"*Leave all the afternoon for exercise and recreation, which are as necessary as reading. I will rather say more necessary because health is worth more than learning.*" - Thomas Jefferson

"Lack of activity destroys the good condition of every human being, while movement and methodical physical exercise save it and preserve it." - Plato

Quantifying Obesity in Economic Research

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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.

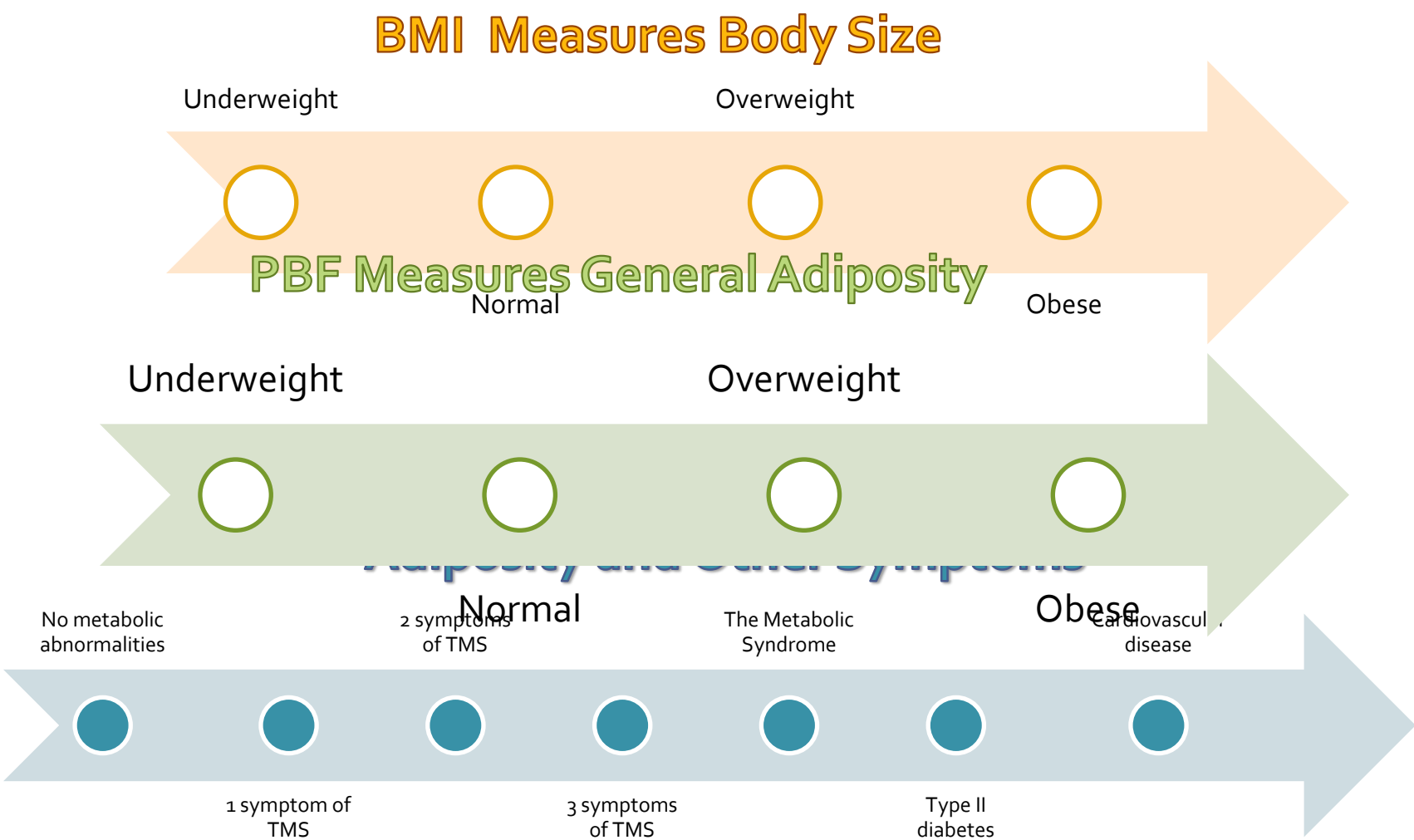
- *Q:* But what if BMI poorly predicts obesity and negative health outcomes?

- *Q:* How might economist's estimates be biased when BMI used as a proxy for obesity?

