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Economic Analysis Of Multidimensional Measures Of Obesity

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DEDICATION

To my husband who has always been a great source of motivation and inspiration.

To my parents and my brother who have supported me all the way since the beginning of my studies.

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CHAPTER 1

INTRODUCTION

1.1 Prevalence of Obesity

Over the past several decades, obesity has become a widespread health problem, affecting people regardless of age, gender and race. According to a report released by the World Health Organization (WHO) in 1998, obesity was ranked among the leading ten global public health problems. The most recent calculations of OECD countries showed that the United States leads all other countries with over 30 percent of the population categorized as obese.[1] In the U.S., poor diet and physical inactivity were the second leading cause of death in 2000 (Mokdad et al 2004).

Obesity is not simply a threat to good appearance and psychological health, but also a path to other more severe health hazards, such as type II diabetes, hyperlipidemia, coronary artery disease, arthritis, gallstones and certain types of cancer (Trayhurn and Beattie 2001; NIH 1998). Carr and Friedman (2005) showed that obese individuals are more likely than normal weight individuals to report interpersonal discrimination, and work-related discrimination. A recent estimate of the causes of preventable deaths in the U.S concluded that obesity was the third leading cause of mortality surpassed only by tobacco smoking and high blood pressure (Danaei et al. 2009).

Health spending related to obesity has exceeded economic growth in many countries, putting pressures on government budgets (Pear 2004). In the U.S. medical spending on conditions associated with obesity has nearly doubled in the past decade,

[1] Obesity is defined by Body Mass Index greater than or equal to 30.

with a 9.1 percent increase in annual health spending, up from 6.5 percent in 1998 (Finkelstein et al. 2009).

The overall economic burden of obesity consists of different costs borne by governments, employers, insurance companies and obese individuals (Bhattacharya and Bundorf 2005; Finkelstein et al. 2009; Komlos et al. 2004; Sturm 2002). Finkelstein et al (2009) showed that across all payers, the cost of obesity is roughly 42 percent higher than for someone of normal weight from 1998 to 2006.

Obesity also has influences on the labor market outcomes. Averett and Korenman (1996) found that obese women tend to have lower family incomes than normal weight women, even after controlling for family background differences. Also studies could be found mentioning wage penalties, reduction of hours of work that were associated with obesity (Mitchell and Burkhauser 1990; Bazzoli 1985).

1.2 Measures of Obesity

With the concerns about more and more obesity-related diseases and economic burden that is on the rise, it is imperative to find accurate measures of obesity. The more accurate the measures are, the more clearly obese people will be identified and more unnecessary spending of curing obesity will be avoided. However, it is not easy to find the most accurate measure since obesity involves complex body composition. Currently, there are several measures of obesity being used by various researchers.

Body Mass Index (BMI)

The most common measure of obesity is Body Mass Index. It was invented between 1830 and 1850 by the Belgian Adolphe Quetelet during the course of developing "social physics". BMI is calculated by dividing a person's weight by the square of his/her height. Obesity defined using BMI thresholds have been changing over time. In 1998, the NIH consolidated the threshold for men and women. When BMI, scaled metrically, is equal to or greater than 30, the individual is classified as obese; when BMI is greater than 25 but less than 30, the person is categorized as overweight.

BMI has the advantage of both being a very simple measure to collect as well as providing a reasonable correlation with the amount of fat in the body for certain groups of people. Most currently available datasets, such as MEPS (Medical Expenditure Panel Survey), HRS (Health and Retirement Study), and NLSY (National Longitudinal Surveys of Youth) provide the necessary data for calculating the BMI. Malina and Katzmarzyk (1999) showed that sampled adolescents who were neither overweight nor at risk for being overweight were classified correctly by BMI. Mei et al (2002) claimed that for children and adolescents aged 2-19 years, the performance of BMI-for-age is better than that of the Rohrer Index (RI)[2]-for-age in predicting the underweight and overweight.

Despite the widespread use of BMI in economic studies[3], within the medical literature BMI is considered to be a very limited measure of obesity (Yusuf et al 2005; Smalley et al 1990; Garn et al 1986). The major assumption of BMI is that this quotient denotes an adiposity level independent of body composition. However, the assumption is

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[2] Rohrer Index (RI): $\frac{BodyWeight(g)*100}{Height(cm)^3}$

[3] Cawley and Burkhauser (2008) mentioned that Econlit listed 55 articles with the words "body mass index" or "BMI" in the abstract or among the keywords, but no articles with the more accurate measures of obesity in the abstract or among the keywords.

weakened when applied to a population of subjects heterogeneous in muscularity, age, or bodyweight. For example, many athletes may be labeled ‘obese’ because of high BMI, even though they actually have low percentages of body fat. Also BMI may also lack accuracy with regard to elderly people who have lost muscle and bone mass. Besides, an overweight individual with a BMI of 29 does not necessarily acquire additional health consequences associated with obesity simply by crossing the BMI threshold greater than 30.

Moreover, the use of BMI to classify people as obese and non-obese may result in misclassification problems. Smalley et al (1990) showed that when obesity is defined by measurements of body fat, the false negative rate of BMI-based definition of obesity was 55.7 percent of obese men and 44.6 percent of obese women in the sample. In other words, large numbers of obese people were misclassified if obesity was defined by BMI. Subsequent medical literature has confirmed this finding (Wellens et al 1996).

Alternative Measures of Obesity

More recently the validity of BMI has been challenged by alternative measures, such as: percent body fat, waist circumference, waist-to-hip ratio and skinfold measure (Cawley and Burkhauser 2008; Chang et al. 2003; Dalton et al. 2003; Deurenberg et al. 2000; Jassen et al. 2004; McCarthy et al. 2003; Sardinha et al. 1999; Yusuf et al. 2005).

According to relevant medical literature, obesity is caused by an abnormal accumulation of body fat. Cawley and Burkhauser (2008) utilized percent body fat as the measure of obese Americans and demonstrated that relative to the percent of body fat, BMI was less accurate for classifying men than women. Deurenberg et al (2000) showed that the relationship between percent body fat and BMI was different between Singaporeans and Caucasians and also among the three ethnic groups in Singapore. If obesity is considered as an excess of body fat, the cut-off points for obesity based on the BMI would need to be lowered.

Other medical studies found that obesity may not only be caused by the amount of fat, but also by the distribution of the fat. Dalton et al. (2003) concluded that, given appropriate cut-off points, waist-to-hip ratio (WHR, where higher values indicate obesity) is a more useful measure of obesity than waist circumference and BMI to identify individuals with cardiovascular disease (CVD) risk factors. McCarthy et al (2003) studied the trend in waist circumference from 1977-1997 and found that for girls, the change of waist circumference had greatly exceeded that of BMI. They concluded that BMI systematically underestimated the prevalence of obesity in young people.

Despite the advances that have been made in measuring obesity, there is still not much evidence on whether the estimates of body fat, skinfolds, waist circumferences and some clinical complications are more accurate than the simple weight-height index and consequently, there is still no agreement on which one of them is the most accurate measure of obesity (Freedman and Perry 2000). One possible explanation is that currently used measures of obesity are not accurate enough.

1.3 Research Questions

In this study, new multidimensional measures of obesity are developed based on six body measures, namely, weight, maximal calf circumference, thigh circumference, subscapular skinfold, waist circumference and percent body fat. The research questions are: are the new multidimensional measures of obesity more accurate than the currently used single indicators of obesity? Comparing the new criterion of obesity which is based on the new multidimensional measures and currently using single criteria (BMI, percent body fat and waist circumference), what are the differences among them to classify obese people?

Proposed Assumption

The new criterion of obesity is defined by using the overall elasticity of multidimensional measures of obesity to income. Here the assumption is that there is negative relationship between obesity and income. According to human capital theory, and health capital theory (Becker 1962; Grossman 1972a, 1972b), being unhealthy can not only reduce today's work ability, but also lower the productivity of the future. Besides, discrimination theory shows that employers tend to hire healthy workers who have greater marginal productivity and lower marginal cost than unhealthy ones.

Multicollinearity Concerns

When several correlated body measures are included in modeling, multicollinearity is a concern. One problem is that the individual *p*-values[4] can be misleading (a *p*-value can be high, even though the variable is important). The second problem is that the confidence intervals on the regression coefficients will be very wide. Further, because the confidence intervals are so wide, excluding one subject or adding a new one, can change the coefficients dramatically, and may even change their signs.

[4] In statistical hypothesis testing, the *p*-value is the probability of obtaining a test statistic at least as extreme as the one that was actually observed, assuming that the null hypothesis is true.

There are number of ways to deal with multicollinearity: 1) increase the sample size; 2) use information from prior research; 3) drop the offending variable; or 4) apply factor analysis to condense the information contained in a number of original variables into a smaller set of dimensions with a minimum loss of information. Given the particular dataset used in this study, factor analysis is chosen to cope with the multicollinearity problems.

Endogeneity Issues

Obesity may not be exogenous to income for the following two reasons. First, there may be a reverse causality problem. While obesity may affect income, it is also possible that income affects obesity since poor people may eat cheaper and less healthy food. Second, there may be unobserved variables that affect both obesity and income (Cawley 2000; Morris 2006). Therefore it is necessary to test the endogeneity problem before conducting any analysis.

There are usually two ways to deal with endogeneity issues of obesity. One approach involves *ad hoc* solutions which often lag the suspect variables, generally BMI, by one or more periods (Averett and Korenman 1996; Conley and Glauber 2005; Tunceli et al. 2006). Another way is through instrumental variables (IV) techniques (Card, 1995; Cawley 2000; Grabowski and Hirth 2003; Morris 2006). Given the datasets applied in this study, I will utilize the IV approach and the area-based indicators are the instruments for obesity measures.

The data come from the National Health and Nutrition Examination Survey (NHANES). It is a nationally representative, cross-sectional probability sample survey designed to analyze the health and nutritional status of adults and children in the United States. The 1999-2004 NHANES is applied in the study. SUDAAN version 10 is used in this study due to the complex survey design of the dataset.

The remainder part of the study is organized as follows. Chapter 2 presents detailed discussion of prior studies. Chapter 3 provides the theoretical framework and Chapter 4 describes the NHANES dataset and variables selected in the study. Chapter 5 shows the statistical estimation modeling, Chapter 6 provides the analysis based on the modeling results, and Chapter 7 states the conclusion and describes possible directions of further research based on this study.

CHAPTER 2

LITERATURE REVIEW

2. 1 Overview of Obesity and Income

Obesity and Health

It has been known by the medical profession, and widely disseminated to the public that obesity impairs health and results in mortality risks. Pi-Sunyer (1993) reviewed 100 studies examining the medical hazards of obesity. These studies assessed the effects of obesity to health by examining the influences on the duration of life and on the onset of premature disease. There was considerable evidence showing that obese persons had a greater risk for high blood pressure (Stamler et al 1978; Itallie 1985), abnormal blood lipid (Gordon et al 1977), higher prevalence of diabetes (Knowler et al 1981; Zimmet et al 1977), greater risk of gallbladder disease (Friedman et al 1966; Bray 1985) , influence on respiratory function (Nalmark and Cheralack 1960; Waltemath and Bergman 1974), increasing prevalence of arthritis (Leach et al 1973; Goldin et al 1976), and higher mortality ratio for cancer (Garfinkel 1985). A recent study from Lewis et al (2009) reviewed a number of studies regarding mortality and BMI in overweight range, and emphasized that overweight is linked with considerable increase in incidence of CVD risk factors, such as, type 2 diabetes mellitus, systemic hypertension, and dyslipidemia. Flegal et al (2010) analyzed the trend and health outcomes in obesity among US adults, and found that the prevalence of diagnosed diabetes increased significantly from 1988-1994 through 2005-2006.

Health and Income

Health capital is an important linkage between obesity and income. Poor health may lower income either by reducing productivity, which results in lower wages or by reducing labor market participation. O'Donnell (2000) presented a conceptual model of human performance. The model demonstrated that business could expect linkages between health, productivity and, even profits. Results showed that performance on the job was higher when employees were physically and emotional able to work and had the desire to work. This led to reduced absenteeism and presenteeism[5], which improved performance.

Boles et al (2004) examined 2264 employees of a large national employer in the Northeast of the U.S. of their health risks and self-reported productivity. In their study, productivity was calculated by self-reported measures of time missed from work and unproductive time while at work because of health problems. Health risks were obtained by a weighting scheme of calculating a risk score of 11 chronic conditions. Results presented higher risks were strongly associated with greater productivity loss. For example, the mean percentage of presenteeism rose for cumulative health risks, ranging from 1.3% for individuals with zero risks to 25.9% for individuals with eight risks.

DeLeire and Manning (2004) analyzed the impact of illness and health impairments on labor market outcomes. They defined the effects of health-impairment on productivity as the differences of marginal product of healthy and health-impaired workers. Results showed that a reduction in the physical productivity of workers on the

[5] According to the definition from http://en.wikipedia.org/wiki/Presenteeism, presenteeism is the act of being present at work even if one is too sick to be productive, or to work beyond the expected hours.

job would reduce the demand by firms for the affected types of laborers, increase the use of substitute types of labor and capital, and decrease the wage rate.

Health care cost is also a major contributing factor in lowering the income. Since obesity is a chronic condition requiring long-term management, obese workers tend to incur higher medical expenditures than normal workers. Cost of employers will increase by hiring obese workers who drive up the insurance premium of the group health insurance that the employer purchased. Therefore, employers tend to offer lower wages to obese workers to make up for the higher premium.

Bertakis and Azari (2005) investigated differences in the use of health care services and related costs between obese and non-obese people. Results demonstrated that obese patients had significantly higher usage of healthcare services such as primary care clinic, specialty care clinic, hospitalization and diagnostic services. Using data from NLSY and MEPS, Bhattacharya and Bundorf (2009) found that the incremental healthcare costs related to obesity were passed on to obese workers who were with employer-sponsored health insurance in the form of lower wages.

