categories; thus, poor males are more likely to heavier than rich males in each body weight category. For non-depressed males, income plays reverse roles in lean and heavy males. Specially, one category increase in income decreases the probabilities to be underweight and normal weight by 0.05% and 0.69%, while increases the probabilities to be overweight and

obese by 0.30% and 1.1%.[2]

The sign of exercise is as expected for underweight and obese man, but the magnitude is small. Race plays a role in affecting some body weight categories among non-depressed and depressed males. Comparing to non-depressed males of other race, black males have 0.23% and 3.63% lower probabilities to be underweight and normal weight, and 5.02% higher probabilities to be obese, which suggest black non-depressed males are more likely to be obese. However, white and Hispanic depressed males are more likely to be overweight and obese. Specially, comparing to depressed males of other race, depressed white (Hispanic) males have 1.86% and 1.37% (1.72% and 2.08%) higher probabilities to be overweight and obese.

Education affects non-depressed and depressed males differently, comparing to non-depressed males only with high school diploma, males with bachelor's degree have 0.33% and 4.42% higher probabilities to be underweight and normal weight, and 1.92% and 6.67% lower probabilities to be overweight and obese, but their depressed counterparts have 0.07%, 1.61%, 1.79% and 0.38% higher probabilities to be underweight, normal weight, overweight and obese. Employment status does not have a significant effect on body weight for both non-depressed and depressed males. Particularly, comparing to depressed male home maker, depressed males who are unable to work have 3.4%, 6.55% and 4.46% higher probabilities to be normal weight, overweight and obese.

Home ownership has a reverse effect on non-depressed males and depressed males. Home ownership increases the probabilities to be overweight and obese by 1.36% and 1.32% among non-depressed males while decreases the probabilities to be overweight and obese by 1.35% and 0.80% among depressed males. In terms of marital status, it plays more roles in affecting non-depressed males than depressed males on their body weight. Comparing to single non-depressed males, married males have 0.31% and 4.06% lower probabilities to be underweight and normal weight and 1.76% and 5.77% higher probabilities to be overweight and obese, which suggest non-depressed married males are more likely to be obese. In addition, divorced and widowed males contribute similarly to their body weight as married males.

Self-reported health status is key determinant in affecting body weight, and very good

[2] Income in this study in divided into categories from 1 to 8.

health dummy and poor health dummy play reverse roles in affecting body weight. Comparing to non-depressed males with good health status, males with very good or excellent (poor) health status have 0.38%, 7.48% and 3.34% (0.28%, 5.77% and 3.10%) higher (lower) probabilities to be underweight, normal weight and overweight, and 4.04% (2.86%) lower (higher) probabilities to be obese. These results suggest non-depressed males with very good or excellent health status are less likely to be obese while non-depressed males with relative poor health status are more likely to be obese. Drinking habit for sugar-sweetened beverages plays roles in affecting body weight, but the signs are ambiguous and magnitudes are small. High blood pressure record has expected signs in affecting body weight and greater magnitudes among non-depressed males. In particular, high blood pressure record in the past associates with 0.68%, 12.88% and 1.53% decreases in the probabilities to be underweight, normal weight and overweight, and 12.78% higher probability to be obese among non-depressed males.

Marginal Effects of Explanatory Variables for Females

Table 7 presents the marginal effects on the joint probabilities of depression and body weight categories for females. There are more factors affecting body weight of non-depressed and depressed females than males. Similar to results for males, age is negatively associated with all body weight categories among depressed females, but positively associates with all body weight categories except for obese category among non-depressed females. For non-depressed (depressed) females, a 10-year increase in age is associated with 0.53%, 4.64% and 0.96% (0.06%, 1.43% and 1.53%) increases (decreases) in the probabilities to be underweight, normal weight and overweight. Income has the similar effects on depressed females as depressed males which is negatively associated with all body weight categories, but compared to non-depressed males, income has reverse effects on underweight and normal weight females. Richer females without depressive symptoms are more likely to be underweight, normal weight and overweight, specially, one category increase in income increases the probabilities to be underweight and normal weight and overweight by 0.10%, 1.00% and 0.29% among non-depressed females.