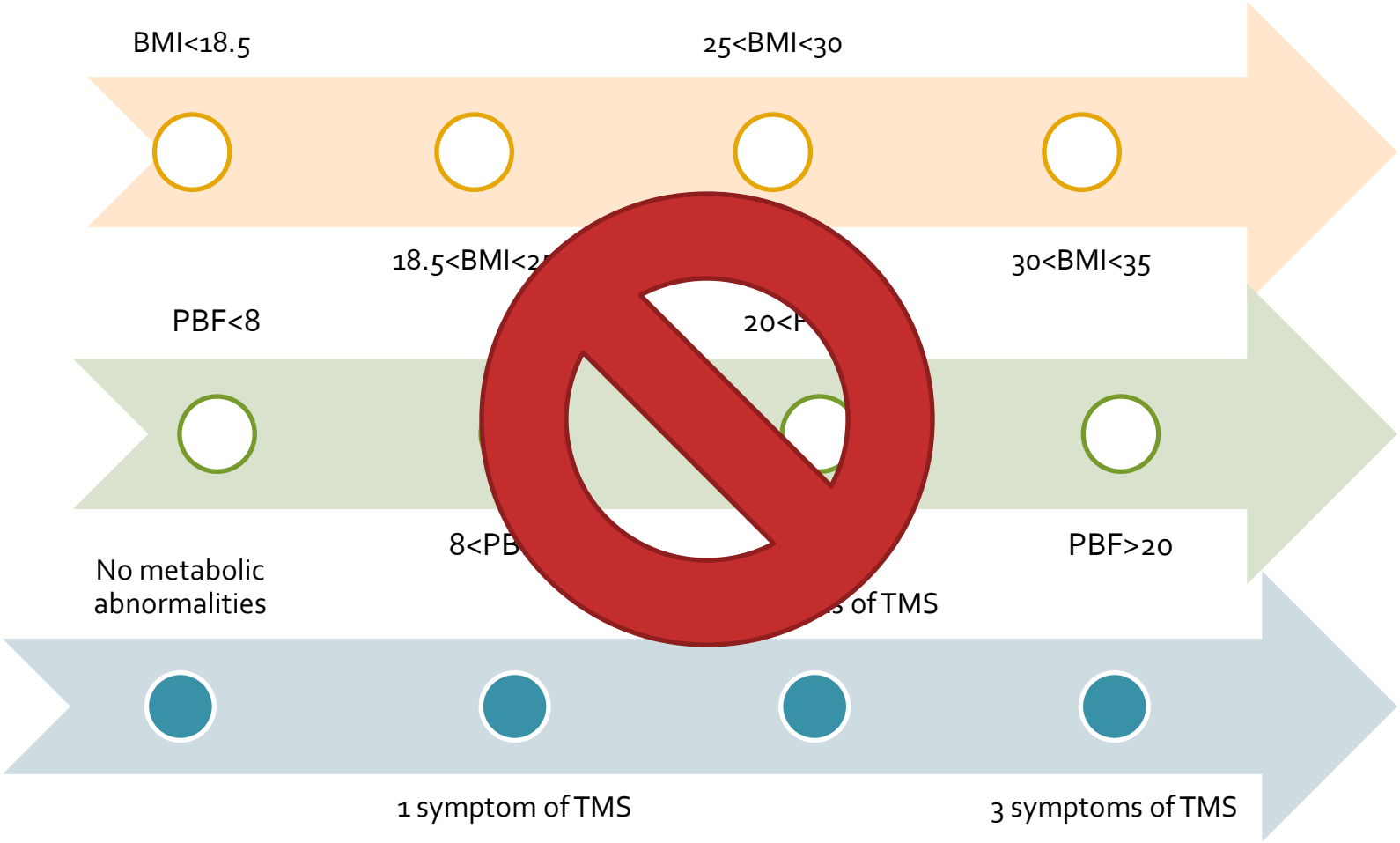
What We Do

- Evaluate BMI as a predictor of obesity as measured by percent body fat (PBF) and the metabolic syndrome (TMS).
  - 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.