Being obese may be associated with unattractiveness, and even cause stigmatizing. Physical appearance discrimination against obese people may affect their labor market outcomes. Frieze et al (1991) examined the relationship between facial attractiveness and earnings. Using longitudinal data on 737 MBA graduates, they found that attractive males were able to get higher starting salaries and that the earning differentials remained over time. Even though the most attractive female graduates did not secure higher starting salaries, they did earn more income later in their career. Biddle and Hamermesh (1998) extended their earlier study by analyzing longitudinal data on a large sample of graduates from one law school. Earnings were self-reported by graduates on follow-up questionnaires from the school and a measure of physical appearance was developed by rating matriculation photographs. Results showed that physical appearance was positively related to earnings for attorneys who graduated in the 1970s and the differential grew with experience. In addition, they found that attorneys in the private sector had higher beauty ratings than attorneys in the public sector. Carr and Friedman (2005) examined a broader range of respondents by using a national survey of more than 3000 adults in 1995. They found that very obese persons (with a BMI greater than 35) are more likely than normal weight respondents to report major discrimination, interpersonal discrimination, and work-related discrimination.

2.2 Empirical Literature Review on Obesity and Income

Many prior studies have devoted to examine the effects of obesity on wages, earnings and income. The results show a strong inverse relationship among women but rather inconsistent findings among men. Most of these studies focused on adolescents in the United States by using the data from the National Longitudinal Survey of Youth (NLSY). The majority of them used body mass index as the measure of obesity, either percentile or categorized.

Register and Williams (1990) examined the effect of obesity on wage rates in a sample of 18- to 25-year-olds from the 1982 round of the National Longitudinal Survey of Youth (NLSY). They defined obesity as body weight 20 percent or more above one’s ideal weight. In employment-selectivity corrected wage equations, the pay differential is minus 12 percent for obese women and minus 5 percent for obese men. They concluded that obese women suffered a wage penalty relative to non-obese women, but obese men did not suffer a similar penalty as compared to non-obese men.

Gortmaker et al (1993) analyzed the effects of obesity on several social and economic outcomes using NLSY. They described being obese as above the 95th percentile of National Center for Health Statistics standard of body mass index. They found that overweight women aged 16 to 24 had lower household incomes ($6,710 less per year) after seven years. There were similar results were for the overweight men.

Averett and Korenman (1996) used the 1988 NLSY data to examine the impact of BMI on income, martial status and hourly pay of 23 to 31 year-old adults. In their research, obesity was defined as categories of body mass index. The findings showed that obese women had lower family income than women whose weight-for-height was in the normal range. Results for men were weaker and mixed. Significant results of lower income could be found among men who were ages 16 to 24, not other age groups.

A later study by Baum and Ford (2004) examined the effects of obesity on wage using NLSY. In their research, not only adolescents but also older respondents were included. Obesity is defined as BMI greater or equal to 30. Their results suggested that obese workers suffered a wage penalty in the rage of 0.7-6.3 percent. Also they found that obese women tended to suffer more of a wage penalty than obese men.

Other studies examined populations outside of the United States. Sargent and Blanchflower (1994) examined the impact of obesity on the earnings of a British cohort of young British adults in the 1981 sweep of the National Child Development Study. They focused on obesity of people aged 11, 16 and 23 years and the impact on hourly earnings at age of 23. In their study, obesity was defined as a BMI at the 90th percentile of the sample distribution or greater. The findings showed no evidence of a statistically significant relationship between obesity at all three ages and earnings at age of 23 in men. For women, obesity had a statistically significant and negative effect on earnings at all ages. The same trend was found by Harper (2000) using a later round (1991) of the same survey. He estimated the impact of obesity at age 23 years on log hourly earnings at age 33 years. Obesity was described by a BMI in the 80-89th percentiles and the 90-100th percentiles of the sample distribution. Harper also found a statistically significant negative effect of obesity on earnings for women, and insignificant effects for men.

Realizing the potential causal effect of body mass on economic status and unobserved heterogeneity factors, Baum and Ford (2004) used individual-fixed effects and sibling difference techniques to cope with the unobserved characteristics. Assuming the individual-specific unobserved heterogeneity fixed over time, they took the difference between wage observations from the same respondent across time. Model results provided further evidence that obesity lowered wages, but the magnitudes were small when compared to the model including the standard covariates. Besides, sibling differences did not have statistically significant effects. Averett and Korenman (1996) analyzed contemporaneous relationships between economic or social outcomes and body weight for two age groups (age 23 to 31 and age 16 to 24). The findings suggested that contemporaneous social and economic differentials could not be the results of adverse labor market outcomes causing weight gain. Then, they used a lagged BMI measure less affected by reverse causality to strengthen the adverse association between obesity and economic status. The estimated effects were similar but less significant in the fixed effect model than the OLS specification

Some other studies explored instrumental variable (IV) model to estimate the potential endogeneity of obesity. Cawley (2000) utilized biological child's BMI as the instrument for the mother's weight. A Hausman test which indicated that the hypothesis that the OLS and IV coefficient are equal can not rejected. That is to say, endogeneity of weight does not affect the OLS estimates, which presented strong evidence that weight lowered wages for white women, weak evidence for Hispanic women and no evidence of black women. A U.K study by Morris (2006) used two area based indicators to instrument BMI in the IV models. The instruments were the mean BMI across individuals and the prevalence of obesity in the health authority where the respondent lives. He constructed a dataset of the instruments by collapsing individual level values of BMI and BMI greater than 30 in the sample respondents of working age by health authority of residence. Then, the newly created dataset was merged with the individual level data to give each individual the mean BMI and prevalence of obesity for the health authority where they lived. Using a Hausman test, he could not reject the hypothesis that the OLS and IV coefficients are equal in the models. In other words, no endogeneity problems can be found for BMI. Then, he concluded that BMI had a positive and significant effect on mean hourly occupational earning in men, but a negative and significant effect on women.

2.3 Prior Studies of Body Composition Measurements

It is commonly acknowledged that obesity involves an excess accumulation of body fat. Of the last several decades, various criteria for excessiveness have been examined by different studies. Early attempt were anthropometric measurements and somatotyping. More recently measures include weight, weight-height, percent body fat, waist circumference, and waist-to-hip ratio. However there is still no agreement on any particular measure.

Sheldon (1940) put forth the theory of somatotypes which stimulated considerable psychological research. However their evaluations depended mainly on visual or photographic inspection which restricted the usage to the broader way. Skeinkamp (1968) estimated body fat on some anthropometric measures for selected respondents who had to be healthy. Since obese people are more likely to have some kind of illnesses, the results from this selected group underestimated the actual effects of obesity. Besides, their evaluations relied on visual or photographic inspection, which did not offer much precision in estimating body fat.

The relationship between bodyweight and body fat is a complicated issue. Overweight always refers to a condition in which the total body mass exceeds certain reference standards. However, a person can be overweight without being overfat. This happens when the overweight person is more muscular than his or her peers. Similarly, it is not necessary the case that a person who conforms to height-weight averages is therefore non-obese. This difference has confounded the comparisons of numerous prior studies. On the one hand, numerous health experts challenged the validity of bodyweight or weight-height and recommended alternative measures of obesity. However, the strengths and weaknesses of each definition of obesity depend on the strengths and weaknesses of the fatness definition on which it is based. On the other hand, many studies which defended BMI (the most commonly used weight-height indicator) as a criterion of obesity can be easily found. However, the conclusion drawn by most of these studies came from the comparison within several weight and weight-height measures.

Keys et al (1972) used measurement of skinfold thickness to examine several commonly used relative weight indices, such as BMI, ponderal index ($H/W^{1/3}$), W/H and $\%\bar{W}$ (relative weight expressed as percent of average weight at given height) in 7,427 sample men in 12 cohorts in five countries. Judged by the criteria of correlation with height (the lower the better) and measure of body fatness (the higher the better), BMI was more preferable over other indices for all populations at all times. A similar finding can be found from Garrow and Webster (1985) that BMI gave values rather close to the true value estimate.

Strain and Zumoff (1992) compared the performances of three measures of obesity: percent deviation from desirable body weight (DBW)[6], and measurement of body fat content. Respondents were 40 men aged 18-50 and 48 women aged 21-47, ranging from non-obese to extremely obese. Results showed that the two weight-height indices gave as accurate a measurement of fatness as the technically complex measurement of the total BFC.

Garn et al (1986), however, presented three possible limitations of the body mass index. Using the data of the first National Health and Nutrition Examination Survey (NHANES I), they found that the correlation between stature and the BMI approximated 0.3 for children, shifted during adolescence, and then became negative. As a consequence, the assumption that the BMI was independent of statue was not quite true over at least part of the age group. Moreover, they examined BMI and relative sitting height (sitting height/stature) and results showed that BMI was not independent of height and relative sitting height. Besides, with use of data from the Tecumseh Community Health Survey,

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[6] Desirable body weight (DBW) was derived by actuaries to indicate that weight which is associated with the lowest mortality.

they estimated correlations of BMI with lean body mass and fat tissue. Results demonstrated that BMI was influenced nearly to an equal degree by both the lean and the fat compartments of the human body. Therefore, they suggested that BMI may be a better measure of amount of lean rather than relative fatness. A subsequent analysis from Gallagher et al (1996) showed that statistically significant sex and age effects were found in the %BF-BMI relations within each ethnic group, and BMI itself can only account for 25% of between-individual differences in body fat percentage of the respondents. Greene et al (2008) analyzed a drawback of BMI from another prospective. They found strong evidence for the presence of the latent classes within BMI-categories and fixed boundary parameters may be inappropriate for at least two distinct groups: those who weight-train and those over 62.

Smalley et al (1990) examined the accuracy of BMI-based definition of obesity at identifying those determined to be obese by measurement of body fat. The results showed that BMI can only correctly identify 44.3 percent of obese men and 55.4 percent of obese women. Besides, they suggested that BMIs should be used with caution as indicators of obesity. They found that 95% confidence intervals of using BMI were very wide. For example, if a man had a BMI of 27, it could only be 95% certain that his %BF would be within 10%-31.7% body fat. A subsequent analysis from Wellens et al (1996) confirmed the findings and suggested that BMI was an uncertain diagnostic index of obesity.

Instead of using BMI, some prior studies used alternative measures to represent obesity. Yusuf et al (2005) concluded that waist-to-hip ratio (WHR) and, to a lesser extent, waist circumference better predict heart attack than BMI. Cawley and Burkhauser (2008) defined obesity as excessive fatness since the medical literature suggested that it is fat that causes morbidity and mortality. Following their proposed definition, they calculated percent body fat from NHANES III. Relative to percent body fat, BMI misclassifies substantial fractions of individuals as obese and non-obese. Also BMI is found to be less accurate for classifying men than women. Besides, total body fat is negatively correlated with employment for some groups and fat-free mass is not significantly correlated with employment for any group.

Johansson et al (2009) examined the relationship between obesity and labor market success in Finland, using several indicators of individual body composition. They found that only waist circumference had a negative effect on wages for women, whereas, no obesity measure was found significant for wages of men. However, all measures of obesity are negatively associated with women’s employment probability, and fat mass has a negative effect on men’s employment. They concluded that without considering body composition, there would be a risk that labor market penalties associated with obesity would be measured with bias.

2.4 Literature Review on Multidimensional Analysis – Evidence from Other Fields

Even though no studies of multidimensional analysis of obesity can be found, references can still be obtained from prior studies in other fields. Jong-A-Pin (2009) examined the multidimensionality of political instability and derived new measures for political instability. He used an exploratory factor analysis approach on a set of 25 political instability indicators and found that political instability had four dimensions: politically motivated violence, mass civil protest, instability within the political regime, and instability of the political regime. Model results showed that the four dimensions of political instability had different effects on economic growth. Perry (1979) analyzed socioeconomic development from a multi-dimensional perspective using time-series data. The framework of development was defined based on four parts ecological complex: population, environment, technology and organization. Then, a set of comparable measures which were comprised of 63 variables from 57 nations at three points in time were brought together. After that, he used factor analysis to derive a number of composite indices to represent different dimensions of development. Model results suggested a complex sequence of development, where changes in certain factors tended to happen before changes in others.

2.5 Contributions of This Study

In this dissertation, I will make a number of contributions to the literature. First, I include six continuous body measures instead of one single indicator to represent obesity. Second, statistical tests will be conducted to compare the performance of current single indicators and the multidimensional measures presented in this study. Third, not only adolescent, but also older respondents will be included in the analysis. Fourth, new obesity criteria, based on elasticity of multidimensional measures in relation to income, will be proposed and a comparison will be made to the previous standard of obesity.

CHAPTER 3

CONCEPTUAL FRAMEWORK

3.1 Conceptual Framework of Income and Obesity

According to human capital theory, individuals increase earnings by investing in education, training, and health. As a capital good, adult health affects income through two human-capital channels. The most obvious channel is that individuals work less when they are sick. That is to say, today's illness can directly reduce the ability to work today. The other channel is the return to human capital through health. The depreciation rate of human capital can be higher if people are ill less often. They may be less healthy now, and they may die earlier. Therefore, early-life investments in human capital should increase.

Grossman (1972a, 1972b) extended Becker's (Becker 1962) human capital theory to explain the production of health capital through the demand for health and health care. In his model, Grossman showed important aspects of health demand. First, medical care demand is a derived demand for an input to produce health. In other words, what people want is health and they demand medical care to produce it. Second, consumers not only purchase health from the market, but also produce health, incorporating time, exercise, diet, and other inputs bought from the market. Third, more importantly, health is a capital good because it can last for more than one period. As a capital good, health is preferred because it can increase the number of healthy days for work in a given period (typically a year), increase the number of years of work, and increase income. It has been known that obesity impairs health and results in mortality risks. Therefore, obesity may lower individual's income.

