Correction for measurement error in nutritional epidemiology
A measurement error model allowing for never-consumers

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\textsuperscript{2}MRC Centre for Nutritional Epidemiology in Cancer Prevention and Survival, University of Cambridge

ISCB 2009 Conference
# Background and motivation

## Question of interest

What is the association between ‘usual’ dietary intake and disease?

‘Usual’ intake of foods and nutrients: Long term average daily intake

### EPIC-Norfolk
- European Prospective Investigation into Cancer and Nutrition
- Cohort of 25,000 individuals

### UK Dietary Cohort Consortium
- 7 UK cohorts: 153,000 individuals

## Measuring dietary intake using diet diaries

- EPIC-Norfolk: 7-day diet diaries
- UK Dietary Cohort Consortium: 4-7 day diet diaries
Measurement error in diet diaries

- A diet diary collects detailed information about dietary intake
- ...but it’s just a ‘snapshot’ of the diet
- Measurements are subject to random within-person error

A specific source of measurement error in diet diaries
- We might not capture consumption of foods which are often not eaten every day, e.g. alcohol, meat
- Distinguish between never-consumers and episodic-consumers

Example: Alcohol intake in EPIC-Norfolk

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Correcting for measurement error

Measurement error results in biased estimates of the diet-disease association

\[
T_i = \text{True average daily intake} \\
R_{ij} = j^{th} \text{ diet diary measurement}, \quad R_i = \{R_{i1}, \ldots, R_{iJ}\} \\
D_i = \text{disease status (0/1)}
\]

True diet-disease association:

\[
\Pr(D_i = 1 | T_i) = \frac{\exp(\alpha + \beta T_i)}{1 + \exp(\alpha + \beta T_i)}
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Estimating \( \beta \) when we can’t observe \( T_i \):

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\Pr(D_i = 1 | R_i) \approx \frac{\exp(\alpha + \beta E(T_i|R_i))}{1 + \exp(\alpha + \beta E(T_i|R_i))}
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This is called regression calibration
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Performing the regression calibration

To perform the regression calibration we need to find $E(T_i|R_i)$

### Linear regression calibration model

$$T_i = \lambda_0 + \lambda_1^T R_i + e_i$$

To fit this model we need

- to assume $E(R_{ij}|T_i) = T_i$
- $\geq 2$ measurements $R_{ij}$
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Never-consumers and episodic-consumers

Is a linear regression calibration model appropriate when we have never-consumers and episodic-consumers?

Aims

1. Define a measurement error model which allows never- and episodic-consumers
2. Find $E(T_i|R_i)$ so that regression calibration can be performed
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Never- and episodic-consumers (NEC) model

1. Never-consumers

Assumption: \( T_i = 0 \Rightarrow R_{ij} = 0, \forall j \)

\[ u_{0i} = \begin{cases} 
1 & \text{if person } i \text{ a never-consumer} \\
0 & \text{if person } i \text{ a consumer} 
\end{cases} \]

\[ P(u_{0i} = 1) = \frac{1}{1 + e^{\gamma_0}} = H(\gamma_0) \]

2. Episodic-consumers

\[ \Pr(R_{ij} = 0 | u_i) = \begin{cases} 
1 & \text{if } u_{0i} = 1 \\
H(\gamma_1 + u_{1i}) & \text{if } u_{0i} = 0 
\end{cases} \]

3. Measurement error for consumers

\[ R_{ij} | u_i \sim N(\gamma_2 + u_{2i}, \sigma_\varepsilon^2) \quad \text{if } R_{ij} > 0 \]

\[ (u_{1i}, u_{2i}) \sim BVN \left( \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_{u_1}^2 & \rho u_1 u_2 \sigma_{u_1} \sigma_{u_2} \\ \rho u_1 u_2 \sigma_{u_1} \sigma_{u_2} & \sigma_{u_2}^2 \end{pmatrix} \right) \]
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Fitting the NEC model

- Reported measurements are modelled using \( \mathbf{u}_i = \{u_{0i}, u_{1i}, u_{2i}\} \)
- 7 parameters \( \theta = \{\gamma_0, \gamma_1, \gamma_2, \sigma^2_{u_1}, \sigma^2_{u_2}, \rho_{u_1 u_2}, \sigma^2_{\varepsilon}\} \)

Joint distribution of the \( \mathbf{R}_i \)

\[
f(\mathbf{R}_i) = \{1 - H(\gamma_0)\} \int f(\mathbf{R}_i | \mathbf{u}_i, u_{0i} = 1)f(u_{1i}, u_{2i})d\mathbf{u}_1 d\mathbf{u}_2 \]