Obesity Measures Differ



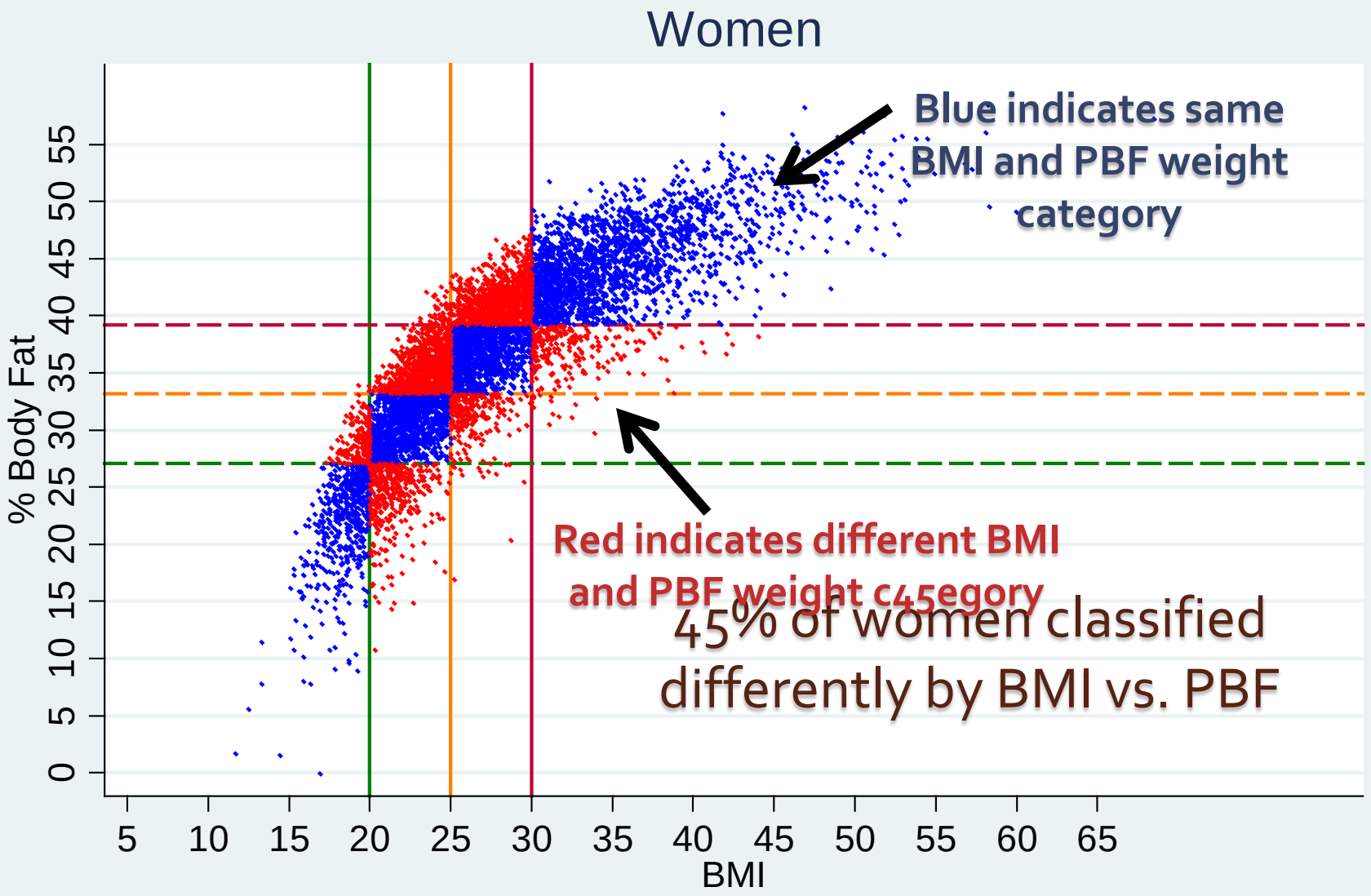
Obesity Measures Differ



Data: NHANES III

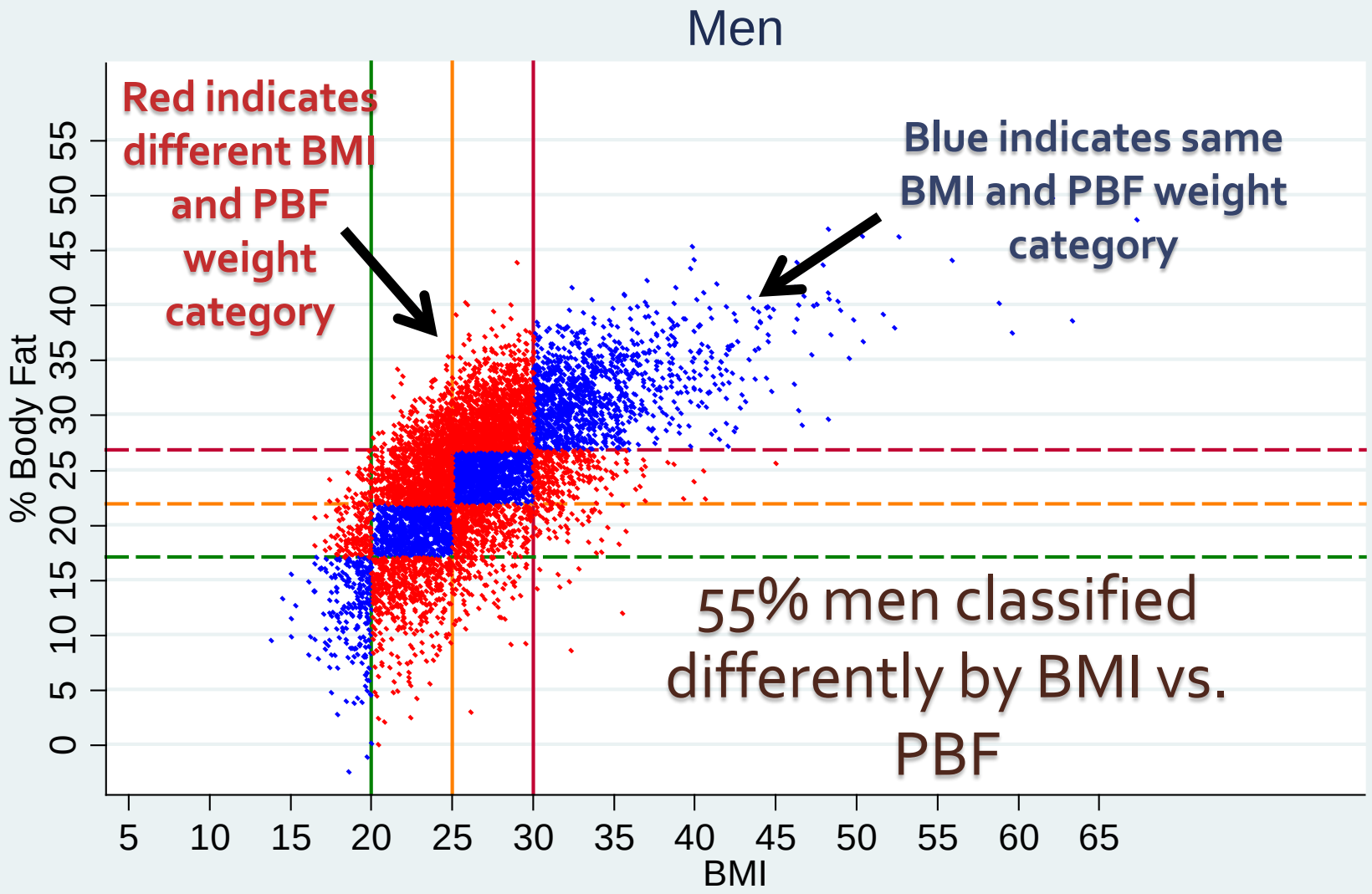
- Third National Health and Nutrition Examination Survey, conducted 1988-1994.
  - Individual and household characteristics
  - Lab tests and exam measurements
  - Mortality follow-up
  - Diet recall
- Bioelectrical impedance analysis (BIA) readings allow for the calculation of PBF.
- 30,818 observations w/ exam data.
  - Have PBF and all other variables for 14,958 respondents.

BMI as a Proxy for PBF



Note: The implied healthy/normal % body fat range for women is 27.1-33.2%.