Exercise also affects females similarly with males. The effects of exercise are not significant due to small magnitude, and exercise contributes most to normal weight category

among non-depressed females which is as expected. Race has a sound effect on both non-depressed and depressed females, especially among non-depressed black females. Comparing to non-depressed females of other race, black females have 1.12% and 9.69% lower probabilities to be underweight and normal weight, and 3.30% and 13.19% higher probabilities to be overweight and obese, which suggest non-depressed black females have relative high risks to be obese. Non-depressed white females are less likely to be normal weight or overweight but depressed white females are more likely to belong to all weight categories comparing to females of other race. For non-depressed Hispanic females, they are less likely to be underweight and normal weight but more likely to be obese. In particular, comparing to non-depressed females of other race, non-depressed Hispanic females have 0.63% and 5.46% lower probabilities to be underweight and normal weight and 4.05% higher probability to be obese.

Education has different effects on non-depressed and depressed females, comparing to non-depressed females only with high school diploma, non-depressed (depressed) females with some college education have 1.50%, 1.35% and 1.18% (1.51%, 1.35% and 1.18%) lower (higher) probabilities to be normal weight, overweight and obese. Non-depressed females with higher education are less likely to be obese and more likely to be thin. Specially, non-depressed females with bachelor's degree have 0.52% and 2.00% higher probabilities to be underweight and normal weight, and 2.90% and 5.13% lower probabilities to be overweight and obese compared with females only with high school diploma. Unlike males, employment status has sound effects on body weight for both non-depressed and depressed females. Comparing to non-depressed female home makers, employed females are 0.18% less likely to be underweight, and 0.84% and 1.63% more likely to be overweight and obese. But for depressed employed females, they are 0.05%, 0.89% and 0.48% less likely to be underweight, normal weight and overweight compared with depressed female home makers. In terms of unemployed females, non-depressed (depressed) females have 3.64%, 2.69% and 2.02% (3.01%, 2.82% and 2.61%) lower (higher) probabilities to be normal weight, overweight and obese comparing to their home maker counterparts.

To be consistent with males, home ownership has a reverse effect on non-depressed and depressed females. Home ownership increases (decreases) the likelihood to be underweight,

normal weight, overweight and obese by 0.20%, 2.82%, 1.55% and 0.79% (0.05%, 1.72%, 1.77% and 1.81%) for non-depressed (depressed) females. Considering marital status, it affects males and females differently. Comparing to single non-depressed (depressed) females, married females have 0.30% (0.04%) more likely to be underweight and 1.66% (0.66%) less likely to be obese, suggesting married females tend to be thin while it is not the case for married males. For non-depressed divorced and widowed females, they contribute similarly to their body weight as their married counterparts.

Self-reported health status is again a key determinant in affecting body weight, and its effects are even greater on females than males. Comparing to non-depressed females with good health status, females with very good or excellent health status have 1.10%, 12.49% and 3.15% higher probabilities to be underweight, normal weight and overweight, and 2.70% lower probabilities to be obese. For depressed females with very good or excellent health status, they are 3.11%, 4.86% and 6.07% less likely to be normal weight, overweight and obese. These results suggest females with very good or excellent health status are less likely to be obese. High blood pressure record has expected signs and similar effects on females as on males. Non-depressed (depressed) females with high blood pressure record have 1.59% and 14.29% (0.21% and 2.71%) lower probabilities to be underweight and normal weight, and 1.84% and 11.70% (0.65% and 4.60%) higher probabilities to be overweight and obese.

Concluding Remarks

This paper examines the mutual causality relation between depression and body weight for males and females using data from a large national sample of the general population in the U.S. Categorical BMI is used to better differentiate body weight groups and an ordered probability simultaneous equation system is develop to address the categorical BMI and mutual causality relation between depression and body weight. Our primary finding is that body weight is positively associated with the risk to be depressed while depression in return, has positive effects on body weight for both males and females, and females are more sensible to the effects of depression on body weight. This study is among the first to evaluate the mutual causality relation between body weight and depression across major socio-demographic factors with

large national representative data. The findings of this study can inform policy makers and doctors who are concerned about depression and obesity issues. We find depressed females are more likely to be overweight and obese, and the probabilities to be overweight and obese are high among less educated, race of black, poor health status and those who had high blood pressure record. While this paper represents one of the first attempts to investigate mutual effects between depression and body weight, further studies might consider the use of longitudinal data and investigate these issues among various sub-population, such as teenagers, minorities, and the disabled.