The effect of obesity on income can also be explained from the employer side by human capital theory and discrimination theory. Employers seeking to maximize profits choose inputs, techniques, and management practices, which minimize production costs for a given level of output. According to human capital theory (Becker 1962), workers are not homogeneous in quality. If more output is produced with a given quantity of inputs, productivity is increased. Productivity is usually measured simply as output per unit of input.

Employers' investments in improving the quality of workers are made with the aim of increasing productivity. For the employer, in order for investment in human capital to be economically feasible, the expected value of the additional output from a given worker should be higher than the extra cost. That is to say, employers prefer to hire a worker with greater marginal productivity than marginal cost. Obesity is associated with many chronic health problems, and therefore it increases the depreciation rate of one's health over time. Obese workers may suffer from functional limitations and have lower marginal productivity than non-obese workers. Therefore, a lower wage will be offered to obese workers.

According to discrimination theory (Becker 1971; Arrow 1971; Phelps 1972), an employer who seeks to maximize profit will discriminate against blacks or women if he believes them to be less qualified and if the cost of gaining information regarding the individual applicants is excessive. In the same way, obesity is known to cause substantial health problems, and therefore an employer will offer lower wages to obese workers, because he believes them to be less productive than non-obese worker even if the obese workers has the same productivity as non-obese peers.

3.2 Methods to Test the Performance of Different Indicators of Obesity

Even though the negative relationship between obesity and income can be found from the above theory, prior empirical work has not shown consistent findings, at least for men. One explanation is that currently used measures of obesity are not accurate enough. In order to develop a better measurement of obesity, I use six body measures by considering body composition. Then the proposed question will be: are the new measures of obesity better than the previous single proxy? Some tests will be conducted to deal with this issue. In prior studies, BMI, percent of body fat and waist circumferences have been commonly used as proxies for obesity. Comparisons of goodness-of-fit (Adjusted R^2) of modeling income will be conducted for: percent of body fat, waist circumference and the new measures. Note that percent of body fat and waist circumference are already included in the new measures. Equation 1 shows the formula of adjusted R^2 where n is the number of observations and k represents the number of predictors.

$$Adjusted\ \ R^2 = \bar{R}^2 = 1 - \frac{n-1}{n-k-1} * (1 - R^2) \qquad (1)$$

For the comparison between the new measures and BMI, a *J*-test[7] will be applied. The *J*-test proposed by Davidson and MacKinnon (1981) is used to compare two different models, each attempting to explain exactly the same dependent variable, but with at least one variable in each model not found in the other. Based on a *t*-statistic, the

[7] Greene, W., 2002. Econometric Analysis. Chapter 8, 152-155

J-test can help us decide if one model is better than the other, or if the best option is to combine the two models in some way. The procedure, for example, is as follows. In equation 2 and equation 3, *Y* is income, *F* represents factor component and I assume there are two factors retained in the model. *X* denotes other controlling variables. First, put BMI and factors in separate models of income (equation 2 and equation 3) and get the fitted value of the dependent variable $(\hat{LnY}_{1i})$ and $(\hat{LnY}_{2i})$ respectively. Second, employ the fitted value $\hat{LnY}_{2i}$ as an additional independent variable in the estimation of equation 2 (equation 4) to get the coefficient of $\hat{LnY}_{2i}$ (α). Similarly put $\hat{LnY}_{1i}$ in the evaluation of equation 3 (equation 5).to get the coefficient of $\hat{LnY}_{1i}$ (α').

There are four situations: if α and α' are significant then both BMI and factors are good indicators; if α is significant but α' is insignificant then factors are the better indicators; if α is insignificant but α' is significant then BMI is a better indicator; if α and α' are insignificant then neither of them are not good indicators.

$$LnY_{1i} = c_0 + c_1 BMI_i + c_3 X_i + \gamma_i \tag{2}$$

$$LnY_{2i} = d_0 + d_1 F_{1i} + d_2 F_{2i} + d_3 X_i + u_i \tag{3}$$

$$LnY = (1-\alpha) LnY_{1i} + \alpha \hat{LnY}_{2i} \tag{4}$$

$$LnY' = (1-\alpha') LnY_{2i} + \alpha' \hat{LnY}_{1i} \tag{5}$$

3.3 The Importance of the Definition of Obesity

Compared with the proposed new measures of obesity in this study, are the previous used single indicators reasonable proxies? *Sensitivity* and *specificity* methods will be used here are widely used terms aiming to describe either diagnostic or screening tests. Following the definitions, sensitivity is the probability of a positive test among patients with obesity and specificity presents the probability of a negative test among patients without the disease. A 2*2 table can explain the test more explicitly.

		True Conditions	
		Patients with Obesity	**Patients without Obesity**
Test Result	**Test is Positive**	**a**	**b**
	Test is Negative	**c**	**d**

By definition, as can be seen from the table:

Sensitivity = a/(a+c) (6)

Specificity = d/(b+d) (7)

Accordingly,

False positive rate (Type I error) = 1-specificity = b/(b+d) (8)

False negative rate (Type II error) = 1-sensitivity = c/(a+c) (9)

Following the relevant theory, I assume that obesity will have negative impacts on income. In order to calculate overall elasticity, I first estimate the contribution of each body measure to income which can be calculated from equation 10 and equation 11, where b_1 to b_6 stand for the six body measures. The elasticity of each body measure to income is calculated by the marginal change multiplied by 1% change at the mean value of each body measure. Assuming a number of Factors F_1 through F_k, related to body measures b_1 to b_6:

$$LnY_i = Y(X_i, F_1(b_1, b_2, b_3, b_4, b_5, b_6), F_2(b_1, b_2, b_3, b_4, b_5, b_6), ...) \tag{10}$$

Marginal Change for b_1: $\frac{\partial Y}{\partial F_1} * \frac{\partial F_1}{\partial b_1} + \frac{\partial Y}{\partial F_2} * \frac{\partial F_2}{\partial b_1}$ (11)

The overall elasticity is calculated as shown in equation 12. b_i and $\bar{b}_i$ are the actual and mean value of each body measure for each respondent; and M_{bi} is the marginal change impact on income. Using the formula from equation 12, the overall elasticity of the six body measures in relation to income of each respondent can be easily calculated.

$$E = Overall\_Elasticity = \sum_{i=1}^{6} \frac{(b_i - \bar{b}_i)}{\bar{b}_i} * M_{bi} \tag{12}$$

Taking obesity status defined using negative overall elasticity as the true obesity status; I will examine how accurately BMI, waist circumference and percent body fat classify people as obese or non-obese. The NIH classifies men at "high risk" if waist circumference exceeds 102 cm (40 inches) or exceeds 88 cm (35 inches) for women and as obese if percent of body fat exceeds 25 percent for men or exceeds 30 percent for women. Measures of sensitivity and specificity can then be calculated to determine how well the simpler measures serve as obesity "screens."

CHAPTER 4

DATA

4.1 The National Health and Nutrition Examination Survey

The data in this study come from the National Health and Nutrition Examination Survey (NHANES). It is a nationally representative, cross-sectional probability sample survey designed to analyze the health and nutritional status of adults and children in the United States. The NHANES program began in the early 1960s and was conducted as a series of surveys focusing on different population groups or health topics. Since 1999, the survey has contained continuous two-year increments focusing on a variety of health and nutrition measurements. The survey examines about 5,000 persons each year. These persons are located in counties across the country, 15 of which are visited each year. All respondents are asked to complete extensive interviews, including demographic, socioeconomic, dietary and health-related questions. Also they are clinically examined on medical, dental and physiological dimensions.

4.2 Sample

This study uses respondents in the following categories: ages 20 and over, non-Hispanic persons who are examined, and women who are not pregnant. In order to avoid analytic problems and misinterpretation of the data, three aspects will be considered.

<u>Sample Size</u>

In the past, NHANES surveys were conducted on a periodic basis and the data were released as single, multiyear data sets. For example, NHANES III contained six calendar years (1988-1994) and was generally analyzed as a single 6-year survey. In addition, previous NHANES files tended to be large. Since 1999, NHANES has been released in two-year increments and on an ongoing basis as many smaller component-specific data files. For a two-year datasets, sample size is smaller and the number of geographic units is more limited than previous datasets. Therefore, it is very necessary to combine more two-year cycles into the research to increase sample size and analytic options. The 1999-2004 NHANES applied in the dissertation consists of three separate two-year increments (NHANES 1999-2000, NHANES 2001-2002, NHANES 2003-2004).

Sample Weights, Stratification and Clustering

Sample weights and the stratification and clustering of the design should be incorporated into the analysis to get proper estimates and standard errors of estimates. The sample weights reflect the unequal probabilities of selection, non-response adjustments and adjustments to independent population controls. Sometimes, data are collected on sub-sample levels. In addition, each subsample involves another stage of selection and separate sample weights that account for that stage of selection and additional non-response. Therefore, appropriate subsample weights should also be included.

Proper variance estimation (sampling errors) needs to be considered in the analysis. The Masked Variance Units (MVU) in the NHANES are collections of secondary sampling units aggregated into groups for the purpose of variance estimation. They provide estimates that closely approximate the variance that would have been estimated using the ‘true’ design structure. In each two-year cycle of NHANES, these MVU have been created and are allowed to be used for any combination of data cycles.

According to the Analytic and Reporting Guidelines of NHANES, for an estimate for the six years 1999-2004, a six-year weight variable will be created by assigning 2/3 of the 4 year weight for 1999-2003 if the person was sampled in 1999-2002 or assigning 1/3 of the 2 year weight for 2003-2004 if the person was sampled in 2003-2004. Table1 shows the number of observations and the weighted counts for each two-year increments in this dissertation. Besides, the stratum variable SDMVSTRA and primary sampling units (PSU), variable SDMVPSU are included for the consideration of stratification and clustering features. For NHANES 1999-2000, SDMVSTRA is numbered 1-13; for NHANES 2001-2002, it is numbered 14-28; and for NHANES 2003-2004 is numbered 29-43. Consequently, these data files can be concatenated without any recoding of the variables.

Table 1. Number of Observations and Weighted Totals for Each Two-Year Increments

	Men		**Women**	
Datasets	N of Obs	Weighted Ct	N of Obs	Weighted Ct
NHANES1999-2000	821	14920612	676	13886707
NHANES2001-2002	1197	20427326	1065	19758022
NHANES2003-2004	1163	19690258	995	18416561
Sum	3181	55038196	2736	52061290

Multiple Imputations

Multiple imputations, which refer to filling in several reasonable values for the missing data, are widely accepted approaches to cope with the missing items in a survey for several reasons. They adjust for observed difference between nonrespondents and respondents and address the nonresponse problem in the same way for all users, so that analyses will be consistent. Compared with single imputation, multiple imputations have been proven to have a better performance of datasets with over 20% missing information and a multi-dimensional quantity.

Dual-energy x-ray absorptiometry (DXA) is one of the most widely accepted methods of measuring body composition due to its speed, ease of use, high precision and low radiation exposure. In the NHANES, DXA scans are administered to qualified participants aged eight and older. For women, only those who aged 12 to 59 and menstruating 8 to 11 year olds are allowed to take the exam. In several situations, respondents can not take the DXA exam: females were pregnant at the time of the exam; females who said they were pregnant at the time of exam even if their pregnancy tests were negative; participants who reported that they were taking tests with radiographic contrast material in the past 72 hours, involved in nuclear medicine studies in the past three days or had a self-reported weight (>300 pounds) or height (>6'5") over the DXA table limit[8]. In this dissertation, DXA examined percent body fat will be included in the analysis.

Due to the strict requirement of DXA exam, the missing data is correlated with age, BMI, weight and height, and possibly other characteristics. For example, as shown in table 2, the percentage of data missing is increasing when the respondents were getting older. In order to solve the problem of potential bias due the unequal missing data, the method of multiple imputations is introduced. In the NHANES, each DXA scan data is

[8] Technical Documentation for the 1999-2004 Dual Energy X-Ray Absorptiometry (DXA) Multiple Imputation Data Files

evaluated five times. For the missing data, each of the five data files contain different imputed values, but the five values of the non-missing files are identical.

Table 2. Percentages of DXA Exam Participants in 1999-2004 with Data Missing for One or More Regions by Age Group[9]

Years	**Percentage**		
	1999-2000	2001-2002	2003-2004
8-11	10	7	7
12-15	11	10	10
16-19	15	14	14
20-29	18	18	20
30-39	21	21	21
40-49	22	21	22
50-59	25	23	27
60-69	28	28	25
70-79	30	27	36
80+	41	41	45

The weighted multiple imputations of the NHANES make the traditional data processing and modeling methods inappropriate here. Instead of processing data files for just one time, estimation procedure will be conducted separately five times for each of the completed data files. Then the five sets of results will be combined to compile a single statistical summary file.

4.3 Using SUDAAN

I consider the complex survey design of the NHANES 1999-2004 by conducting the analysis and models using SAS-callable SUDAAN version 10. It is a versatile software package for analyzing data from complex survey data. Other statistical tools, such as SAS, also have survey module, but few of them have the procedure to deal with

[9] Technical Documentation for the 1999-2004 Dual Energy X-Ray Absorptiometry (DXA) Multiple Imputation Data Files

survey and multiple imputations altogether. This section compares and contrasts SAS-callable SUDAAN software 10.0 and SAS/STAT Version 9.2.

Both SAS and SUDAAN procedures are based on the Taylor linear approximation method to calculate the variance estimates. The SAS-callable version of SUDAAN is designed to use within the framework of SAS and it uses the SAS dataset format. Thus, much of the syntax of a procedure is similar.