BMI as a Proxy for PBF



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

BMI as Proxy for PBF

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

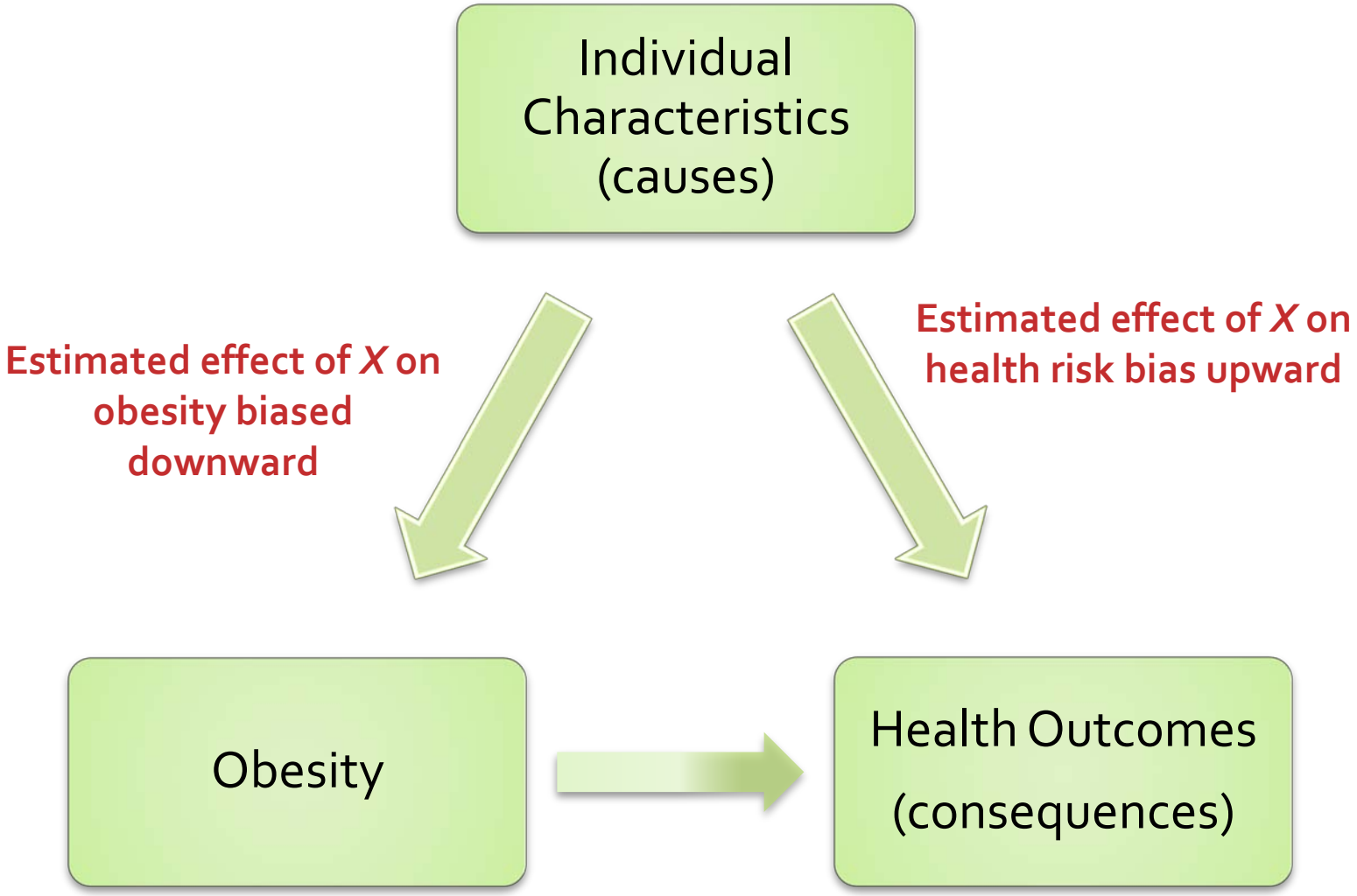
Measurement Error Bias

- Measurement error bias exists when X_i contains more or different information about BMI than it does about PBF

- Measurement error bias present if $\delta \neq 0$ in the regressions:

3. $$PBF_i = \alpha BMI_i + \delta' X_i + \nu_i$$

Interpreting Measurement Error Bias: $\delta > 0$



Percent Body Fat Measurement Error Regressions

	Women	*Men*
BMI	1.01**	0.83**
Age	0.07**	0.05
Age^2	-0.0006**	-0.0002
Black	0.90**	0.31
Current Smoker	-0.29	0.02
Ex-Smoker	-0.01	0.35
Heavy Alcohol Use	-0.21	-0.32
Menopause	0.65**	
< 5 Yrs HRT	0.28	
> 5 Yrs HRT	1.05**	
Insomnia Spells	-0.28	-0.02
Hypersomnia Spells	-0.06	-0.37
Constant	6.25**	-0.02
Observations	7,738	7,220
R^2	0.72	0.46
Null F-Stat	48.08	33.40
Null p-value	0.00	0.00

