Supplementary Information for "Exposures to carbon monoxide in a cookstove intervention in Northern Ghana"

Ricardo Piedrahita, Evan R. Coffey, Yolanda Cecil-Hager, Ernest Kanyomse, Christine Wiedinmyer, Katie L. Dickinson, Abraham Oduro, Michael P. Hannigan

1. Lascar CO monitors deployed for exposure assessment

Figure S1. Lascar CO monitors worn on lanyards around the neck or placed inside custom pockets on project t-shirts.

2. Daily CO exposure study summary statistics

Summary statistics are presented in Table S1 grouped by the same variable categories as used in the exposure model presented in Section 3.1. Uncertainty of the group mean ($\bar{\sigma}$) is reported as the quotient of the individual sample uncertainty (σ_n) estimated as the Lascar duplicate RMSE of 1.16ppm (Fig. S5), and the square root of the number of independent daily samples for each group (n). Independent samples were considered to be the number of unique participants as opposed to the total non-flagged deployment days representing a conservative estimate of uncertainty of the group means.

Table S1. Descriptive 24hr average CO exposure statistics

	Mean (ppm)	Median (ppm)	Std dev (ppm)	$\bar{\sigma}\,(ppm) = \sigma_n/\sqrt{n}$
Control group	1.05	0.50	2.08	0.15
Gyapa/Philips	0.94	0.49	1.48	0.14

Philips/Philips	0.90	0.32	1.52	0.14
Gyapa/Gyapa	1.15	0.52	1.87	0.14
Primary cook females	1.15	0.57	2.01	
Non-primary cook females	0.84	0.37	1.29	
Non-primary cook males	0.80	0.31	1.42	
Least poor	0.89	0.28	1.51	
Less poor	0.98	0.36	2.28	
Poor	1.03	0.50	1.86	
Poorer	1.06	0.49	1.47	
Poorest	1.01	0.61	1.62	
Harmattan bush burning	0.87	0.44	1.42	
Transition	1.00	0.34	1.55	
Light rainy	1.25	0.63	1.47	
Heavy rainy	1.23	0.53	2.47	
Hot dry	0.80	0.22	1.59	

Exceedances of WHO Tier-1 standards from this study were calculated using the calibrated minute-data from the Lascar USB-CO monitors, and required 75% data completion for each time scale in order to be included. The fraction of exposure exceeding WHO tier-1 standards was low compared to most previous cookstove studies.