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Table 1

Frequency distribution of depression and body weight categories

	Body weight category				
Depression	Under	Normal	Over	Obese	Total
			Male		
Non-depressed	116	4984	8480	4793	18373
Depressed	24	529	840	691	2084
Total	140	5513	9320	5484	
			Female		
Non-depressed	332	8072	6200	4411	19015
Depressed	100	1629	1494	1807	5030
Total	432	9701	7694	6218	

Table 2

Definitions and sample statistics of variables in male and female samples [a]

Variable	Definitions	Male	Female
Endogenous variables			
Body Weight	Ordinal indicator of body mass index, ranging from 1 to 4	2.98	2.82
		(0.75)	(0.84)
Depression	Have depressive symptoms or not	0.10	0.21
Continuous explanatory variables			
Age	Age in years	54.04	55.09
		(16.02)	(15.64)
Income	Annual household income level from 1 to 8	6.36	5.89
		(1.93)	(2.14)
No. Children	Number of children in household age < 18	0.55	0.57
		(1.07)	(1.06)
No. Sugar drinks	The number of times to have sugar-sweetened drinks	9.41	6.43
	during the past 30 days	(24.27)	(21.78)
Binary explanatory variables (yes = 1, no = 0)			
Exercise	Do physical activity ≥15 times during last 30 days	15.96	16.03
White	Race is White	0.86	0.82
Black	Race is Black	0.09	0.13
Hispanic	Race is Hispanic	0.03	0.03
Other race	Other race (Reference)	0.02	0.02
Base	Do not have high school diploma	0.02	0.05
High school	Has a high school diploma or GED (reference)	0.24	0.25
Some college	Has some college but not a Bachelor's degree	0.25	0.28
College degree	Has a Bachelor's degree or above	0.46	0.43
Employed	Employed	0.61	0.51
Unemployed	Unemployed	0.05	0.04
Retired	Retired	0.28	0.27
Student	Student	0.02	0.02
Unable	Unable to work	0.04	0.06
Homemaker	Homemaker (reference)	0.003	0.10
Home owner	Home owner	0.80	0.80
Married	Married	0.64	0.53
Divorced	Divorced	0.11	0.15
Widowed	Widowed	0.05	0.15
Separated	Separated	0.01	0.02
Single	Single (reference)	0.17	0.15
High blood pressure	Have been told by a doctor that have high blood pressure	0.40	0.36
Very good health	Self-report very good and excellent health status	0.60	0.61

Good health	Self- report good health status (reference)	0.28	0.27
Poor health	Self-report poor health status	0.11	0.12
Sample size		20457	24045

[a] Standard deviations are in parentheses. Income is the annual household income reported as categories from 1 to 8: 1 = less than $10,000, 2= $10,000 to $15,000, 3= $15,000 to $20,000, 4= $20,000 to $25,000, 5= $25,000 to $35,000, 6= $35,000 to $50,000, 7= $50,000 to $75,000, and 8= $75,000 or more.

Table 3

Full Information Maximum-likelihood estimation of simultaneous equation system [a]