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

The Metabolic Syndrome Measurement Error Regressions

	Women	*Men*
BMI	0.0316**	0.0473**
Age	-0.0013	0.0094**
Age^2	0.0001**	-0.0000
Black	-0.0621**	-0.0935**
Current Smoker	0.0251	0.0736**
Ex-Smoker	0.0144	0.0642**
Heavy Alcohol Use	-0.0265	-0.0539**
Menopause	0.0950**	
< 5 Yrs HRT	0.0255	
> 5 Yrs HRT	-0.0008	
Insomnia Spells	0.0150	0.0038
Hypersomnia Spells	0.0468	0.0022
Constant	-0.6773**	-1.2756**
Observations	7,738	7,220
R^2	0.34	0.35
Null F-Stat	34.10	34.48
Null p-value	0.00	0.00

Notes: **p<0.01, *p<0.05. HRT=hormone replacement therapy (estrogen). TMS is binary indicator for having the metabolic syndrome according to IDF definition.

Measuring Obesity as Increased Health Risk from Excess Fat

- $\overline{F}_i$ is a "healthy" amount of fat
- D_i equals one in the event of a bad health outcome.
- Then obesity index for *i* is:

$$OB_i = Pr\left(D_i = 1 \middle| F_i, X_i\right) - Pr\left(D_i = 1 \middle| \overline{F}_i, X_i\right)$$

The Obesity Index

- Combines the effects of excess adipose tissue, abdominal obesity, and metabolic abnormalities on the risk of disease and death.
  - TMS_i = the # of TMS criteria satisfied by *i*

4.

$$Pr\left(D_i = 1 \middle| F_i, X_i\right) = \beta_0 + \beta_1 PBF_i + \beta_2 \left(PBF_i\right)^2 + \beta_3 Female_i \times PBF_i + \beta_4 Female_i \times \left(PBF_i\right)^2 + \beta_5 Black_i \times PBF_i + \beta_6 Black_i \times \left(PBF_i\right)^2 + \beta_7 TMS_i + \beta_8 Female_i \times TMS_i + \beta_9 Black_i \times TMS_i + \theta' X_i$$

Measurement Error Bias

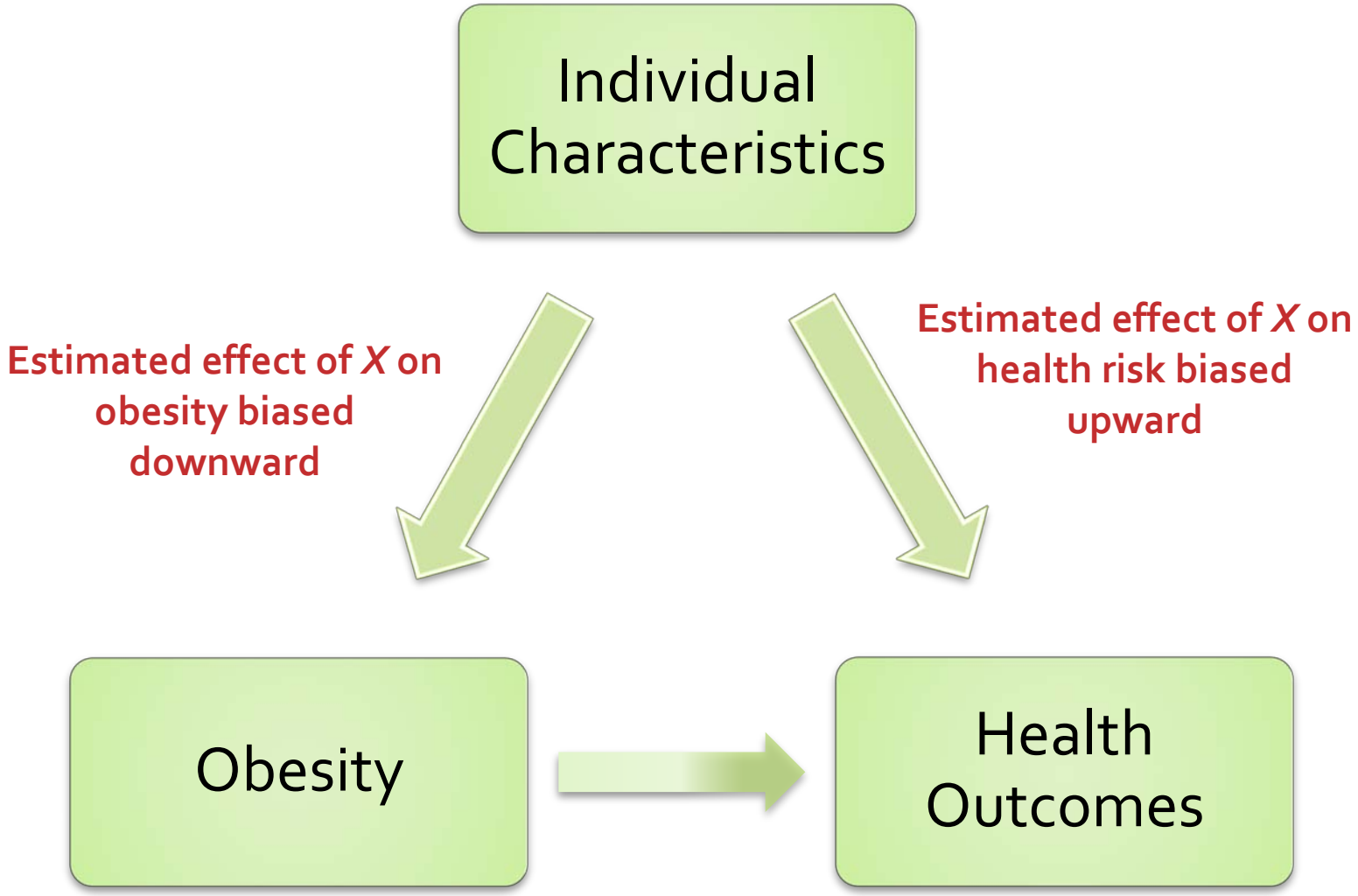
5. $Pr\left(D_i = 1 \middle| F_i, X_i\right) = \{\text{obesity index}_i\} + \theta' X_i$
6. $Pr\left(D_i = 1 \middle| F_i, X_i\right) = \phi_{0i} + \alpha BMI_i + \eta' X_i$