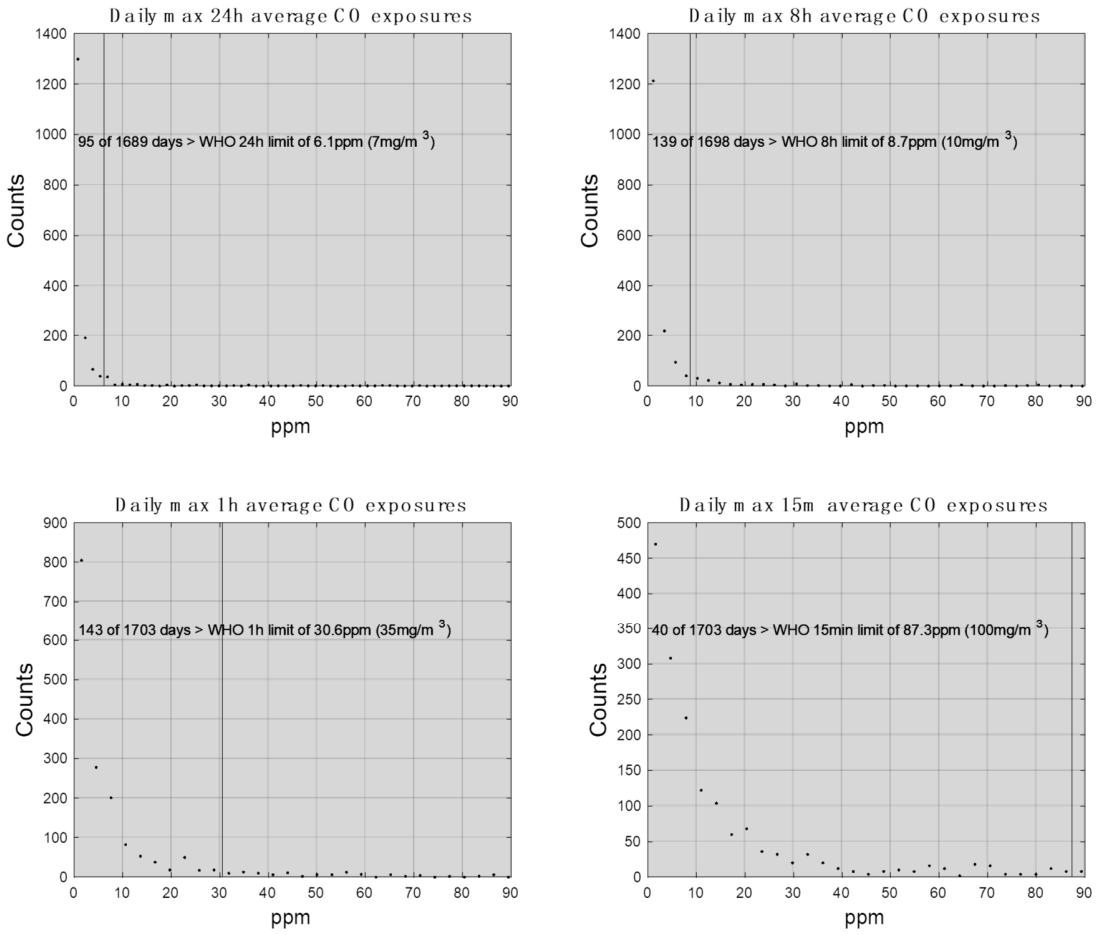

Figure S2. Distributions of average CO exposure by time periods relevant to WHO tier-1 standards

3. Lascar USB-CO calibration and quality assurance

Lascar monitors were calibrated with NIST traceable CO gas standards at the Hannigan Research Lab at CU Boulder. Typically, three or more calibrations points were used (Figure S3), but in some cases two-point span checks were employed. In the field, balanced sampling was performed from high and low concentration time points,

representative of the concentrations the monitors were exposed to in the field.

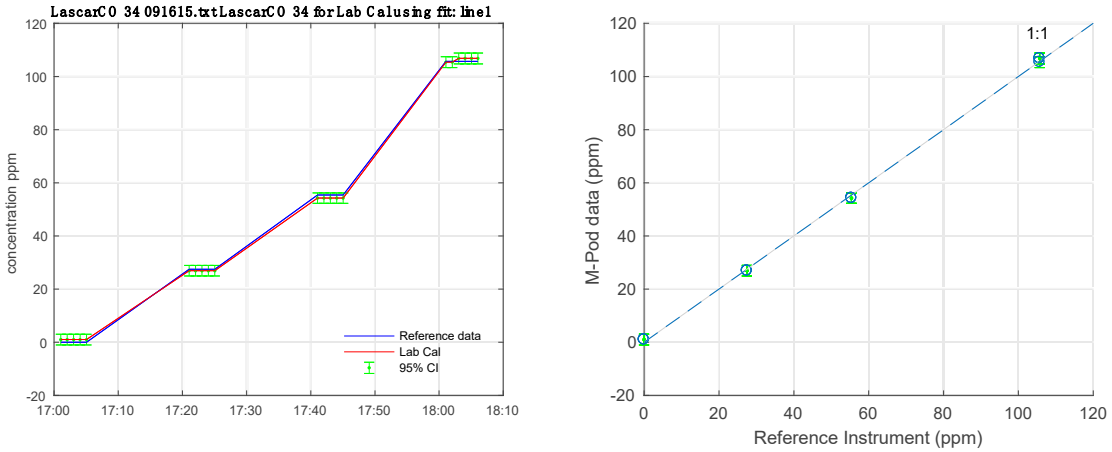

Figure S3. Example calibration of a Lascar that returned from the field after deployment to Navrongo.

Data filtering for quality assurance was manually performed consistently and blind to the study group. There were various types of error observed with the monitors over time, and the data checker relied on consistency of issues, duplicate measures, and calibration quality to remove suspect data. A time series of calibration data deployments, both successful and flagged, is shown in Figure S4.

Figure S4. Lascar USB-CO calibration and data quality time line. Some Lascar monitors like #1 and #3 never operated correctly and were returned to the manufacturer. In most cases, the monitors were non-operational upon their return to the CU Boulder Hannigan Lab, so a post-calibration could not be performed.