	Male		Female	
Variable	Depression	Body Weight	Depression	Body Weight
Depression ($\gamma 1$)		0.446 (0.030)***		0.482 (0.021)***
Body weight ($\gamma 2$)	0.341 (0.061)***		0.204 (0.049)***	
Constant	–1.252 (0.257)***	1.181 (0.177)***	–1.079 (0.144)***	1.495 (0.109)***
Age/10	0.016 (0.071)	0.488 (0.044)***	0.276 (0.057)***	0.383 (0.040)***
$Age^2/1000$	–0.136 (0.073)*	–0.459 (0.045)***	–0.454 (0.057)***	–0.328 (0.041)***
Exercise	–0.000 (0.001)	–0.003 (0.001)***	–0.004 (0.001)***	–0.003 (0.001)***
Income	–0.049 (0.008)***	0.047 (0.006)***	–0.050 (0.007)***	0.007 (0.006)
No. Children	0.007 (0.014)	–0.005 (0.010)	–0.021 (0.011)*	0.008 (0.009)
White	0.283 (0.086)***	–0.079 (0.060)	0.400 (0.072)***	–0.149 (0.056)***
Black	–0.167 (0.095)*	0.194 (0.066)***	–0.337 (0.080)***	0.519 (0.060)***
Hispanic	0.175 (0.109)	0.067 (0.079)	0.032 (0.091)	0.145 (0.072)**
< High school	0.039 (0.057)	–0.058 (0.041)	–0.008 (0.050)	–0.057 (0.038)
Some college	0.207 (0.036)***	–0.088 (0.026)***	0.167 (0.029)***	–0.080 (0.023)***
College degree	0.305 (0.036)***	–0.292 (0.024)***	0.259 (0.029)***	–0.257 (0.023)***
Employed	–0.289 (0.203)	0.220 (0.135)	–0.072 (0.037)**	0.079 (0.030)***
Unemployed	0.220 (0.208)	–0.034 (0.140)	0.319 (0.055)***	–0.137 (0.045)***
Retired	–0.197 (0.205)	0.197 (0.137)	–0.059 (0.044)	0.102 (0.034)***
Student	–0.006 (0.218)	–0.010 (0.150)	0.162 (0.080)**	–0.230 (0.065)***
Unable	0.639 (0.208)***	–0.247 (0.142)*	0.737 (0.054)***	–0.417 (0.049)***
Home owner	–0.184 (0.034)***	0.095 (0.025)***	–0.206 (0.028)***	0.071 (0.023)***
Married	–0.252 (0.040)***	0.250 (0.029)***	–0.002 (0.034)	–0.064 (0.027)**
Divorced	0.028 (0.047)	0.083 (0.035)**	0.218 (0.038)***	–0.196 (0.031)***
Widowed	–0.045 (0.071)	0.123 (0.049)**	0.080 (0.044)*	–0.114 (0.034)***
Separated	0.223 (0.089)**	–0.074 (0.068)	0.250 (0.070)***	–0.199 (0.058)***
Very good health	–0.367 (0.035)***		–0.490 (0.028)***	
Poor health	0.290 (0.034)***		0.345 (0.029)***	
No. Sugar drinks		–0.001 (0.000)*		0.001 (0.960)
High blood pressure		0.359 (0.024)***		0.427 (0.021)***
$\mu 2$, $\xi 2$		1.780 (0.040)***		1.839 (0.029)***
$\mu 3$, $\xi 3$		2.951 (0.054)***		2.687 (0.038)***
ρ		–0.687 (0.050)***		–0.586 (0.043)***
Log likelihood	–26969.178		–36115.423	

[a] Asymptotic standard errors are in parentheses. Asterisks indicate levels of significance: *** = 1%, ** = 5%, *= 10%.

Table 4

Average treatment effects of depression on the probabilities of body weight categories for males

Body Weight Category	ATE
Underweight (BMI = 1)	0.028 (0.058)
Normal Weight (BMI = 2)	0.421 (0.875)
Overweight (BMI = 3)	0.016 (0.039)
Obese (BMI = 4)	–0.433 (0.089)

Note: Asymptotic standard errors in parentheses. *** 1%, ** 5%, * 10%. All marginal effects and standard errors are multiplied by 100.

Table 5

Average treatment effects of depression on the probabilities of body weight categories for females

Body Weight Category	ATE
Underweight (BMI = 1)	–0.450 (0.081)***
Normal Weight (BMI = 2)	–3.410 (0.639)***
Overweight (BMI = 3)	0.684 (0.116)***
Obese (BMI = 4)	3.180 (0.604)***

Note: Asymptotic standard errors in parentheses. *** 1%, ** 5%, * 10%. All marginal effects and standard errors are multiplied by 100.