Consumers

\[
+ H(\gamma_0) \prod_{j=1}^{J} \left(1 - I(R_{ij} > 0)\right)
\]

Never-consumers

Parameters \( \theta \) can be estimated by maximum likelihood provided we have \( \geq 2 \) measurements \( R_{ij} \)
Finding fitted values $E(T_i|R_i; \theta)$

**Assumption**

Reported measurements $R_{ij}$ are **unbiased estimates** of true intake $T_i$

$$T_i = E(R_{ij}|u_i)$$

$$= \begin{cases} 
0 & \text{if } u_{0i} = 1 \\
1 - H(\gamma_1 + u_{1i}) (\gamma_2 + u_{2i}) & \text{if } u_{0i} = 0 
\end{cases}$$

Fitted values for true intake

$$E(T_i|R_i; \theta) = \frac{\int T_i(u_i) f(R_i|u_i; \theta) f(u_i; \theta) du_i}{\int f(R_i|u_i; \theta) f(u_i; \theta) du_i}$$
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1. How well can we estimate the parameters of the NEC model?

2. Is the NEC model successful in allowing us to correct for the effects of measurement error on the diet-disease association?

3. How do the results from the NEC model compare with alternative approaches?
Simulation study: Alcohol intake in EPIC-Norfolk

- We fitted the never- and episodic-consumers model for alcohol intake in EPIC-Norfolk
- 2 reported measurements $R_{i1}, R_{i2}$ for a subset of the study population

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200 simulated data sets
- 1000 individuals ($i = 1, \ldots, 1000$)
- Obtain true intake $T_i$
- Obtain reported measurements $R_i = \{R_{i1}, R_{i2}, R_{i3}, R_{i4}\}$

We fit the NEC model using 2 measurements $\{R_{i1}, R_{i2}\}$ and 4 measurements $\{R_{i1}, R_{i2}, R_{i3}, R_{i4}\}$
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2 measurements

4 measurements

Estimate of $\sigma^2_{u_1}$
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**Graphs:**

- **2 measurements**
- **4 measurements**
Correcting the diet-disease association

Regression calibration
We replace $T_i$ by $E(T_i|R_i)$ in the disease model

Simulation study
- We generated disease status (0/1) according to a logistic model
  \[
  \Pr(D_i = 1 | T_i) = \frac{\exp(\alpha + \beta T_i)}{1 + \exp(\alpha + \beta T_i)}
  \]
  - ...using $\beta = 0.2$
  - $\alpha$ chosen to give a 10% disease probability

Compare with 3 alternative methods for estimating $\beta$
- ‘Naive’ method: Use mean($R_{i1}, R_{i2}$) in place of $T_i$
- Using linear regression calibration to obtain $E(T_i|R_i)$
- Using an episodic-consumers model to obtain $E(T_i|R_i)$
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- \( \beta = 0.2 \)
- \( \alpha \) chosen to give a 10% disease probability

Compare with 3 alternative methods for estimating \( \beta \)
- ‘Naive’ method: Use \( \text{mean}(R_{i1}, R_{i2}) \) in place of \( T_i \)
- Using linear regression calibration to obtain \( E(T_i|R_i) \)
- Using an episodic-consumers model to obtain \( E(T_i|R_i) \)
Comparison with alternative methods: log(OR)s
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Never & episodic consumers model

Using observed measurements

Using T_i

NEC model

Average( R_{i1}, R_{i2} )

Using observed measurements

Using T_i
Comparison with alternative methods: log(OR)s

Never & episodic consumers model

Using T_i

NEC model

Linear Regression Calibration

Using T_i

Linear RC model

Using observed measurements

Average( R_{i1}, R_{i2} )

Using T_i
Comparison with alternative methods: log(OR)s

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Linear Regression Calibration

Episodic consumers model
Some comments

- Some parameters of the model may be badly estimated using only two reported measurements $R_{i1}, R_{i2}$ per person.

- The never- and episodic-consumers model provides a method for correcting the diet-disease association for measurement error.

- ...but we may often be able to achieve similar results using standard linear regression calibration or episodic-consumers model.

- We have not yet looked at other aspects of the different approaches such as coverage probabilities.

- There may be situations in which it is useful to be able to correctly model the association between true intake and reported intake using the never- and episodic-consumers model.
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