4. Lascar USB-CO duplicate analysis

The duplicate Lascar CO monitors were primarily deployed in the latter half of the study. In Figure S5 we present the comparison among duplicate measures for both the uncalibrated and calibrated data.

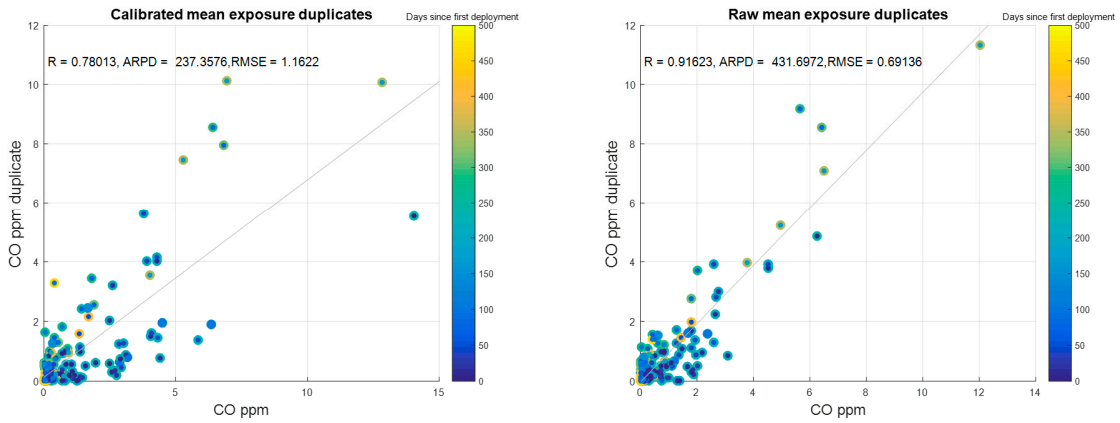

Figure S5. Agreement of daily average Lascar USB-CO duplicates for both calibrated and raw values colored by days since first deployed.

5. Complete CO exposure mixed effects model results

The mixed effects model results presented in section 3.1 are presented in detail here with complete model output. The calibrated and uncalibrated model results are shown for comparison purposes.

5.1. Calibrated CO exposure mixed effects model results

Linear mixed-effects model fit by ML

Model information:

Number of observations	786
Fixed effects coefficients	14
Random effects coefficients	267
Covariance parameters	2

Formula:

LogPersonalCOMeans ~ 1 + SES + season + StoveGroup + primarycookbygender + (1 | UserID)

Model fit statistics:

AIC	BIC	LogLikelihood	Deviance
3001.7	3076.4	-1484.8	2969.7

Fixed effects coefficients (95% CIs):

Name	Estimate	SE	tStat	DF	pValue	Lower	Upper
'(Intercept)'	-0.59272	0.24587	-2.4107	772	0.016155	-1.0754	-0.11006
'SES_Poorer'	0.034473	0.22765	0.15143	772	0.87968	-0.41242	0.48137
'SES_Poor'	-0.078249	0.23998	-0.32607	772	0.74446	-0.54934	0.39284
'SES_Less_poor'	-0.34384	0.25071	-1.3715	772	0.17062	-0.83599	0.1483

'SES_Least_poor'	-0.48844	0.24786	-1.9706	772	0.049128	-0.975	-0.00187
'season_Heavy_Rainy'	0.14376	0.16491	0.87171	772	0.38364	-0.17998	0.46749
'season_Light_Rainy'	0.46369	0.19201	2.415	772	0.015967	0.086776	0.84061
'season_Transition'	-0.15665	0.22173	-0.7065	772	0.48009	-0.59191	0.27861
'season_Hot_dry'	-0.35792	0.1869	-1.915	772	0.055862	-0.72482	0.0089789
'StoveGroup_C'	-0.10758	0.20924	-0.51414	772	0.6073	-0.51832	0.30316
'StoveGroup_B'	-0.36125	0.20627	-1.7513	772	0.080287	-0.76618	0.043671
'StoveGroup_A'	-0.11112	0.2231	-0.49808	772	0.61857	-0.54907	0.32683
'primarycookbygender_0F'	-0.40336	0.18075	-2.2316	772	0.025928	-0.75818	-0.048541
'primarycookbygender_0M'	-0.45763	0.1897	-2.4123	772	0.016083	-0.83003	-0.085231

