Quantifying Obesity in Economic Research: How Misleading is the Body Mass Index?

Joanna C. Parks, Aaron Smith, and Julian M. Alston
University of California, Davis

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BMI is Ubiquitous

- Economists and epidemiologists use BMI to:
  - Estimate relative risk of death and disease for overweight and obese.
  - Calculate costs of obesity and related conditions.
  - Estimate effect of economic factors on obesity.

- \(Q:\) But what if BMI poorly predicts obesity and negative health outcomes?

- \(Q:\) How might economist’s estimates be biased when BMI used as a proxy for obesity?
What We Do

- Evaluate BMI as a predictor of obesity as measured by percent body fat (%BF).
  - Quantify nature and magnitude of measurement error bias.

- Evaluate BMI as a predictor of morbidity and mortality relative to our obesity index.
  - Quantify nature and magnitude of measurement error bias.
  - Identify variables associated with bias in models that use BMI.

Obesity Measures Differ
**Obesity Measures Differ**

<table>
<thead>
<tr>
<th>BMI&lt;18.5</th>
<th>25&lt;BMI&lt;30</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBF&lt;8</td>
<td>20&lt;BF&lt;30</td>
</tr>
</tbody>
</table>

No metabolic abnormalities
1 symptom of TMS
3 symptoms of TMS

**Same BMI, but Twice the Percent Body Fat**

→ Man A:
BMI = 31.74
%BF = 13
Wt(kg) = 106.3
Ht (m) = 1.83 m

← Man B →:
BMI = 31.67
%BF = 26.3
Wt(kg) = 98.1
Ht (m) = 1.76
**BMI as a Proxy for %BF**

**Men**

- Red indicates different BMI and %BF weight category
- Blue indicates same BMI and %BF weight category

Note: The implied healthy/normal % body fat range for men is 17.1-21.9%.

**Data: NHANES III**

  - Individual and household characteristics
  - Lab tests and exam measurements
  - Mortality follow-up (December, 2006)
  - Diet recall
- Bioelectrical impedance analysis (BIA) readings allow for the calculation of %BF.

- 30,818 observations w/ exam data.
  - Have PBF and all other variables for 14,958 respondents.
BMI as Proxy for %BF

- Would like to model determinants of obesity and estimate:
  1. \( \%BF_i = \beta'X_i + \varepsilon_i \)
     - \( X \)s are individual characteristics,
     - \( \beta \)s are the coefficients of interest.
- But economist (usually) does not observe \( \%BF \), so they estimate:
  2. \( BMI_i = \gamma'X_i + u_i \)

Measurement Error Bias

- Measurement error bias exists when \( X \)i contains more or different information about BMI than it does about \( \%BF \)
- Measurement error bias present if \( \delta \neq 0 \) in the regressions:
  3. \( \%BF_i = \alpha BMI_i + \delta'X_i + \nu_i \)
Interpreting Measurement Error Bias: $\delta > 0$

Individual Characteristics (causes)

Estimated effect of $X$ on obesity biased downward

Estimated effect of $X$ on health risk biased upward

Obesity

Health Outcomes (consequences)

Percent Body Fat Measurement Error Regressions

<table>
<thead>
<tr>
<th></th>
<th>Women</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI</td>
<td>0.94**</td>
<td>0.77**</td>
</tr>
<tr>
<td>Age</td>
<td>0.23**</td>
<td>0.11</td>
</tr>
<tr>
<td>Age^2</td>
<td>-0.002**</td>
<td>-0.001</td>
</tr>
<tr>
<td>Black</td>
<td>0.80**</td>
<td>0.31</td>
</tr>
<tr>
<td>Current Smoker</td>
<td>-0.57*</td>
<td>-0.41</td>
</tr>
<tr>
<td>Ex-Smoker</td>
<td>0.15</td>
<td>0.10</td>
</tr>
<tr>
<td>Menopause</td>
<td>0.63*</td>
<td></td>
</tr>
<tr>
<td>&lt; 5'Yrs HRT</td>
<td>0.37</td>
<td></td>
</tr>
<tr>
<td>&gt; 5'Yrs HRT</td>
<td>0.91**</td>
<td></td>
</tr>
<tr>
<td>Family History T2D</td>
<td>-0.01</td>
<td>-0.01</td>
</tr>
<tr>
<td>Insomnia Spells</td>
<td>0.2</td>
<td>0.91</td>
</tr>
<tr>
<td>Hypersomnia Spells</td>
<td>-0.73</td>
<td>0.14</td>
</tr>
<tr>
<td>Constant</td>
<td>4.36*</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Notes: **p<0.01, *p<0.05, HRT=hormone replacement therapy (estrogen).

$$\%BF_j = \alpha BMI_i + \delta^*X_j + \nu_i$$
Measuring Obesity as Increased Health Risk from Excess Fat

- $\bar{F}_i$ is a “healthy” amount of fat

- $D_i$ equals one in the event of a bad health outcome.
  - Type 2 diabetes, CVD, death, death from obesity related cause.