The differences between SAS and SUDAAN lie in the following aspects. First, SAS assumes that first-stage sampling is with replacement although in reality that is often not the case, Sampling with replacement can result in a slight overestimate of the variance. SUDAAN, on the other hand, offers a choice in determining what kind of sampling design the survey is based on. Second, a CLASS variable in SUDAAN can take on any values but must be numeric. A SAS CLASS variable can be either numeric or character. Third, unlike SAS, SUDAAN has no default printing of output. SUDAAN also does not provide the variance names in the output unless they are specified in the label of the variable.

Table 3 shows the mean value of percent body fat using SAS and SUDAAN for men. Since the methodology of NHANES is sampling with replacement, therefore, for each single dataset, both SAS and SUDAAN show the same mean value. When survey methodology and multiple imputations are considered at the same time, only SUDAAN can incorporate the five datasets and come up with one mean value. Since SAS can only conduct analysis of single dataset at one time, there will be underestimating and overestimating problems which depend on the choice of the dataset. Similar findings can be found for women in table 3.b.

Table 3.a Mean Value of Percent Body Fat of Performing SAS and SUDAAN for Men

Dataset	**SUDAAN**				**SAS**	
	Survey and Multiple Imputation		Survey		Survey	
	Mean	Se Mean	Mean	Se Mean	Mean	Se Mean
Dataset1	26.9036	0.1264	26.9170	0.1275	26.9170	0.1275
Dataset2			26.9036	0.1254	26.9036	0.1254
Dataset3			26.9380	0.1246	26.9380	0.1246
Dataset4			26.9195	0.1244	26.9195	0.1244
Dataset5			26.9033	0.1263	26.9033	0.1263

Table 3.b Mean Value of Percent Body Fat of performing SAS and SUDAAN for Women

Dataset	**SUDAAN**				**SAS**	
	Survey and Multiple Imputation		Survey		Survey	
	Mean	Se Mean	Mean	Se Mean	Mean	Se Mean
Dataset1	37.9565	0.2252	37.9498	0.2190	37.9498	0.2190
Dataset2			37.9778	0.2282	37.9778	0.2282
Dataset3			37.9425	0.2231	37.9425	0.2231
Dataset4			37.9820	0.2264	37.9820	0.2264
Dataset5			37.9563	0.2251	37.9563	0.2251

4.4 Dependent Variable

The dependent variable is a natural log of relative household income. In the NHANES, data on income was denoted as an poverty income ratio; which is the ratio of annual household income to the family’s appropriate poverty threshold in that year (US Census Bureau, 2003, 2007). The thresholds are updated annually for inflation with the Consumer Price Index. In the study, I use the weighted average threshold of a family with four people from the survey year which came from the U.S census bureau and multiply by the PIR to get the actual family income for each respondent.

4.5 Explanatory Variables

Body Measures[10]

The single most important feature of NHANES data is that the body measures are not based on self-reported value, but rather on clinical measures, which may reduce the potential biases associated with self-reported data.

When a respondent's weight is measured, he or she wears underpants only. If the examinee weighs more than 440 pounds, two Seca digital scales are used to have the person stand with one foot on each scale and then add the weight from each scale to obtain an approximation of their total weight.

Standing height is an assessment of maximum vertical size without wearing hair ornaments, jewelry, buns, braids and corn rolls on the top of the head. When a respondent stands on the floor, his heels of both feet are together and the toes point slightly outward. Besides, the position of the heels, the buttocks, shoulder blades, and the back of the head should contact with the vertical backboard. Once the respondent correctly stands, the headboard is positioned firmly on the top of the head with sufficient pressure to compress the hair, and the reading is the actual height.

Maximal Calf circumference is measured on the right calf. While the respondent is sitting, the measuring tape is placed around the calf and moved up and down to locate the maximum circumference in a plane perpendicular to the long axis of the calf.

In order to define the level where the waist circumference is measured, a bony landmark and a lateral border of the ilium should be located. First, locate the right ilium. Subsequently, draw a horizontal line just above the uppermost lateral border of the right

[10] National Health and Nutrition Examination Survey (NHANES) survey operations manuals, brochures and consent documents.

ilium, and then cross the line to indicate the midaxillary line of the body. Finally, a measuring tape is placed around the trunk in a horizontal plane at the level marked on the right side of the trunk.

For thigh circumference, a standardized position is required. The respondent stands with most of the weight on the left leg with the right leg forward, knee slightly flexed and soles of both feet flat on the floor. The measuring tape is placed around the mid-thigh at the point that is already marked by a (+). Then, the tape perpendicular is positioned to the long axix of the thigh with the zero end of the tape held below the measurement value.

Triceps skinfold is measured on the posterior surface of the right upper arm. The respondent should stand straight with shoulders relaxed, and the arms hanging freely at the sides. An examiner stands behind the respondent's right side and gently grasps a fold of skin with thumb and index finger, approximately 2.0 cm above the marked point that was marked for the mid-upper arm circumference. The skinfold should be parallel to the long axis of the arm. Then, the tips of the caliper jaws are placed over the marked point, vertical to the length of the fold. The triceps skinfold is measured to the nearest 0.1mm.

When the subscapular skinfold is measured, first, a cross mark is made on the inferior angle of the scapula; after that, a fold of skin is gently grasped with the index finger directly above (1.0 cm) and medial to the inferior angle of the scapula, with the thumb reaching toward the spine. The tips of the caliper jaws are positioned 2.0 cm above the place where the measurement is to be taken.

Body fat is measured by dual-energy x-ray absorptiometry (DXA) which has long been accepted as the primary method for measuring bone mineral content and bone mineral density, because it is a high precision, accuracy, and low radiation exposure measure.

Due to the limited information of socioeconomic variables in NHANES, other explanatory variables include age, gender, marital status, race, and education attainment.

CHAPTER 5

STATISTICAL MODELING

5.1 Factor Analysis

I examine the dimensionality of obesity using factor analysis. Factor analysis can be used to create a set of factors to be treated as uncorrelated variables to handle multicollinearity in multiple regressions. By assuming that the observed indicators are created by a linear combination of unobserved factors and some individual error terms, a model structure is imposed on the covariance matrix of the indicators. Here, I apply a flow diagram (Figure 2) to explain an overview of the steps involved in factor analysis.

Multicollinearity Test

Before conducting factor analysis, I first perform a multicollinearity test. If there is a multicollinearity problem, it will be difficult to determine which variable is actually producing the effect on dependent variable. Each respondent’s body measures are to some extent correlated. For example, individuals with higher body weights are relatively more likely to have higher waist circumferences. Here, I will first examine the bivariate correlations of the six body measures. If the values are big, it may suggest that there are multicollinearity problems. However, high values do not necessarily mean multicollinearity because it is possible that one body measure may be a linear combination of several body measures. Therefore, I will further check multicollinearity by adding body measures one at a time to the modeling of income to look for changes in values and the signs of their coefficients. If there are some changes of the signs which switch from positive to negative or the value of coefficients change sharply, then, it indicates multicollinearity. Detailed results and explanations will be shown in chapter 6.

Estimating Communality

Factor analysis begins by substituting the diagonal of the correlation matrix with communality estimates. Communality is the squared multiple correlation for the variable as dependent using the factors as predictors. It measures the percent of variance in a variable explained by all the factors jointly and may not be interpreted as the reliability of the indicator. Generally, higher communality indicates the variable plays a better role in interpreting the factor. There are several approaches to estimate communalities. Here, I will apply a commonly used approach which uses the squared multiple correlation between the variable and all other variables to estimate communalities.

Number of Factors to be Retained

Determining the optimal number of factors to extract is not a straightforward task since the decision involves some investigator judgement. There are several rules which have been suggested for determining how many factors should be retained, but these are empirical guidelines rather than an exact quantitative solution. In practice, most factor analysis uses several criteria to decide on the number of factor to exact instead of just using a single criteria. Some of the most commonly used guidelines are the Kaiser rule, scree plot criterion, variance explained criterion, and Joliffe criterion.

1. Kaiser criterion: retain only those factors with an eigenvalue[11] larger than 1;

[11] Eigenvalue: also called characteristic roots. The eigenvalue for a given factor measures the variance in all the variables which is accounted for by that factor.

2. Scree plot: make a scree-plot and keep all the factors before the breaking point or elbow;
3. Variance explained criterion: keep enough factors to account for 90% (sometimes 80%) of the variance;
4. Joliff criterion[12]: crop all components with eigenvalues under 0.7

<u>Factor Rotation</u>

After factor extraction, it might be difficult to explain and name the factors based on their factor loadings. A solution for this difficulty is factor rotation. It changes the pattern of the factor loadings, and therefore can improve interpretation. Rotation can be explained clearly by imagining factors as axes in a graph, where the original variables load. By rotating these axes, it is possible to make clusters of variables load optimally.

There are several methods to conduct rotations, such as varimax, quartimax, equamax. These options are orthogonal rotations. They result in rotated factors that show the 'post-rotation' loadings of the original variables on the extracted factors, and a transformation matrix which gives information regarding the angle of rotation. Following most of the prior studies, I will use varimax method as the rotation procedure.

<u>Interpretation of factors</u>

The output of the factor analysis is a matrix of factor loadings. A factor loading is a correlation matrix between the original variables and their factors. A decision needs to be made regarding which constitutes a significant loading. A rule of thumb is that factor

[12] The Joliffe criterion is a more liberal rule of thumb which may result in twice as many factors as the Kaiser criterion

loadings greater than 0.30 in absolute value are considered to be significant. This criterion is just a guideline and sometimes needs some adjustments. There are two steps involved to interpret a factor matrix. First, identify significant loadings. The ideal situation is a single significant loading for each variable on only one factor. If there are variables that fail to load significantly on any factor, then they should be critically evaluated and a new factor should be considered after eliminating them. Second, interpret the factors. Generally, the larger the absolute value of the factor loading of a variable, the more important the variable is in interpreting the factor. Beside, the signs of the loadings also need to be considered when labeling the factors.

5.2 Baseline Model

<u>Ordinary Least Square Model</u>

I begin with the baseline model:

$$LnY_i = a_0 + \alpha_j \sum_{j=1}^{r} F_j + \beta_1 X_i + \upsilon_i \tag{13}$$

Y is the family income measured as a continuous variable, X is a vector of exogenous variables. F represents factor of obesity and υ is the error term. First I will estimate equation (13) by OLS. The OLS modeling assumes: (1) there is no correlation between the disturbances (υ) and the independent variables (F and X); (2) each disturbance has the same finite variance, and is uncorrelated with every other disturbance.

<u>Two Stage Least Squares Model</u>

The factors of body composition may not be exogenous to income for a number of reasons. First, there may be reverse causality problem. While body composition may affect income, it is also possible that income affects body composition. Second, there may be unobserved variables that affect both body composition and income. The unobserved factors include genetic factors and non-genetic factors such as individual's time, risk preference.

2SLS provides a general solution to the endogenous explanatory variable. To use the 2SLS model, an observable variable *Z*, instrumental variable, will be constructed. It satisfies two conditions. First, *Z* must be uncorrelated with υ:

$$\text{Cov}(Z, \upsilon)=0 \qquad (14)$$

That is to say, *Z* is exogenous in equation 13.

The second condition requires the correlation between *Z* and the endogenous variable (*F*). A precise statement requires a linear projection of *F* onto all the exogenous variables:

$$F_j = \beta_2 X_i + \gamma_1 Z_i + \alpha_2 \sum_{k=1}^{s} F_k + \varepsilon_i \qquad (15)$$

Where E(ε)=0 and ε is uncorrelated with *X* and Z. F_k represents the remaining *F* excluding F_j. Besides, the coefficient on *Z* is nonzero:

$$\gamma \neq 0 \qquad (16)$$

There are two steps to conduct 2SLS regression. First, obtain the fitted value $\hat{F}$ from the regression of equation 15. This is called the first-stage regression. Second, run the OLS regression equation 17

$$LnY_i = \delta_j \sum_{j=1}^{r} \hat{F}_j + \beta_3 X_i + \varsigma_i \qquad (17)$$

Specification Test

To test for endogeneity, the most common method is based on the Hausman test. Hausman (1978) suggested comparing the OLS and 2SLS estimators of F in equation 1 as formal test of endogeneity. If F is uncorrelated with the error term, the OLS and 2SLS estimators should be differ only by sampling error. This reasoning leads to the Hausman test for endogeneity.

There are two steps involved in conducting the test. First, make each factor component or F in equation 13 exogenous by creating a new F variable (equation 15, $\hat{F}$). This variable is formed by regressing all the exogenous variables and taking the fitted value as the new variable. Since the new variable is created from exogenous variables, it should not be correlated with the disturbance term, and can be considered exogenous. Second, run a regression of equation 17 adding the residual left over when $\hat{F}$ was created. Under the null hypothesis that F is exogenous; the coefficient on the residuals ε will be zero. An F-test of the significance of the residuals is a direct test. If the coefficient is significantly different from zero, the null is rejected and IV methods should be employed (Hausman, 1978). If we fail to reject the null hypothesis, then assume that the instruments are valid, so it is not possible to indentify any endogeneity problem with respect to F. In this situation, OLS estimates are preferred than 2SLS, since they have lower standard errors (Baum et al., 2004).