Random effects covariance parameters (95% CIs):

Group: UserID (267 Levels)

Name1	Name2	Type	Estimate	Lower	Upper
'(Intercept)'	'(Intercept)'	'std'	0.79691	0.64514	0.98438

Group: Error

Name	Estimate	Lower	Upper
'Res Std'	1.4422	1.3562	1.5336

5.2. Un-calibrated CO exposure mixed effects model results

Linear mixed-effects model fit by ML

Model information:

Number of observations	786
Fixed effects coefficients	14
Random effects coefficients	267
Covariance parameters	2

Formula:

LogPersonalCOMeans ~ 1 + SES + season + StoveGroup + primarycookbygender + (1 | UserID)

Model fit statistics:

AIC	BIC	LogLikelihood	Deviance
2959.7	3034.4	-1463.9	2927.7

Fixed effects coefficients (95% CIs):

Name	Estimate	SE	tStat	DF	pValue	Lower	Upper
'(Intercept)'	-0.68681	0.23933	-2.8697	772	0.0042205	-1.1566	-0.217
'SES_Poorer'	0.066981	0.2216	0.30227	772	0.76253	-0.36802	0.50198
'SES_Poor'	-0.0033174	0.23359	-0.014202	772	0.98867	-0.46187	0.45523
'SES_Less_poor'	-0.30485	0.24403	-1.2492	772	0.21197	-0.7839	0.1742
'SES_Least_poor'	-0.43274	0.24127	-1.7936	772	0.073267	-0.90635	0.040879
'season_Heavy_Rainy'	0.0046051	0.16057	0.02868	772	0.97713	-0.3106	0.31981
'season_Light_Rainy'	0.18906	0.18695	1.0113	772	0.31219	-0.17793	0.55605
'season_Transition'	-0.23058	0.21588	-1.0681	772	0.28581	-0.65435	0.1932
'season_Hot_dry'	-0.55054	0.18197	-3.0254	772	0.0025652	-0.90775	-0.19332
'StoveGroup_C'	-0.1071	0.20366	-0.52589	772	0.59912	-0.50691	0.2927
'StoveGroup_B'	-0.34267	0.20078	-1.7067	772	0.08828	-0.7368	0.051467
'StoveGroup_A'	-0.14824	0.21716	-0.68262	772	0.49505	-0.57453	0.27805
'primarycookbygender_0F'	-0.31728	0.17594	-1.8033	772	0.071728	-0.66266	0.028102
'primarycookbygender_0M'	-0.39979	0.18466	-2.165	772	0.030691	-0.76228	-0.037299

Random effects covariance parameters (95% CIs):

Group: UserID (267 Levels)

Name1	Name2	Type	Estimate	Lower	Upper
'(Intercept)'	'(Intercept)'	'std'	0.77531	0.62647	0.95951