- Then obesity index for $i$ is:
  $$OB_i = Pr(D_i = 1|F_i, X_i) - Pr(D_i = 1|\bar{F}_i, X_i)$$

The Obesity Index

- Combines the effects of excess adipose tissue, abdominal obesity, and metabolic abnormalities on the risk of disease and death.
5. \( \Pr(D_i = 1|F_i, X_i) = [\text{Obesity Index}_i] + \theta' X_i \)

6. \( \Pr(D_i = 1|F_i, X_i) = \phi_{0i} + \alpha \text{BMI}_i + \eta' X_i \)

- Measurement error bias problem if:
  \( \eta - \theta = \delta \neq 0 \)
- i.e., when the coefficients on \( X \) differ depending on which measure of fatness is used to predict health outcomes.

**Interpreting Measurement Error Bias: \( \delta > 0 \)**

- **Individual Characteristics**
  - Estimated effect of \( X \) on obesity biased downward
  - Estimated effect of \( X \) on health risk biased upward

- **Obesity** ➔ **Health Outcomes**
### BMI vs. Obesity Index Effects on Type 2 Diabetes and CVD

<table>
<thead>
<tr>
<th>BMI vs. Obesity Index Effects on Health Outcomes</th>
<th><strong>Type 2 Diabetes</strong></th>
<th><strong>Cardiovascular Disease</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>BMI</strong></td>
<td>0.006**</td>
<td>0.003**</td>
</tr>
<tr>
<td>%BF</td>
<td>-0.006</td>
<td>0.02</td>
</tr>
<tr>
<td>%BF²</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>%BF₁₀₀</td>
<td>0.001</td>
<td>-0.004*</td>
</tr>
<tr>
<td>(%BF₁₀₀)²</td>
<td>0.0001**</td>
<td>0.00006*</td>
</tr>
<tr>
<td>Female*%BF</td>
<td>0.005</td>
<td>-0.002</td>
</tr>
<tr>
<td>Female*%BF²</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Black*%BF</td>
<td>-0.007</td>
<td>-0.007</td>
</tr>
<tr>
<td>Black*(%BF)²</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Waist Circumference</td>
<td>0.00136*</td>
<td>-0.001</td>
</tr>
</tbody>
</table>

**Criteria for Metabolic Syndrome:**
- Triglycerides: -0.012* , 0.026*  
- HDL Cholesterol: 0.001 , 0.046**  
- Blood Pressure: 0.625** , 0.492**  
- QUICKI: -5.450** , 0.162  
- (Blood Pressure)*(QUICKI): -4.025** , -3.074**  
- (Abdominal Obesity)*(QUICKI): -0.144* , 0.049  
- (BP)*(Abdominal Obesity): -0.038** , -0.032  

**R²**: 0.230 | 0.069 | 0.080 | 0.060

### Measurement Error Bias in BMI vs. Obesity Index Effects on Health Outcomes

<table>
<thead>
<tr>
<th>Measurement Error Bias in BMI vs. Obesity Index Effects on Health Outcomes</th>
<th><strong>Type 2 Diabetes</strong></th>
<th><strong>CVD</strong></th>
<th><strong>Mortality</strong></th>
<th><strong>Obesity Related COD</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>δs</strong></td>
<td><strong>δs</strong></td>
<td><strong>δs</strong></td>
<td><strong>δs</strong></td>
<td></td>
</tr>
</tbody>
</table>
| **Female** | -0.01994 | -0.04751 | -0.14233 | -0.05444  
| **Black** | -0.07193 | -0.10068 | -0.17422 | 0.04697  
| **Age** | 0.00203** | 0.00226** | 0.00144** | 0.00516**  
| **Age²** | -0.00001 | -0.00002** | 0.00000 | -0.00003  
| **Current Smoker** | 0.00244 | 0.00519 | 0.00124 | 0.01122  
| **Former Smoker** | 0.00636 | 0.00731** | 0.00229 | 0.01093  
| **Alcohol Cal Share** | -0.00167** | -0.00091** | 0.00028 | -0.00115**  
| (Alcohol Cal Share)² | 0.00001 | 0.00001 | 0.00000 | 0.00002  
| **Family History** | 0.02279** | 0.00881** | 0.00739** | 0.01094**  
| **T2D** | -0.00324** | -0.00091 | -0.00166** | -0.00102**  
| **Income to Poverty Ratio** | -0.00002 | 0.0036 | -0.00088 | -0.01525  
| **Insomnia Spells** | 0.00156 | -0.00156 | 0.00072 | 0.01276  
| **Hypersomnia Spells** | 9.595 | 4.051 | 3.423 | 1.369  
| **F-Stat** | 0.000 | 0.000 | 0.000 | 0.173  

**Notes:** Standard errors in parentheses, **p<0.01, *p<0.05
Conclusion

- BMI not closely related to obesity as measured by PBF or our obesity index.
  - Low $R^2$ and many people misclassified by BMI vs. PBF.
- Age, sex, race, smoking and alcohol affect BMI and PBF differently.
  - Bias in estimated causes of obesity
  - Might misinterpret of the causes and their relative importance in explaining obesity.
- The measurement error is more than just noise, it is systematically related to specific variables.
  - Misleading results for causes and consequences of obesity.
Thank You!