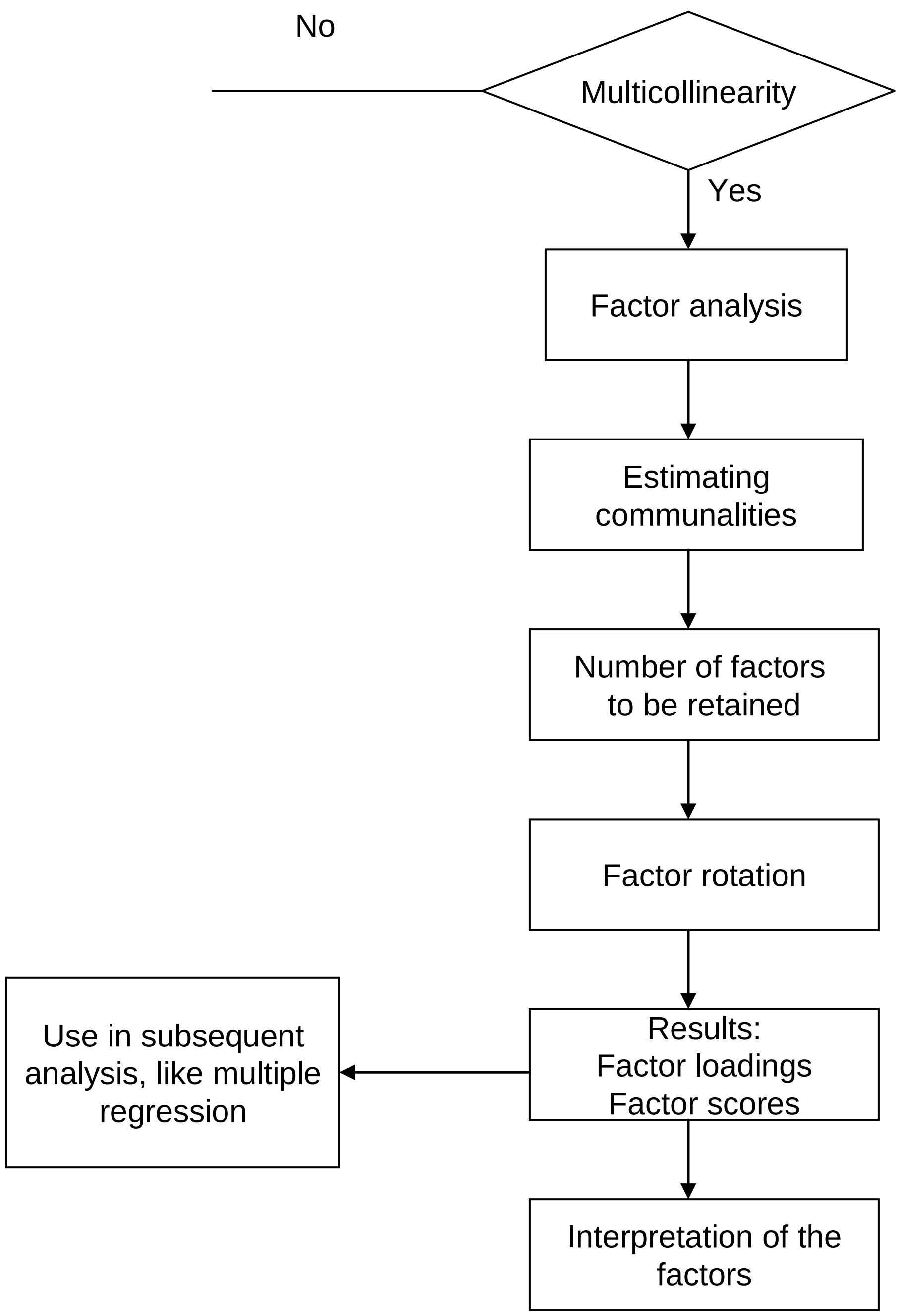
Instrumental Variables

The major difficulty with the IV approach is finding proper instrumental variables for F. The requirements are first, that the instruments are highly correlated with each F, once other exogenous variables have been controlled; second, the instruments should be orthogonal to the error term in the second stage regression. If the first condition does not hold, the instrumental variable will be inconsistent. An empirical test for weak instruments is to test the joint significance of Z in the first stage regression using an F-test. If the second condition is not met, the instrument is itself endogenous, and then δ is no longer a consistent estimate of the impact of the factors of body composition. It is not possible to test directly whether the instruments are exogenous, though in an overidentified model it is possible to test the conditional validity of the additional instruments under other maintained assumptions.

I use area-based indicators as instrument factors in the IV model. Area-based measures have been used as instruments for individual level variables in prior studies (Grabowski and Hirth, 2003; Sloan et al., 2001). According to the first requirement of an instrument, it should be correlated with the factors of body composition that represent level of obesity conditional on the other variables that affect occupational attainment. The major risk elements for obesity are excessive intake of high-fat and high-calorie foods and physical inactivity. Environmental influences, which affect behavior of food intake and exercise, are important determinants of obesity. They provide a summary measure of obesity-affecting environmental influences, and therefore is not a weak predictor of the factors of body composition. As of the second requirement of an instrument variable, it is not correlated the error term of obesity-income estimation. The area-based measures include a large and comprehensive set of individual elements and therefore they would not be a component of the error term of the estimation for individual level.

The instruments are constructed by first calculating the mean value for each body measure at a primary sampling unit (PSU) level of each stratum. According to the analytical guideline of NHANES, PSUs are generally single counties, or small adjacent counties to be combined to meet a minimum population size. In other words, the respondents who come from the same PSU will have the same mean value of each body measure. After I insert all corresponding mean values of each body measure to each respondent, factor analysis will be conducted of the mean body measures. Mean factor components one and two will be the instruments for factor component one; and the mean factor component two will be the instrument for factor component two in the model; since they are significant in the first stage of the IV model.

Figure 1.Factor Analysis Decision Diagram



CHAPTER 6

ANALYSIS

In this chapter, I presented the results of the analysis that estimates the multidimensional measures of obesity. In the descriptive section, I provide detailed results of factor analysis of the six body measures for men and women separately. Then, I show the regression results of the 2SLS model. Further, I compare the performance of the multidimensional measures with currently used single indicators, such as, BMI, waist circumference and percent body fat, in modeling income. In the second section, I apply sensitivity and specificity test to demonstrate the possible misclassification by using one-indicator defined obesity.

6.1 Descriptive Analysis

Descriptive Statistics

Table 4 displays descriptive statistics. The explanatory variables include: age (both linear and squared), education (three categories), white (race), marital status and time dummies. Compared with women, the men in the sample have higher incomes and are slightly more educated. Women are more likely to be white, married and older.

As for the body measures, men tend to have slightly higher mean BMI, calf circumference, thigh circumference. They also tend to have relatively higher body weight (84.2501 kg vs. 68.8216 kg) and waist circumference (97.0235 cm vs. 88.4460 cm). Women show a relatively higher mean value of: triceps skinfold (22.9642 mm vs.

13.7344 mm), percent of body fat (37.9565 vs. 26.9036), and a slightly higher value of subscapular skinfold (19.5929 mm vs. 18.6943 mm).

Testing for Multicollinearity

Before conducting factor analysis, I first tested for issues of multicollinearity among the variables. Tables 5.a and 5.b examine the bivariate correlations of the six body measures for men and women separately. For men, the body measures have correlation values ranging from 0.3947 (body fat to thigh circumference) to 0.8543 (weight to waist). Moreover, ten out of the fifteen correlations are over 0.6. A similar pattern can be found for women that eleven out of fifteen correlation values are over 0.6.

In additional analyses, I add the body measures one at a time to the model of income to confirm my findings. Table 6.a and 6.b present the results for men and women respectively. For men, controlling the socioeconomic variables, if there is only waist circumference, its coefficient is 0.0022. However, when other body measures are considered, the coefficient becomes negative. Besides, the coefficient of calf circumference becomes insignificant when more body measures are included. For women, when more body measures are included in the model, the effect of weight changes from significant to insignificant. Moreover, percent body fat shows insignificant influence, which was proved to be an important factor in prior studies (Cawley and Burkhauser 2008; Smalley et al 1990). These findings together suggest that there exist multicollinearity problems for the six body measures in the models of both men and women. In the next section, I use a factor analysis approach to deal with the problem.

Results of Factor Analysis

As noted previously, factor analysis is often used to reduce the impacts of variable multicollinearity. Moreover, in a theoretical sense, *k* measured components may in fact summarize a smaller number of latent factors that truly describe behaviors. Such factors are often used in studies of neighborhood quality with respects to school or crime, or in psychometric measuring dimensions of individual intelligence.

Table 7 presents the results of factor analysis of men and women respectively. The first six rows are eigenvectors or loadings that indicate the relative importance of each variable within the individual axis. The opposite signs represent negative correlation. Factor loadings are rotated by varimax rotation; which is an orthogonal rotation of the factor axes to maximize the variance of the squared loadings of a factor on all the variables in a factor matrix. This varimax method serves to make the output more understandable and is necessary to facilitate interpretation. The last two rows provide eigenvalues and variance for each axis. The eigenvalue for a given factor measures the variance of all variables which are accounted for by that factor.

Following the variance explained criteria and Joliff criterion, the first two factors for men and the first factor for women are retained in the analysis. When additional body measures are included, the Kaiser criterion is also met. This confirms the appropriateness of the choice of factors used in this analysis.

For men: weight, calf circumference and thigh circumference have relatively higher loadings on factor one; whereas, waist circumference, subscapular skinfold and percent body fat have higher loadings on factor two. Besides, these two groups of variables have a negative sign on both factors which indicates that there is a negative correlation. Factor one is termed *body weight* and related body measures and factor two is termed *body fat* and its distribution measures. The results for men indicate that it is necessary to include body weight, body fat and its distributions to represent obesity.

For women only factor one is retained. Except for calf circumference and thigh circumference, all other body measures display a positive sign. Compared with the body measures of men, women did not show much deviation in: body weight measures and body fat and its distribution. Because of the differences in these obesity factors, it is essential to perform separate gender analyses.

Testing for the Endogeneity of Factor Components

I examine the endogeneity of the factor components following the two-stage endogeneity test based on the Hausman test (1978). In the first stage, I estimate reduced form of factor components. In the second stage, I consider both predicted value of factor components and the predicted error term from the first stage in the model of income. If the coefficient of the first stage residual is significantly different from zero the null hypothesis is rejected and IV methods should be employed.

Table 8 presents the estimation results of the first stage reduced form model for men and women respectively. For men, education, marital status, age and race are significantly correlated with the factor components. For women, education, age and race are significantly associated with the factor components. In addition, the coefficients of all the instrumental variables are significant for both men and women. Therefore, area-based instruments are proved to be valid predicators of individual level factor components of body measures.

Using a Hausman test, I can reject the hypothesis that the OLS and IV coefficients are equal in the model of income for both men and women. In other words, an F-test rejects the hypothesis that the coefficient for first step residual is equal to zero. Consequently, there exist endogeneity problems and 2SLS modeling should be performed.

Performance of Different Measures of Obesity in Modeling Income

Table 9 presents the summary of comparisons of R^2 and adjusted R^2.[13] The detailed model results are presented in Appendix 1, 2 and 3. For men, when percent of body fat or waist circumferences is added to OLS and 2SLS models, instead of factor one and factor two, the adjusted R^2 decreases. Therefore, multidimensional measures fit the model better and turn out to be improved indicators than percent of body fat or waist circumference alone. However, for women, the results are inconsistent. Adjusted R^2 is greater when factor one is in the OLS model, but it becomes larger in the 2SLS model if waist circumference is added.

Table 10 summarizes the results of the *J*-test parameters α and α' with detailed model results in Appendix 5. a and 5.b. As can be seen from table 10, for both OLS and 2SLS models, α is significant for men; but α' is insignificant, which means factors are better proxies than BMI. For women, both α and α' are significant; therefore, both factor and BMI are valid indicators. The hypothesis test results demonstrate that factors are better proxies for men, but not necessarily for women.

Multivariate Analysis

[13] Greene, W., 2002. Econometric Analysis. Chapter 8, 159-160

This section presents the OLS and 2SLS regression results with the dependent variable as log of income. The supporting OLS and 2SLS results are included as Appendix 1. For men, factor one (body weight) shows positive effect on income, while factor two (body fat) presents negative influence. For women, the effect of factor component (body weight) on income is negative.

Table 11.a and 11.b show the marginal and elasticity of each body measure to income for men and women respectively. OLS results report that men's body weight has positive and significant effects on income. The elasticity is 0.9578, which means that 10% increase of body weight will result in 9.578% increase in mean income. Besides, calf circumference and thigh circumference also have a positive elasticity of 0.1773 and 0.2757. However, the elasticity of percent body fat, waist circumference and subscapular skinfold have negative elasticities: -0.084, -0.9987 and -0.0203. For women, most of the body measures have negative and significant elasticity with respect to income.

In terms of the IV approach, results confirm the findings of the OLS regression and the absolute value of marginal effects and elasticity are greater than that of OLS. For example, the elasticity of body weight for men in 2SLS model is 4.0204 comparing to 1.1368 in the OLS model. Further, the increasing rate of elasticity of each body measure is different. The body weight and related measures (body weight, maximal calf circumference, and thigh circumference) have lower increasing rate than the body fat and related measures (waist circumference, subscapular skinfold, and percent body fat).

6.2 Analysis of Sensitivity and Specificity Measures

When comparing continuous body measures and continuous single proxy, hypothesis tests from the model explain that for men, it is better to include more body measures than just the single proxy. In this section, sensitivity and specificity tests will be applied to demonstrate the possible misclassification by using one indicator defined obesity.

Table 12.a shows that the accuracy of obesity defined using BMI varies by gender. For example, only 1.13% of all women classified as obese by BMI are actually not obese, judging by the overall elasticity. In contrast, 16.59% of all positives are false for men. That is to say, BMI-defined obesity is a better indicator of identifying non-obese women rather than non-obese men. One important reason for this difference by gender is that men are more likely to have considerably higher muscle mass. The results of false negatives indicate 62.41% for women vs. 77.48% for men. Therefore, BMI defined obesity does a poor job of identifying obese men and women. Consistent with previous studies (Smalley et al., 1990; Cawley et al., 2008), obesity defined using BMI is not good at classifying people as obese or non-obese, especially men.