- 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: $\delta > 0$



BMI vs. PBF-TMS Obesity Index Effects on Health Outcomes

	Type II Diabetes		Death		Death from Obesity Related Cause	
	(1)	(2)	(3)	(4)	(5)	(6)
BMI		0.0064**		-0.001		0.0127**
PBF	-0.012*		-0.0037		-0.009	
PBF^2	0.00027*		0.00009		0.0002	
TMS	0.033**		-0.006		0.074**	
Female*PBF	-0.0004		0.00032		0.02991	
Female*$(PBF)^2$	-0.0001		-0.00003		-0.00056	
Black*PBF	-0.0033		-0.00780		0.00012	
Black*$(PBF)^2$	0.00005		0.00007		0.00015	
Female*(TMS)	0.0105		-0.00585		-0.02743	
Black*(TMS)	0.019*		0.01434*		-0.06230**	
R^2	0.08	0.06	0.22	0.22	0.07	0.05

Measurement Error Biases in BMI vs. PBF-TMS Obesity Index Effects on Health Outcomes

	Type II Diabetes δ=(2)-(1)	Death δ=(4)-(3)	Death from Obesity Related Cause δ=(6)-(5)
Female	-0.110	-0.032	0.330
Black	-0.026	-0.133	-0.023
Age	**0.002***	0.000	**0.008****
Age^2	-0.00001	0.000	**-0.00005****
Current Smoker	**0.011****	-0.001	0.022
Former Smoker	**0.004***	0.001	**0.017***
Light Alcohol	0.000	0.000	-0.059
Moderate Alcohol	-0.007	0.002	-0.071
Heavy Alcohol	**-0.005****	-0.001	-0.009
Mother had Type II Diabetes	0.004	0.000	0.001
Poverty Income Ratio	0.000	0.000	0.002
Insomnia Spells	0.003	0.000	-0.008
Hypersomnia Spells	-0.001	0.002	0.019

Conclusion

- BMI not closely related to obesity as measured by PBF or TMS.
  - Low R^2 and many people misclassified by BMI vs. PBF.
- Age, sex, race, smoking and alcohol affect BMI and PBF (and TMS) 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.

"My law firm is suing your law firm because when your law firm sued the tobacco industry, you drove up the price of cigarettes, smoking rates went down, and consequently more people got fat. We're demanding from you the billions of dollars obesity costs society each year."