Table 6

Marginal effects of explanatory variables on joint probability of depression and body weight categories for male sample

	Non-depressed and				Depressed			
Variable	Underweight	Normal weight	Overweight	Obese	Underweight	Normal weight	Overweight	Obese
Continuous explanatory variables								
Age/10	0.131 (0.025)***	2.884 (0.242)***	1.145 (0.103)***	–2.039 (0.232)***	–0.019 (0.003)***	–0.405 (0.057)***	–0.856 (0.084)***	–0.841 (0.062)***
Income	–0.051 (0.010)***	–0.694 (0.144)***	0.304 (0.056)***	1.060 (0.150)***	–0.009 (0.002)***	–0.245 (0.035)***	–0.291 (0.056)***	–0.073 (0.040)*
No. Children	0.003 (0.014)	0.039 (0.227)	–0.043 (0.095)	–0.090 (0.238)	0.001 (0.002)	0.030 (0.058)	0.042 (0.095)	0.019 (0.067)
No. Sugar drinks	0.001 (0.001)*	0.017 (0.009)*	0.001 (0.001)	–0.016 (0.008)*	0.000 (0.000)*	0.001 (0.001)*	–0.001 (0.001)*	–0.003 (0.002)*
Binary explanatory variables								
Exercise	0.007 (0.001)***	0.116 (0.017)***	0.007 (0.008)	–0.107 (0.018)***	0.001 (0.000)***	0.006 (0.005)	–0.009 (0.008)	–0.020 (0.005)***
White	–0.143 (0.096)	–2.727 (1.354)**	–1.785 (0.475)***	0.500 (1.397)	0.020 (0.010)**	0.909 (0.284)***	1.859 (0.453)***	1.368 (0.303)***
Black	–0.225 (0.072)***	–3.630 (1.358)***	0.586 (0.583)	5.022 (1.694)***	–0.030 (0.009)***	–0.800 (0.310)***	–0.871 (0.572)	–0.053 (0.440)
Hispanic	–0.286 (0.076)***	–5.662 (1.572)***	–2.231 (0.961)**	4.036 (2.085)*	–0.008 (0.014)	0.349 (0.502)	1.719 (0.937)*	2.083 (0.773)***
< High school	0.096 (0.070)	1.351 (0.998)	–0.241 (0.413)	–1.556 (0.992)	0.012 (0.010)	0.245 (0.261)	0.173 (0.403)	–0.080 (0.271)
Some college	–0.034 (0.038)	–1.044 (0.603)*	–1.569 (0.282)***	–0.828 (0.626)	0.022 (0.007)***	0.863 (0.176)***	1.571 (0.282)***	1.018 (0.198)***
College degree	0.325 (0.044)***	4.415 (0.577)***	–1.917 (0.261)***	–6.666 (0.592)***	0.066 (0.009)***	1.608 (0.171)***	1.790 (0.254)***	0.379 (0.169)**
Employed	–0.181 (0.233)	–2.076 (3.580)	2.027 (1.590)	4.396 (3.353)	–0.050 (0.034)	–1.419 (0.973)	–1.917 (1.603)	–0.780 (1.135)
Unemployed	–0.159 (0.186)	–3.223 (3.466)	–2.014 (1.928)	1.011 (3.628)	0.012 (0.032)	0.793 (1.033)	1.936 (1.879)	1.645 (1.504)
Retired	–0.222 (0.207)	–3.180 (3.456)	1.006 (1.372)	4.700 (3.640)	–0.034 (0.022)	–0.925 (0.726)	–1.102 (1.332)	–0.242 (1.056)
Student	0.031 (0.252)	0.493 (3.897)	0.062 (1.520)	–0.411 (3.792)	0.002 (0.031)	0.002 (0.908)	–0.074 (1.526)	–0.105 (1.104)
Unable	–0.170 (0.183)	–4.864 (3.454)	–6.566 (2.740)**	–2.888 (3.415)	0.080 (0.057)	3.400 (1.605)**	6.546 (2.720)**	4.463 (2.109)**
Home owner	–0.010 (0.038)	0.301 (0.593)	1.363 (0.267)***	1.319 (0.610)**	–0.023 (0.006)***	–0.799 (0.164)***	–1.353 (0.266)***	–0.798 (0.188)***
Married	–0.307 (0.053)***	–4.056 (0.699)***	1.760 (0.304)***	5.774 (0.691)***	–0.049 (0.008)***	–1.318 (0.185)***	–1.506 (0.292)***	–0.299 (0.198)
Divorced	–0.198 (0.045)***	–3.472 (0.798)***	–0.576 (0.346)*	3.180 (0.932)***	–0.013 (0.006)**	–0.098 (0.196)	0.421 (0.339)	0.756 (0.262)***
Widowed	–0.204 (0.058)***	–3.444 (1.080)***	–0.124 (0.498)	3.838 (1.292)***	–0.020 (0.008)**	–0.377 (0.260)	–0.103 (0.481)	0.434 (0.382)
Separated	–0.082 (0.099)	–1.909 (1.664)	–1.874 (0.796)**	–0.299 (1.750)	0.021 (0.017)	0.925 (0.487)*	1.869 (0.794)**	1.350 (0.608)**
Very good health	0.379 (0.037)***	7.476 (0.447)***	3.342 (0.233)***	–4.040 (0.406)***	–0.009 (0.003)***	–1.206 (0.115)***	–3.247 (0.219)***	–2.695 (0.168)***
Poor health	–0.277 (0.032)***	–5.768 (0.549)***	–3.104 (0.359)***	2.857 (0.389)***	0.006 (0.003)**	0.940 (0.116)***	2.776 (0.299)***	2.571 (0.287)***
High blood pressure	–0.682 (0.057)***	–12.881 (0.457)***	–1.527 (0.249)***	12.783 (0.530)***	–0.054 (0.006)***	–0.814 (0.117)***	0.881 (0.211)***	2.294 (0.159)***