Table 12.b shows the accuracy of obesity defined using BMI by category. When BMI ≥ 30 (obese group), 57% of sample men are actually obese due to negative overall elasticity criterion. When BMI is greater than 25 but less than 30 (overweight group), 56% display negative overall elasticity. When BMI categories are defined as normal weight and under weight, there is a 38% and 27% negative overall elasticity. On the one hand, the outcomes prove that the higher the BMI category, the more obese people there will be in that category. In other words, the order of categories of BMI reflects the correct arrangement of the obese group.

On the other hand, more importantly, the results illustrate that obesity defined using BMI can not clearly classify the boundary between obese and non-obese. For the group of BMI greater than or equal to 30, about 43% of them were misclassified as obese by BMI categories. For women, not much misspecification can be found. When BMI is greater than or equal to 30 (obese group), 97% of them have negative overall elasticity; when BMI is greater than 25 but less than 30 (overweight group), 75% of them have negative overall elasticity. Sixteen percent and 0% display a negative overall elasticity when BMI categories are defined as normal weight and under weight.

Findings from tables 13 depict a false positive and a false negative for obesity defined by the percent of body fat. Similarly table 14 shows results for waist circumference. For both men and women, percent body fat-defined obesity is not good at identifying non-obese people with a false positive of 43.73% and 74.83% but is good at identifying obese people, especially women. The false negative for men and women are 11.61% and 0.13%, respectively. As for waist circumference defined obesity, it is a relatively good indicator for classifying obese (FN: 13.65%) and non-obese (FP: 10.73%) women; but not good for identifying obese men (FN: 54.49%) and non-obese men (FP: 21.82%).

The major reason for the difference between these standards is dissimilar thresholds. Compared with overall elasticity of body measures to income, BMI and waist circumference have lower thresholds, while percent body fat has a higher threshold. Table 15 shows that 19.53% of men are classified as obese using BMI, whereas about three times as many are classified as obese by utilizing percent body fat.[14] This comparison shows that using only one indictor will easily cause either underestimation or overestimation problems when identifying obesity.

The results of this chapter suggest that body composition is more complicated for men than for women, and, at least for men, it is unduly limiting to use one single indicator to represent obesity. Besides, obesity defined using single indicators results in substantial misclassification of individuals as obese and non-obese. BMI is particularly likely to classify obese men inaccurately, leading to underestimates of the prevalence of obesity of men. Waist circumference is a better indicator than BMI, but underestimation problem still exist. Such findings suggest that single indicators of obesity are not only theoretically inferior, but also not reasonable proxies.

[14] Cawley, J., 2008 calculated the prevalence of obesity by BMI and percent body fat by gender and showed that for women, the prevalence is 23.3% (BMI) vs. 70.1% (PBF) ; for men, the prevalence is 18.9% (BMI) vs. 43.3% (PBF).

Table 4 Descriptive Statistics

	Men		Women		Difference of Mean
	Mean	Se Mean	Mean	Se Mean	
Ln_Income	10.8573	0.0254	10.7497	0.0336	0.1076
Age in Years	45.7226	0.3601	47.7601	0.4521	-2.0375
White-1 if white, 0 if Black	0.8921	0.0101	0.9011	0.0107	-0.0090
Married-1 if married, 0 if Otherwise	0.6691	0.0156	0.7737	0.0147	-0.1046
Education:					
High School-1 if yes, 0 if Otherwise(Omitted Category)	0.4240	0.0194	0.4126	0.0189	0.0114
Some College-1 if yes, 0 if Otherwise	0.2870	0.0092	0.3176	0.0131	-0.0306
College-1 if yes, 0 if Otherwise	0.2891	0.0178	0.2698	0.0182	0.0193
Time:					
Time1-1 if NHANES1999-2000,0 Otherwise(Omitted Category)	0.2711	0.0207	0.2667	0.0258	0.0044
Time2-1 if NHANES2001-2002,0 Otherwise	0.3711	0.0202	0.3795	0.0240	-0.0084
Time3-1 if NHANES2003-2004,0 Otherwise	0.3578	0.0235	0.3537	0.0260	0.0041
Body Measures:					
Body Weight (Kg)	84.2501	0.2614	68.8216	0.4243	15.4285
BMI-Body Mass Index	26.7229	0.0754	25.8383	0.1632	0.8846
Waist Circumference(cm)	97.0253	0.2501	88.4460	0.4100	8.5793
Maximal Calf Circumference(cm)	38.8203	0.0767	37.2558	0.1015	1.5645
Thigh Circumference(cm)	52.8794	0.1104	51.3666	0.1766	1.5128
Triceps Skinfold (mm)	13.7344	0.1389	22.9642	0.2001	-9.2298
Subscapular Skinfold (mm)	18.6943	0.1543	19.5929	0.2342	-0.8986
Total Percent Fat	26.9033	0.1263	37.9563	0.2251	-11.0530
N of Observations	3181		2736		
Weighed count	55038196		52061290		

Table 5.a Correlation Matrix of the Body Measures for Men

Variables	Waist	Weight	Calf Circumference	Thigh Circumference	Subscapular Skinfold	Percent Body Fat
Waist	1.0000					
Weight	0.8543	1.0000				
Calf Circumference	0.6520	0.8377	1.0000			
Thigh Circumference	0.5914	0.8285	0.8383	1.0000		
Subscapular Skinfold	0.6954	0.6396	0.5276	0.5059	1.0000	
Percent Body Fat	0.8292	0.6119	0.4586	0.3947	0.6675	1.0000

Table 5.b Correlation Matrix of the Body Measures for Women

Variables	Waist	Weight	Calf Circumference	Thigh Circumference	Subscapular Skinfold	Percent Body Fat
Waist	1.0000					
Weight	0.8504	1.0000				
Calf Circumference	0.5974	0.8256	1.0000			
Thigh Circumference	0.6215	0.8556	0.8523	1.0000		
Subscapular Skinfold	0.6806	0.6895	0.5282	0.5930	1.0000	
Percent Body Fat	0.7516	0.6997	0.5408	0.6089	0.6365	1.0000

Table 6.a Multicollinearity Test for Men

Variables	Regression1	Regression2	Regression3	Regression4	Regression5	Regression6
Intercept	9.1639***	9.4137***	9.1470***	9.0632***	9.2384***	9.3263***
	(0.1471)	(0.1501)	(0.1987)	(0.2379)	(0.2466)	(0.2422)
Edu_Some College	0.2298***	0.2140***	0.2119***	0.2117***	0.2105***	0.2101***
	(0.0395)	(0.0380)	(0.0374)	(0.0373)	(0.0367)	(0.0369)
Edu_College	0.4891***	0.4525***	0.4465***	0.4459***	0.4412***	0.4390***
	(0.0370)	(0.0360)	(0.0364)	(0.0362)	(0.0361)	(0.0362)
Married	0.1553***	0.1449***	0.1441***	0.1436***	0.1396***	0.1387***
	(0.0288)	(0.0298)	(0.0296)	(0.0298)	(0.0301)	(0.0304)
Age	0.0366***	0.0389***	0.0388***	0.0394***	0.0390***	0.0340***
	(0.0047)	(0.0048)	(0.0048)	(0.0048)	(0.0047)	(0.0047)
Age_Sqr	-0.0004***	-0.0003***	-0.0003***	-0.0003***	-0.0003***	-0.0004***
	(4.5E-5)	(4.5E-5)	(4.5E-5)	(4.4E-5)	(4.5E-5)	(4.5E-5)
Time2	0.0973**	0.0903*	0.0897*	0.0890*	0.0892*	0.0927*
	(0.0465)	(0.0466)	(0.0463)	(0.0466)	(0.0474)	(0.0473)
Time3	0.0949*	0.0920*	0.0918*	0.0916*	0.0905*	0.0933*
	(0.0517)	(0.0505)	(0.0500)	(0.0450)	(0.0504)	(0.0500)
Whites	0.3220***	0.3805***	0.3766***	0.3833***	0.3979***	0.3908***
	(0.0443)	(0.0440)	(0.0025)	(0.0462)	(0.0458)	(0.0465)
Waist Circumference	0.0022*	-0.0142***	-0.0138***	-0.0138***	-0.0167***	-0.0205***
	(0.0012)	(0.0026)	(0.0025)	(0.0025)	(0.0027)	(0.0029)
Weight		0.0139***	0.0115***	0.0107***	0.0110***	0.0123***
		(0.0021)	(0.0023)	(0.0023)	(0.0023)	(0.0023)
Calf Circumference			0.0113*	0.0090	0.0083	0.0080
			(0.0068)	(0.0070)	(0.0071)	(0.0070)
Thigh Circumference				0.0040	0.0035	0.0029
				(0.0053)	(0.0053)	(0.0053)
Subscapular Skinfold					0.0068***	0.0053**
					(0.0022)	(0.0022)
Percent Body Fat						0.0083***
						(0.0030)
N of Obs	3181	3181	3181	3181	3181	3181
Weighted Ct	55038196	55038196	55038196	55038196	55038196	55038196
R Square	0.1916	0.2072	0.2081	0.2082	0.2105	0.2117
Adjusted R Square	0.1893	0.2047	0.2054	0.2052	0.2073	0.2082

Notes:

1) Standard error in parentheses

2) Asterisks indicate level of statistical significance: ***p<0.01, **p<0.05, *p<0.1

Table 6.b Multicollinearity Test for Women

Variables	Regression1	Regression2	Regression3	Regression4	Regression5	Regression6
Intercept	8.7682***	8.9695***	8.7470***	8.5688***	8.8102***	8.8006***
	(0.1536)	(0.1714)	(0.1825)	(0.2037)	(0.2000)	(0.2006)
Edu_Some College	0.3745***	0.3583***	0.3575***	0.3577***	0.3555***	0.3540***
	(0.0278)	(0.0275)	(0.0274)	(0.0275)	(0.0276)	(0.0278)
Edu_College	0.6455***	0.6234***	0.6207***	0.6197***	0.6160***	0.6118***
	(0.0350)	(0.0346)	(0.0351)	(0.0353)	(0.0356)	(0.0358)
Married	0.1872***	0.1834***	0.1825***	0.1835***	0.1814***	0.1811***
	(0.0434)	(0.0427)	(0.0425)	(0.0424)	(0.0418)	(0.0418)
Age	0.0692***	0.0671***	0.0674***	0.0682***	0.0653***	0.0654***
	(0.0056)	(0.0060)	(0.0060)	(0.0060)	(0.0059)	(0.0059)
Age_Sqr	-0.0007***	-0.0006***	-0.0006***	-0.0006***	-0.0006***	-0.0006
	(5.18E-5)	(5.61E-5)	(5.61E-5)	(5.62E-5)	(5.5E-5)	(5.54E-5)
Time2	0.0454	0.0455	0.0426	0.0386	0.0423	0.0392
	(0.0615)	(0.0614)	(0.0606)	(0.0600)	(0.0594)	(0.0579)
Time3	0.0906	0.1103*	0.1061*	0.1046*	0.1084*	0.1070*
	(0.0615)	(0.0624)	(0.0617)	(0.0615)	(0.0614)	(0.0607)
Whites	0.3945***	0.4142***	0.4074***	0.4277***	0.4436***	0.4576***
	(0.0550)	(0.0538)	(0.0542)	(0.0537)	(0.0516)	(0.0511)
Waist Circumference	-0.0054***	-0.0158***	-0.0148***	-0.0142***	-0.0175***	-0.0168***
	(0.0010)	(0.0023)	(0.0021)	(0.0021)	(0.0024)	(0.0024)
Weight		0.0103***	0.0076***	0.0046*	0.0040*	0.0039
		(0.0021)	(0.0020)	(0.0023)	(0.0023)	(0.0023)
Calf Circumference			0.0088	0.0020	0.0033	0.0024
			(0.0058)	(0.0059)	(0.0057)	(0.0056)
Thigh Circumference				0.0104***	0.0084**	0.0108**
				(0.0034)	(0.0034)	(0.0040)
Subscapular Skinfold					0.0098***	0.0108***
					(0.0025)	(0.0026)
Percent Body Fat						-0.0050
						(0.0035)
N of Obs	2736	2736	2736	2736	2736	2736
Weighted Ct	52061290	52061290	52061290	52061290	52061290	52061290
R Square	0.2980	0.3055	0.3060	0.3072	0.3120	0.3126
Adjusted R Square	0.2957	0.3030	0.3032	0.3041	0.3087	0.3091

Notes:

1) Standard error in parentheses

2) Asterisks indicate level of statistical significance: ***p<0.01, **p<0.05, *p<0.1

Table 7 Results of Factor Analysis

Variables	**Men**		**Women**
	Factor1	**Factor2**	**Factor1**
Weight(kg)	0.7331	-0.2945	0.1941
Waist Circumference(cm)	-0.4611	0.8422	0.6638
Maximal Calf Circumference(cm)	0.2987	-0.1066	-0.2565
Thigh Circumference(cm)	0.3430	-0.1157	-0.1884
Subscapular Skinfold (mm)	-0.0294	0.1433	0.1626
Total Percent Fat	-0.1105	0.3386	0.2377
Eigenvalue	4.1246	0.6676	4.2259
Variance	0.8887	0.1438	0.9422

Table 8 First-Stage Estimation Results of Factor Components

	Men		Women
Variables	**Factor1**	**Factor2**	**Factor1**
Intercept	0.0027	-0.1624***	-0.0822***
	(0.0091)	(0.0106)	(0.0100)
Edu_Some College	0.0096**	-0.0010	-0.0059*
	(0.0037)	(0.0027)	(0.0029)
Edu_College	0.0174***	-0.0077***	-0.0207***
	(0.0038)	(0.0026)	(0.0029)
Married	0.0098***	0.0025	-0.0021
	(0.0028)	(0.0033)	(0.0022)
Age	0.0014***	0.0038***	0.0030***
	(0.0003)	(0.0005)	(0.0004)
Age_Sqr	-3.1E-05***	-1.9E-05***	-1.7E-05***
	(3.1E-06)	(4.2E-06)	(3.6E-06)
Time2	-7.3E-05	-0.0009	-0.0007
	(0.0014)	(0.0019)	(0.0017)
Time3	0.0001	0.0031	0.0004
	(0.0013)	(0.0025)	(0.0015)
Whites	-0.0109***	0.0361***	-0.0105***
	(0.0040)	(0.0029)	(0.0033)
IV_Factor1	0.1781***	0.0314**	0.1717***
	(0.0077)	(0.0145)	(0.0162)
IV_Factor2	0.0523***	0.1130***	
	(0.0069)	(0.0139)	
Number of Obs	3181	3181	2736
Weighted Count	55038196	55038196	52061290
R Square	0.2044	0.3005	0.2076
Adjusted R Square	0.2019	0.2985	0.2050

Notes:

1) Standard error in parentheses

2) Asterisks indicate level of statistical significance: ***p<0.01, **p<0.05, *p<0.1

Table 9 Comparison of Adjusted R Square

Adjusted R Square	Men			Women		
	F1&F2	% Body Fat	Waist	F1	%Body Fat	Waist
OLS	0.2019	0.1894	0.1893	0.2959	0.2890	0.2957
2SLS	0.1948	0.1886	0.1883	0.2926	0.2932	0.2952

Notes:

1. Dependent variable is log (Income)
2. Explanatory Variables: age, age squared, marital status, education categories, time dummies, factor 1 and factor 2 for men, factor1 for women.