Group: Error

Name	Estimate	Lower	Upper
'Res Std'	1.4044	1.3204	1.4937

6. Time of day trends for cooking area CO and CO_2 and personal CO

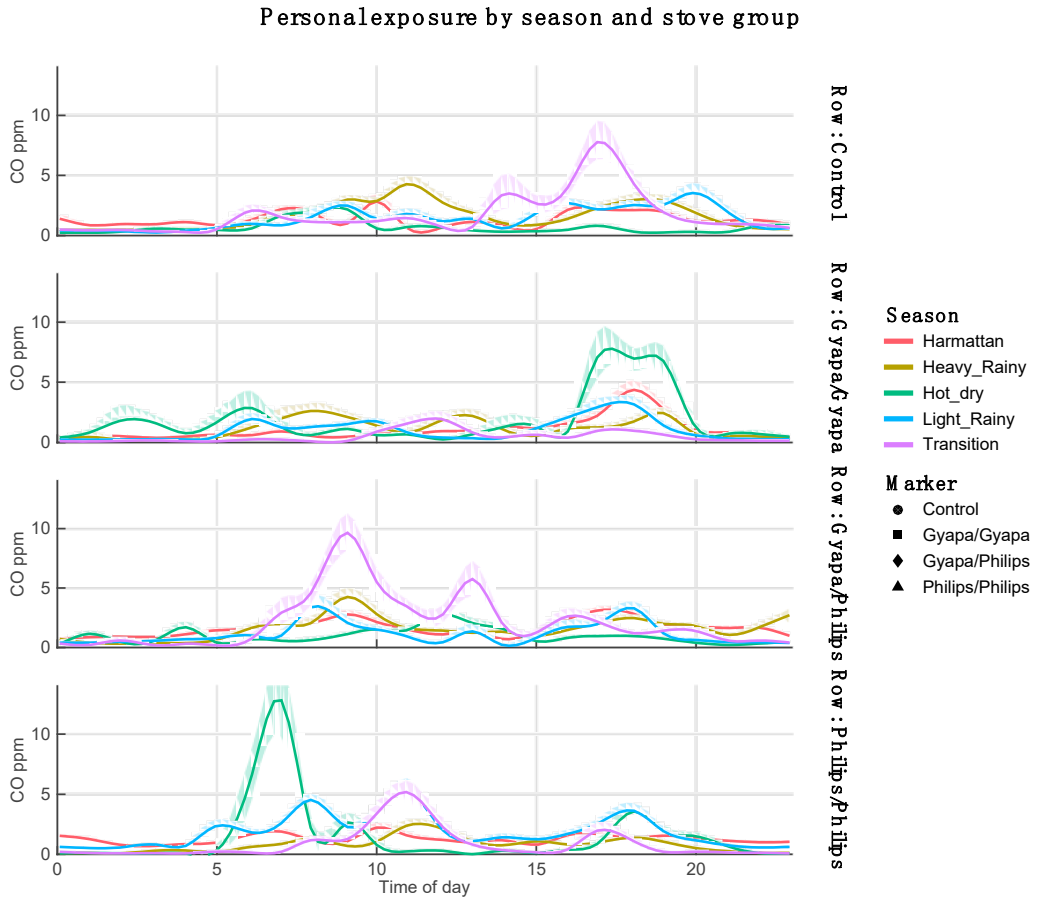

Figure S6. Personal exposure by season and stove group, smoothed using b-splines

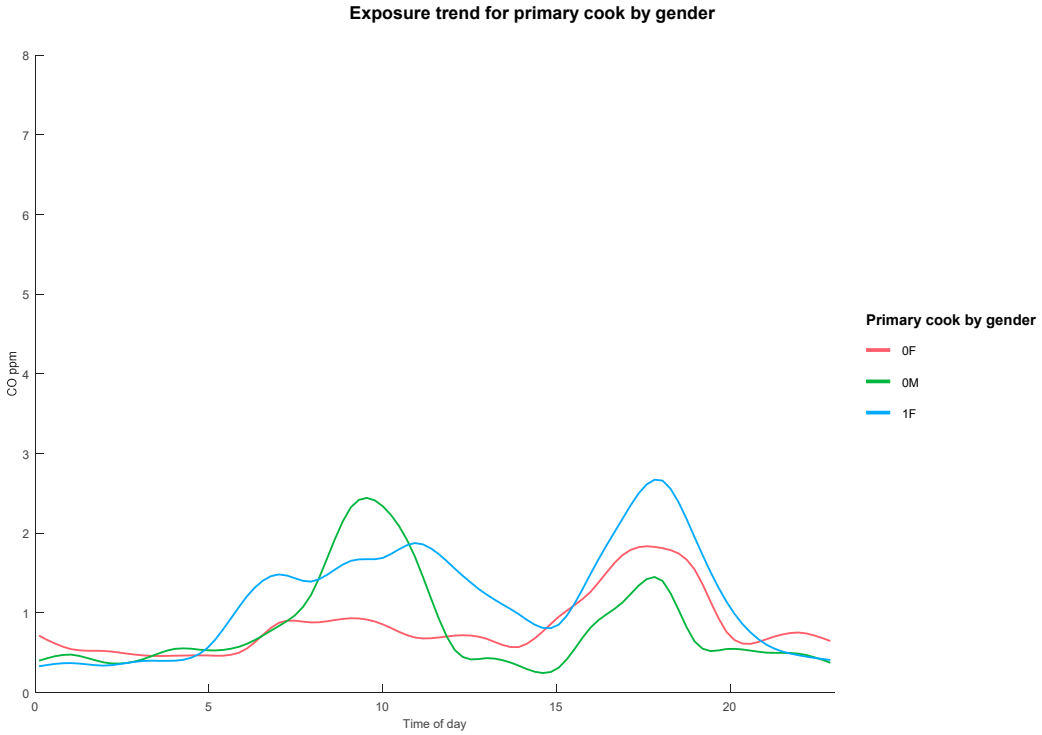

Figure S7. B-spline smoothed personal CO exposure grouped by primary cook status gender group. '0' values are for non-primary cooks, and '1' is for the females listed as primary cooks. No males were listed as primary cooks.