Note: All effects on probabilities are multiplied by 100. Asymptotic standard errors are in parentheses. *** 1%, ** 5%, * 10%. All marginal effects and standard errors are multiplied by 100.

Table 7

Marginal effects of explanatory variables on joint probability of depression and body weight categories for female sample

	Non-depressed and				Depressed			
Variable	Underweight	Normal weight	Overweight	Obese	Underweight	Normal weight	Overweight	Obese
Continuous explanatory variables								
Age/10	0.531 (0.048)***	4.640 (0.227)***	0.961 (0.106)***	–1.196 (0.193)***	–0.056 (0.007)***	–1.426 (0.102)***	–1.528 (0.079)***	–1.924 (0.089)***
Income	0.096 (0.018)***	0.998 (0.132)***	0.287 (0.058)***	–0.096 (0.113)	–0.006 (0.003)*	–0.334 (0.063)***	–0.426 (0.051)***	–0.521 (0.057)***
No. Children	0.015 (0.031)	0.240 (0.230)	0.155 (0.100)	0.101 (0.199)	–0.006 (0.006)	–0.173 (0.108)	–0.169 (0.086)**	–0.164 (0.096)*
No. Sugar drinks	–0.000 (0.001)	–0.000 (0.008)	0.000 (0.002)	0.000 (0.007)	0.000 (0.000)	–0.000 (0.002)	0.000 (0.001)	0.000 (0.003)
Binary explanatory variables								
Exercise	0.027 (0.002)***	0.222 (0.014)***	0.001 (0.007)	–0.113 (0.013)***	0.002 (0.000)***	–0.006 (0.008)	–0.046 (0.007)***	–0.087 (0.007)***
White	–0.333 (0.204)	–4.535 (1.334)***	–2.518 (0.584)***	–1.432 (1.189)	0.093 (0.025)***	2.852 (0.529)***	2.891 (0.451)***	2.982 (0.495)***
Black	–1.121 (0.106)***	–9.686 (1.388)***	3.302 (0.526)***	13.191 (1.601)***	–0.192 (0.017)***	–4.111 (0.461)***	–2.278 (0.526)***	0.896 (0.724)
Hispanic	–0.627 (0.162)***	–5.455 (1.702)***	0.365 (0.773)	4.045 (1.712)**	–0.075 (0.033)**	–0.715 (0.813)	0.476 (0.754)	1.985 (0.934)**
< High school	0.305 (0.148)**	2.053 (0.973)**	–0.361 (0.454)	–1.488 (0.790)*	0.037 (0.028)	0.287 (0.492)	–0.185 (0.379)	–0.647 (0.394)
Some college	–0.057 (0.074)	–1.503 (0.566)***	–1.346 (0.264)***	–1.184 (0.478)**	0.058 (0.017)***	1.507 (0.297)***	1.345 (0.235)***	1.180 (0.258)***
College degree	0.521 (0.080)***	2.003 (0.573)***	–2.900 (0.262)***	–5.126 (0.479)***	0.170 (0.019)***	3.109 (0.289)***	1.793 (0.225)***	0.431 (0.243)*