Table 10 Results of the J-test

	Men		Women	
	OLS	2SLS	OLS	2SLS
α	1.0645***	0.9350***	1.5068***	0.9041*
α'	-1.2929	0.6396	-1.1220*	0.8221***

Notes:

1) Standard error in parentheses

2) Asterisks indicate level of statistical significance: ***p<0.01, **p<0.05, *p<0.1

Table 11.a Men's Elasticity of Body Measures to Income

Body Measures	**OLS**		**2SLS**	
	Marginal	Elasticity	Marginal	Elasticity
Body Weight(kg)	1.1368	0.9578	4.7720	4.0204
Waist Circumference(cm)	-1.0293	-0.9987	-6.0630	-5.8827
Maximal Calf Circumference(cm)	0.4568	0.1773	1.8819	0.7306
Thigh Circumference(cm)	0.5213	0.2757	2.1297	1.1262
Subscapular Skinfold (mm)	-0.1085	-0.0203	-0.8041	-0.1503
Total Percent Fat	-0.3121	-0.0840	-2.0904	-0.5624

Table 11.b Women's Elasticity of Body Measures to Income

Body Measures	**OLS**		**2SLS**	
	Marginal	Elasticity	Marginal	Elasticity
Body Weight(kg)	-0.2138	-0.1471	-0.8939	-0.6152
Waist Circumference(cm)	-0.7310	-0.6466	-3.0572	-2.7040
Maximal Calf Circumference(cm)	0.2825	0.1052	1.1813	0.4401
Thigh Circumference(cm)	0.2075	0.1066	0.8677	0.4457
Subscapular Skinfold (mm)	-0.1791	-0.0351	-0.7489	-0.1467
Total Percent Fat	-0.2618	-0.0994	-1.0948	-0.4155

Notes:

1. Dependent variable is log (Income)
2. Explanatory Variables: age, age squared, marital status, education categories, time dummies, factor 1 and factor 2 for men, factor1 for women

Table 12.a Sensitivity and Specificity Results of BMI

Group	Sensitivity	Specificity	False Negative	False Positive
Men	22.52%	83.41%	77.48%	16.59%
Women	37.59%	98.87%	62.41%	1.13%

Table 12.b Misspecification of BMI

	Men			Women		
	Weighted Count	Weighted Count of E<0	Percent	Weighted Count	Weighted Count of E<0	Percent
Obese: BMI>=30	10746656	6129839	57.04%	9976119	9678634	97.02%
Over Weight: 25<=BMI<30	24442635	13703043	56.06%	16164847	12162987	75.24%
Normal Weight: 18.5<=BMI<25	19264205	7224476	37.50%	24070249	3903809	16.22%
Under Weight: BMI<18.5	584700	156813	26.82%	1850075	0	0.00%
Overall Weighted Ct.	55038196	27214171	49.45%	52061290	25745430	49.45%

Notes:
1. Dependent variable is log (Income).
2. Explanatory Variables: age, age squared, marital status, education categories, time dummies, factor 1 and factor 2 for men, factor1 for women.
3. $E = Overall\_Elasticity = \sum_{i=1}^{6} \frac{(b_i - \bar{b}_i)}{\bar{b}_i} * M_{bi}$, where b_i and $\bar{b}_i$ respectively represent actual value and mean value of each body measure, M_{bi} is the marginal change of that measure.
4. The golden rule of obesity: E (Overall Elasticity) is less than zero; BMI defined obesity: BMI>=30.

Table 13 Sensitivity and Specificity Result of Percent Body Fat

Group	Sensitivity	Specificity	False Negative	False Positive
Men	88.39%	56.27%	11.61%	43.73%
Women	99.87%	25.17%	0.13%	74.83%

Note:

1. Dependent variable is log (Income).

2. Explanatory Variables: age, age squared, marital status, education categories, time dummies, factor 1 and factor 2 for men, factor1 for women.

3. $E = Overall\_Elasticity = \sum_{i=1}^{6} \frac{(b_i - \bar{b}_i)}{\bar{b}_i} * M_{bi}$, where b_i and $\bar{b}_i$ respectively represent actual value and mean value of each body measure, M_{bi} is the marginal change of that measure.

4. The golden rule of obesity: E (overall Elasticity) is less than zero.

5. NIH-recommend cutoffs of PBF for obesity: 25% for men, 30% for women

Table 14 Sensitivity and Specificity Results of Waist Circumference

Group	**Sensitivity**	**Specificity**	**False Negative**	**False Positive**
Men	45.51%	78.18%	54.49%	21.82%
Women	86.35%	89.27%	13.65%	10.73%

Note:

1. Dependent variable is log (Income).

2. Explanatory Variables: age, age squared, marital status, education categories, time dummies, factor 1 and factor 2 for men, factor1 for women.

3. $E = Overall\_Elasticity = \sum_{i=1}^{6} \frac{(b_i - \bar{b}_i)}{\bar{b}_i} * M_{bi}$, where b_i and $\bar{b}_i$ respectively represent actual value and mean value of each body measure, M_{bi} is the marginal change of that measure.

4. The golden rule of obesity: E (overall Elasticity) is less than zero.

5. NIH-recommend cutoffs of waist circumference for obesity: 102cm for men, 88cm for women

Table 15 Prevalence of Obesity Measured by BMI, Waist Circumference, PBF and Overall Elasticity

	Percent Obese Defined Using BMI	**Percent Obese Defined Using Waist Circumference**	**Percent Obese Defined Using Percent Body Fat**	**Percent Obese Defined Using Overall Elasticity to Income**
Men	19.53%	33.53%	65.81%	49.45%
Women	19.16%	48.13%	87.21%	49.45%

Note:

1. $E = Overall\_Elasticity = \sum_{i=1}^{6} \frac{(b_i - \bar{b}_i)}{\bar{b}_i} * M_{bi}$, where b_i and $\bar{b}_i$ respectively represent actual value and mean value of each body measure, M_{bi} is the marginal change of that measure.

2. The golden rule of obesity: E (overall Elasticity) is less than zero.

3. NIH-recommend cutoffs of PBF for obesity: 25% for men, 30% for women

   NIH-recommend cutoffs of waist circumference for obesity: 102cm for men, 88cm for women

4. BMI defined obesity: BMI>=30

CHAPTER 7

CONCLUSIONS

In this study, the NHANES 1999-2004 database is used to develop multidimensional body measures which are based on six body measures. Findings show that body composition is more complicated for men than for women. Both OLS and 2SLS models showed that for men the multidimensional measures have better performance than currently used single indicators. However, this is not the case for women. Furthermore, the new criterion of obesity based on multidimensional measures significantly affects the categorization of people as obese and non-obese. Relative to BMI and waist circumference, multidimensional measures identify more obese men who were otherwise classified as non-obese.

Findings from body measures analysis show that the body compositions of men are more complicated than women. Based on the rules of number of factors to be retained, there are two factors for men and only one factor retained for women. Also, for men, besides the body weight and its related body measures, there are deviations of body fat and its distribution measures. That is to say, body weights can not necessarily represent body fat measures for men. One explanation is that at least some men are more dedicated to working out and building muscles. When the weight of a man increases, there may be an increase in the amount of muscle and a decrease in the amount of body fat.

Also, physiology plays a role. Most medical literature showed that the essential fat of average men is lower than average women, since women include sex-characteristic fat related to child-bearing. However, this is not necessarily so for women. When the weight of a woman increases, it is more likely that her body fat also increases. This explanation is consistent with findings of prior studies (Jago et al 2005; Caspersen et al 2000). For example, Caspersen et al (2000) showed that male respondents had 11.3 percent higher rate of regular and vigorous activity than their peer respondents.

With respect to the comparison of performance of the new measures and previous commonly used proxies (such as: BMI, percent body fat or waist circumferences), the hypothesis tests for both OLS and 2SLS models demonstrate that for men the new measures are better than the older single indicator. For women, however the results are inconsistent. The findings show that for men the more accurate way to measure obesity is to include more than one single indicator. At least for men, body weight, body fat and its distribution all have contributions in measuring obesity. Most of the prior studies used single indicator, for example, BMI with the assumption that it represent an adiposity level independent of body composition. This study demonstrates that this assumption is very limited for men. Some recent studies used single indicators, such as percent body fat and waist circumference, considering the influence of body composition, but they still can not catch the full picture to measure obesity.

After controlling for a comprehensive set of individual and time covariates, for women, four out of six body measures have relatively higher negative effects on income. When the value of body measures increase, the negative effects are even greater. My results for women are consistent with prior findings (Averett and Korenman 1996; Pagan and Davila 1997; Morris 2006), which showed that obesity measures had a significant negative impact on income. However, the case for men is more complicated. For average men, body weight, calf circumference and thigh circumference has a positive elasticity in relation to income. Waist circumference, subscapular skinfold and percent body fat has yet a negative elasticity. The overall elasticity for a male respondent depends on which group of body measures has greater effect. The results for men explain the inconsistencies prevalent in prior studies, some of which found no significant influence of obesity to income (Register and Williams 1990; Baum and Ford 2004; Sargent and Blanchflower 1994), while some of which showed significant effect (Gortmaker et al 1993; Averett and Korenman 1996). Whether the obesity measure has a positive or negative effect on income will highly depend upon the body composition, not just the body weight.

In this study, obesity defined using the overall elasticity of six body measures to income presents a very different picture of Americans, especially men. Relative to the new criterion, BMI identifies fewer obese men who are otherwise classified as obese. As for gender differences, BMI is better at identifying non-obese women rather than non-obese men. In addition, even though the order of categories of BMI correctly reflects the arrangement of the obese group, obesity defined using BMI cannot clearly classify the boundary between obese and non-obese. Some prior studies examined the performance of BMI-defined obesity (Smalley et al 1990; Wellens et al 1996; Cawley and Burkhauser 2008) and had similar findings. For example, Cawley and Burkhauser (2008) argued that 33.5 percent of sampled men classified as non-obese by BMI are actually obese by percent body fat; 14.2 percent of men sampled categorized as obese by BMI were actually not obese by percent body fat. One major explanation is that BMI does not distinguish body composition.

Waist circumference performs better at classifying obese and non-obese women than men. In addition, it identifies more obese people than BMI when obesity is defined by the new criterion. As Yusuf et al (2005) argued in their study, waist circumference better predicted heart attack than does BMI. The finding in this dissertation confirms the result of their research.

Compared with the new criterion, percent body fat-defined obesity brings a strikingly higher prevalence of obesity. The reason is that percent body fat has an even lower threshold of obesity. In other words, larger percentages of people are classified as obese using percent body fat threshold. Cawley and Burkhauser (2008) also had similar findings. They compared the performances between BMI and percent body fat and found that the latter one tended to classify three times as many as obese as BMI for women and over two times for men.

Policy Implications

This study suggests some aspects that policy makers should address in the future. First, the findings from this dissertation suggest that more body measures should be included in measuring obesity, but the reality is that there are few datasets containing relevant information for body measures. Even though NHANES has data on body measures, it only includes very limited socioeconomic information. The reason for this situation is partly because of the high cost of collecting such data. I hope the results from this study can lead to more government grants on datasets which can provide such information.

Second, some additional conditions should be added to the clinical guidelines in terms of defining obesity, at least for men. According to the NIH (1998), the assessment of a patient for the risk status considers the patient's BMI, waist circumference, and overall risk status. However, multidimensional measures in this study proof that at least for men, it is not only the location or distribution of body fat that matters, but also the amount of that fat. Thus, more measures are necessary to be included in assessing man's risk status of obesity.

Finally, more workplace programs should be launched to keeping people away from obesity. As suggested from this study, the more possible people become obese, the more likely they will end up with lower income. Therefore, helping in the prevention of obesity can be a very effective way to increase income. Specific programs can aim at diet, exercise, and weight loss.