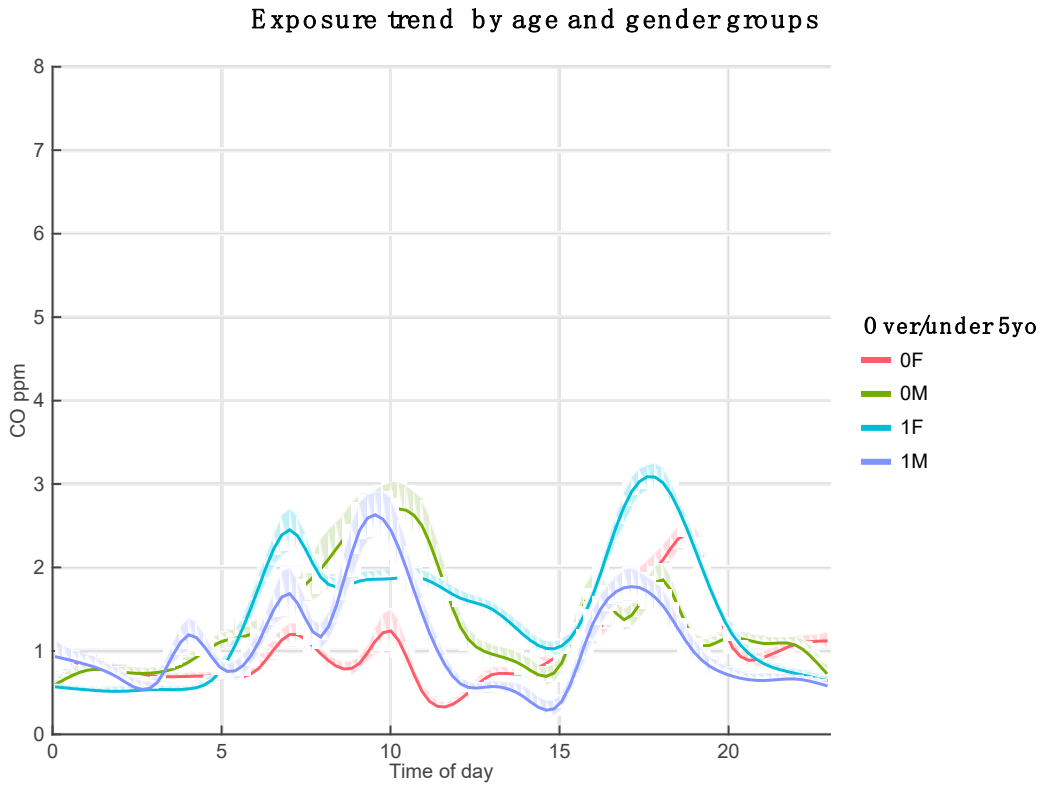

Figure S8. B-spline smoothed personal CO exposure grouped by age and gender group. '0' values are under 5, and '1's are over 5 years of age.

7. Modeling calibrated CO with carbonaceous $PM_{2.5}$

model_EC

Linear regression model:

LogECugm3 ~ 1 + LogCO

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	0.019559	0.15853	0.12338	0.90204
LogCO	0.08017	0.094532	0.84808	0.39829

Number of observations: 109, Error degrees of freedom: 107

Root Mean Squared Error: 1.43

R-squared: 0.00668, Adjusted R-Squared -0.00261

F-statistic vs. constant model: 0.719, p-value = 0.398

model_OC

Linear regression model:

LogOCugm3 ~ 1 + LogCO

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	3.3242	0.12938	25.692	1.416e-47
LogCO	0.19596	0.077155	2.5398	0.012529

Number of observations: 109, Error degrees of freedom: 107

Root Mean Squared Error: 1.17

R-squared: 0.0569, Adjusted R-Squared 0.048

F-statistic vs. constant model: 6.45, p-value = 0.0125