Employed	–0.180 (0.102)*	–0.799 (0.753)	0.837 (0.332)**	1.631 (0.642)**	–0.051 (0.020)***	–0.894 (0.363)**	–0.484 (0.288)*	–0.061 (0.319)
Unemployed	–0.192 (0.142)	–3.640 (1.137)***	–2.689 (0.561)***	–2.022 (0.931)**	0.108 (0.040)***	3.008 (0.680)***	2.816 (0.520)***	2.611 (0.605)***
Retired	–0.313 (0.108)***	–1.907 (0.853)**	0.884 (0.378)**	2.347 (0.762)***	–0.059 (0.019)***	–0.928 (0.398)**	–0.342 (0.340)	0.317 (0.384)
Student	0.752 (0.298)**	3.206 (1.611)**	–2.510 (0.845)***	–4.647 (1.192)***	0.192 (0.071)***	2.576 (0.981)***	0.914 (0.657)	–0.484 (0.641)
Unable	–0.094 (0.142)	–6.785 (1.081)***	–7.471 (0.638)***	–7.179 (0.777)***	0.438 (0.073)***	9.133 (0.913)***	6.922 (0.600)***	5.035 (0.666)***
Home owner	0.199 (0.071)***	2.816 (0.564)***	1.550 (0.264)***	0.789 (0.477)*	–0.053 (0.016)***	–1.717 (0.300)***	–1.770 (0.242)***	–1.814 (0.270)***
Married	0.297 (0.092)***	2.126 (0.688)***	–0.374 (0.301)	–1.658 (0.587)***	0.039 (0.017)**	0.369 (0.326)	–0.137 (0.265)	–0.661 (0.295)**
Divorced	0.365 (0.119)***	0.819 (0.767)	–2.404 (0.377)***	–3.740 (0.604)***	0.154 (0.029)***	2.673 (0.441)***	1.577 (0.322)***	0.558 (0.339)
Widowed	0.338 (0.131)***	1.693 (0.873)*	–1.143 (0.414)***	–2.422 (0.700)***	0.082 (0.029)***	1.194 (0.468)**	0.472 (0.353)	–0.214 (0.368)
Separated	0.285 (0.229)	–0.007 (1.465)	–2.642 (0.732)***	–3.633 (1.123)***	0.167 (0.061)***	3.029 (0.885)***	1.908 (0.623)***	0.893 (0.669)
Very good health	1.097 (0.065)***	12.494 (0.479)***	3.151 (0.201)***	–2.700 (0.328)***	–0.006 (0.009)	–3.112 (0.210)***	–4.860 (0.212)***	–6.065 (0.243)***
Poor health	–0.733 (0.056)***	–8.528 (0.616)***	–2.494 (0.248)***	1.445 (0.236)***	0.001 (0.006)	2.049 (0.190)***	3.441 (0.279)***	4.819 (0.403)***
High blood pressure	–1.592 (0.078)***	–14.293 (0.481)***	1.854 (0.224)***	11.699 (0.462)***	–0.206 (0.014)***	–2.711 (0.211)***	0.648 (0.202)***	4.601 (0.244)***

Note: All effects on probabilities are multiplied by 100. Asymptotic standard errors are in parentheses. *** 1%, ** 5%, * 10%. All marginal effects and standard errors are multiplied by 100.