Limitations and Further Directions

This study has some limitations that could be addressed in further research. First, little data on health status, labor market activity is included in the analysis. The NHANES data contain rich information in measured body composition, such as weight, height, waist circumference, and percent body fat. However, a key limitation of the NHANES database is that it contains little data on socioeconomic outcomes. Prior studies showed that these variables have effects on income (Averett and Korenman 1996; Cawley 2000).

Second, the role of education associated with both obesity and income should be addressed in further research. In this study education acts as a control variable which is assumed to be not influenced by obesity. However, prior studies had consistently mentioned the effect of education and schooling on income or specifically speaking, labor market outcomes (Morris 2006; Grabner 2009). For instance, Grabner (2009) found a strong and statistically significant negative effect of additional schooling on BMI measures, especially on women. Therefore, the potential interaction between education and obesity and their effect on income should be addressed in more sophisticated structural models in future studies.

Third, this study only conducted separate gender analysis due to the limited data. However, there were prior studies investigated the effect of race and found significant results (Averett and Korenman 1999; Cawley and Burkhauser 2008). Cawley and Burkhauser (2008) presented significant results that African American people tended to have more fat-free mass than white people. That is to say, the effect of obesity is greater for whites than blacks. Therefore, it is necessary to reexamine by separate race groups to identify the effect of multidimensional measures of obesity.

Finally, the result is limited to Americans. US residents have incomes, culture and lifestyles that may differ from those elsewhere. As more international data become available, it would be most instructive to see whether these findings generalize across populations in other countries, or whether separate analyses must be done by country.

APPENDIX

Table A 1: Regression of Log Income with Factor Components Included

Variables	Men		Women	
	OLS	2SLS	OLS	2SLS
Intercept	9.2387***	8.5438***	8.2717***	7.9539***
	(0.1360)	(0.4252)	(0.1387)	(0.1876)
Edu_Some College	0.2149***	0.1714***	0.3724***	0.3497***
	(0.0376)	(0.0419)	(0.0278)	(0.0287)
Edu_College	0.4554***	0.3481***	0.6409***	0.5554***
	(0.0358)	(0.0470)	(0.0353)	(0.0652)
Married	0.1464***	0.1295***	0.1866***	0.1834***
	(0.0291)	(0.0312)	(0.0433)	(0.0429)
Age	0.0382***	0.0496***	0.0699***	0.0816***
	(0.0047)	(0.0099)	(0.0056)	(0.0062)
Age_Sqr	-0.0003***	-0.0003***	-0.0007***	-0.0007***
	(4.5E-05)	(6.2E-05)	(5.2E-05)	(4.7E-05)
Time2	0.0874*	0.0596	0.0405	0.0202
	(0.0463)	(0.0433)	(0.0609)	(0.0562)
Time3	0.0892*	0.0868*	0.0875	0.0987
	(0.0500)	(0.0447)	(0.0613)	(0.0598)
Whites	0.3680***	0.5720***	0.3974***	0.3656***
	(0.0447)	(0.1142)	(0.0548)	(0.0555)
Factor 1	1.3585***	4.6372***	-1.1013***	-4.6056*
	(0.2356)	(1.4343)	(0.2161)	(2.3855)
Factor 2	-0.4784**	-4.6602*		
	(0.2355)	(2.4063)		
N of Observations	3181	3181	2736	2736
Weighted Count	55038196	55038196	52061290	52061290
R-Square	0.2044		0.2982	
Adjusted R-Squre	0.2019		0.2959	

Notes:

1. Dependent variable is log (Income).

2. Standard error in parentheses

3. Asterisks indicate level of statistical significance: ***p<0.01, **p<0.05, *p<0.1

Table A 2: Regression of Log Income with Percent Body Fat Included

Variables	**Men**		**Women**	
	OLS	2SLS	OLS	2SLS
Intercept	9.2366***	9.0692***	8.5067***	9.5707***
	(0.1285)	(0.3896)	(0.1482)	(0.5500)
Edu_Some College	0.2303***	0.2298***	0.3785***	0.3707***
	(0.0395)	(0.0397)	(0.0283)	(0.0274)
Edu_College	0.4885***	0.4896***	0.6594***	0.5944***
	(0.0370)	(0.0370)	(0.0355)	(0.0414)
Married	0.1553***	0.1507***	0.1876***	0.1879***
	(0.0290)	(0.0296)	(0.0433)	(0.0428)
Age	0.0374***	0.0355***	0.0676***	0.0789***
	(0.0046)	(0.0050)	(0.0056)	(0.0054)
Age_Sqr	-0.0004***	-0.0004***	-0.0006***	-0.0007***
	(4.38E-5)	(4.23E-5)	(5.12E-5)	(4.68E-5)
Time2	0.0998**	0.1012**	0.0444	0.0247
	(0.0465)	(0.0479)	(0.0623)	(0.0580)
Time3	0.0973*	0.0937*	0.0838	0.0820
	(0.0516)	(0.0497)	(0.0631)	(0.0572)
Whites	0.3209***	0.2894***	0.4084***	0.4169***
	(0.0454)	(0.0834)	(0.0548)	(0.0528)
Percent Body Fat	0.0045*	0.0145	-0.0047**	-0.0419**
	(0.0023)	(0.0197)	(0.0022)	(0.0169)
N of Observations	3181	3181	2736	2736
Weighted Count	55038196	55038196	52061290	52061290
R-Square	0.1917		0.2923	
Adjusted R-Squre	0.1894		0.2890	

Notes:

1. Dependent variable is log (Income).

2. Standard error in parentheses

3. Asterisks indicate level of statistical significance: ***p<0.01, **p<0.05, *p<0.1

Table A 3: Regression of Log Income with Waist Circumference Included

Variables	**Men**		**Women**	
	OLS	2SLS	OLS	2SLS
Intercept	9.1640***	8.9784***	8.7682***	10.1611***
	(0.1471)	(0.6116)	(0.1536)	(0.6522)
Edu_Some College	0.2298***	0.2288***	0.3745***	0.3569***
	(0.0395)	(0.0403)	(0.0278)	(0.0278)
Edu_College	0.4891***	0.4906***	0.6455***	0.5675***
	(0.0370)	(0.0366)	(0.0350)	(0.0468)
Married	0.1553***	0.1528***	0.1872***	0.1860***
	(0.0288)	(0.0294)	(0.0434)	(0.0426)
Age	0.0367***	0.0346***	0.0692***	0.0795***
	(0.0047)	(0.0069)	(0.0056)	(0.0052)
Age_Sqr	-0.0004***	-0.0003***	-0.0007***	-0.0007***
	(4.52E-5)	(5.74E-5)	(5.18E-5)	(4.9E-5)
Time2	0.0973**	0.0951**	0.0454	0.0404
	(0.0465)	(0.0445)	(0.0615)	(0.0567)
Time3	0.0948*	0.0898*	0.0906	0.1140*
	(0.0465)	(0.0481)	(0.0614)	(0.0590)
Whites	0.3220***	0.3057***	0.3945***	0.3493***
	(0.0443)	(0.0737)	(0.0550)	(0.0566)
Waist Circumference	0.0022*	0.0049	-0.0054***	-0.0242***
	(0.0012)	(0.0083)	(0.0010)	(0.0078)
N of Observations	3181	3181	2736	2736
Weighted Count	55038196	55038196	52061290	52061290
R-Square	0.1916		0.2980	
Adjusted R-Squre	0.1893		0.2957	

Notes:

1) Standard error in parentheses

2) Asterisks indicate level of statistical significance: ***p<0.01, **p<0.05, *p<0.1

Table A 4: Regression Results of α

Variables	Men		Women	
	OLS	**2SLS**	**OLS**	**2SLS**
Intercept	-0.5556	0.4235	-4.4236	0.9340
	(1.9112)	(2.8420)	(3.1790)	(4.2991)
Edu_Some College	-0.0144	0.0130	-0.1908	0.0352
	(0.0553)	(0.0800)	(0.1452)	(0.1924)
Edu_College	-0.0312	0.0323	-0.3272	0.0559
	(0.1052)	(0.1450)	(0.2460)	(0.3452)
Married	-0.0089	0.0052	-0.0953	0.0182
	(0.0480)	(0.0561)	(0.0824)	(0.1049)
Age	-0.0020	0.0007	-0.0354	0.0077
	(0.0084)	(0.0111)	(0.0267)	(0.0385)
Age_Sqr	2.0E-05	-8.6E-06	0.0003	7.1E-05
	(8.4E-05)	(1.1E-04)	(0.0003)	(0.0004)
Time2	-0.0057	0.0037	-0.0223	0.0037
	(0.0549)	(0.0491)	(0.0593)	(0.0564)
Time3	-0.0054	0.0023	-0.0406	0.0066
	(0.0578)	(0.0541)	(0.0659)	(0.0550)
Whites	-0.0200	0.0153	-0.1933	0.0296
	(0.0809)	(0.0034)	(0.1681)	(0.2136)
BMI	-0.0022	0.0089**	0.0083*	-0.0060
	(0.0041)	(0.0034)	(0.0047)	(0.0024)**
$\hat{LnY}_{2i}$	1.0645***	0.9350***	1.5068***	0.9041*
	(0.2089)	(0.3033)	(0.3712)	(0.5200)
N of Observations	3181	3181	2736	2736
Weighted Count	55038196	55038196	52061290	52061290
R-Square	0.2043		0.2990	
Adjusted R-Squre	0.2018		0.2964	

Notes:

1) Standard error in parentheses

2) Asterisks indicate level of statistical significance: ***p<0.01, **p<0.05, *p<0.1

Table A 5: Regression Results of α'

Variables	Men OLS	Men 2SLS	Women OLS	Women 2SLS
Intercept	21.3673**	3.2783	17.6142***	1.4021
	(8.6459)	(5.2720)	(5.3300)	(2.7575)
Edu_Some College	0.5083**	0.0678	0.7946***	0.0613
	(0.2000)	(0.1361)	(0.2391)	(0.1247)
Edu_College	1.0806**	0.1439	1.3764***	0.0954
	(0.4417)	(0.2728)	(0.4201)	(0.2215)
Married	0.3429**	0.0460	0.3965***	0.0325
	(0.1357)	(0.0931)	(0.1159)	(0.0679)
Age	0.0851**	0.0138	0.1460***	0.0150
	(0.0338)	(0.0208)	(0.0433)	(0.0249)
Age_Sqr	-0.0008**	-0.0001	-0.0014***	-0.0001
	(0.0003)	(0.0002)	(0.0004)	(0.0002)
Time2	0.2111**	0.0244	0.0898	0.0028
	(0.1015)	(0.0586)	(0.0701)	(0.0598)
Time3	0.2088*	0.0265	0.1836**	0.0180
	(0.1073)	(0.0670)	(0.0835)	(0.0595)
Whites	0.7854**	0.1543	0.8493***	0.0638
	(0.2930)	(0.2060)	(0.2537)	(0.1470)
Factor1	18.6564***	13.1716***	-1.6594***	-0.9570***
	(4.2391)	(2.4059)	(0.4091)	(0.2054)
Factor2	0.2489	-5.0374**		
	(4.0618)	(2.3255)		
$\widehat{LnY_{1i}}$	-1.2929	0.6396	-1.1220*	0.8221***
	(0.9209)	(0.5622)	(0.6378)	(0.3349)
N of Observations	3181	3181	2736	2736
Weighted Count	55038196	55038196	52061290	52061290
R-Square	0.2054		0.3017	
Adjusted R-Squre	0.2026		0.2991	

Notes

1) Standard error in parentheses

2) Asterisks indicate level of statistical significance: ***p<0.01, **p<0.05, *p<0.1.

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ABSTRACT

ECONOMIC ANALYSIS OF MULTIDIMENSIONAL MEASURES OF OBESITY

by

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This study develops multidimensional measures of obesity based on six body measures, namely, weight, maximal calf circumference, thigh circumference, subscapular skinfold, waist circumference and percent body fat. Previous studies have used body mass index (BMI) as the measure of obesity. BMI does not fully consider body composition and is even more limited when applied to a population of subjects that are heterogeneous in muscularity, age, or bodyweight. Moreover, the use of BMI to classify people as obese and non-obese may result in misclassification problems. More recent studies have chosen some alternative measures of obesity, but there is no consensus on which one is the most accurate one.

This study employs the NHANES 1999-2004 database. To account for the complex survey design of the database, SAS-callable SUDAAN version 10 is used to conduct the analysis. The study sample includes respondents aged 20 and over, non-Hispanic persons who are examined, and women who are not pregnant. There are 2,736

women and 3,181 men who represent respectively, 52.06 million (men) and 55.04 million (women) in the overall population in the study.

In coping with the multicollinearity concerns over the correlated body measures, factor analysis is chosen here. In this study, the baseline model is OLS. Due to the potential endogeneity of obesity, Hausman specification tests are performed, and their results show that 2SLS is preferred over OLS for both gender.

The findings from body measures analysis show that the body compositions of men are more complicated than women. For men, besides the body weight and its related body measures, there are deviations of body fat and its distribution measures. The hypothesis tests for both OLS and 2SLS models demonstrate that for men the new multidimensional measures of obesity are better than the older single indicator in modeling income. For women, however the results are inconsistent.

In this study, obesity defined using the overall elasticity of six body measures to income presents a very different picture of Americans, especially men. Relative to the new criterion, BMI identifies fewer obese men who are otherwise classified as obese. Waist circumference identifies more obese people than BMI when obesity is defined by the new criterion.

In sum, the findings from this dissertation suggest that more body measures should be included in measuring obesity, at least, for men. Relative to most single indicators, multidimensional measures identify more obese men who were otherwise classified as non-obese. The study suggests that policy makers should pay more attention of the possible underestimation of the population of obese men.

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