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Impact of Climate Change on Influenza Mortality in the US

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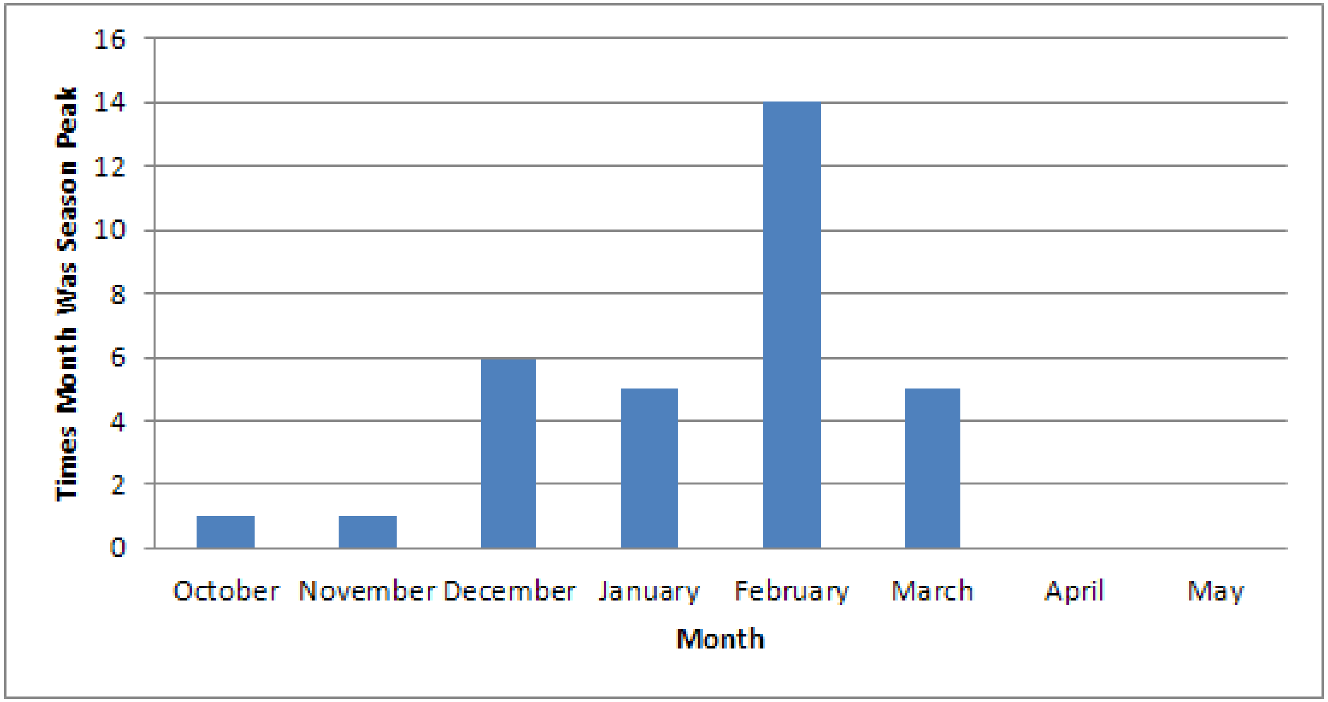
Introduction

- Each year approximately **5-20%** of US residents get the flu
- More than **200,000 people** are hospitalized
  - Usually contagious for 1-2 weeks
- Between 2008 and 2010, influenza related medical costs were estimated at over $10 billion
- Relationship between temperature, humidity and influenza has been well studied in epidemiology
- Weekly data from 122 cities during 1970 – 2010 in US
- Non-parametric approach
  - Generalized Additive Model

Flu Season in the US

- Typical flu season in the US – October to March
- Flu activity peaks between December and February



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Literature

- Positive association with humidity in El Salvador and Panama but negative association in Guatemala (Soebiyanto et. al, 2014 - PLOS ONE)
- Number of studies (Barecca and Shimshack, 2012; Deschenes and Moretti, 2007 and Martens, 1998) state that colder temperatures have greater influence on mortality
  - But high temperatures are may affect the inter-temporal distribution of mortality
- Based on laboratory experiments on guinea pigs, Lowen et al. (2007) show that both low temperatures and low humidity enhance viral stability

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Climatic Variables and Influenza Interaction

- Low temperatures and/or extreme humidity increases mortality risk
- Impacts on cardiovascular and respiratory systems
- Low temperatures
  - Reduce blood flow and inhalation of cold air which may increase susceptibility
  - Limits exposure to vitamin D and increases indoor crowding

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Climatic Variables and Influenza Interaction

- Low humidity
  - Leads to dehydration and increases spread of influenza by increased viral shedding
  - Also increases survival times of viral aerosols
  - It may also be connected through changes in the virus stability and transmission
- High humidity
  - Impairs body’s ability to sweat and cool itself

Gap in the Literature

- Despite the hypothesized mechanisms - impact of climatic variables on influenza mortality are not well established
  - Especially on human population
  - Little empirical evidence
- Existing literature have used simplistic linear models
- Papers using more complex methodologies have focused on specific cities/regions
- Use of relative humidity
  - Strong positive correlation with temperature
- Assuming that patients are contagious for months
- Furthermore, understanding is limited to *a priori* assumptions of the pre-determined knots of the exposure variables' distributions

Gap in the Literature

- Large dataset at the city by week level reduces misclassification errors that may plague data observed on larger geographic scales like such as or nations
- We consider temperature and humidity simultaneously
- Use of GAM

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Data

- Global Land Data Assimilation System (GLDAS 2)
  - Utilizes ground and satellite measurements
  - Models global terrestrial geophysical parameters
  - 0.25° by 0.25° spatial and 3-hourly temporal resolution
- Surface air temperature (K) and specific humidity
  - Specific humidity is the ratio between mass of water vapor and the mass of air (g/kg)
- Influenza mortality data from the Morbidity and Mortality Weekly Report (MMWR) on 122 cities
  - Weekly epidemiological digest for US published by CDC
- To obtain weekly data, we averaged the pixels and aggregated the 3-hourly data into daily data, and finally
  - Computed weekly maximum, minimum, and mean

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Descriptive Statistics

	Mortality	Temp-Max	Temp-Min	Temp-Mean	Humid-Max	Humid-Min	Humid-Mean
Median	3.00	22.93	7.24	14.06	0.011	0.005	0.007
Mean	5.08	21.03	6.79	13.01	0.012	0.006	0.008
Std. Dev	5.64	12.15	9.04	10.21	0.006	0.004	0.005

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Methodology: Generalized Additive Models

- No *a priori* reason for choosing a particular response function
- Allows response functions to be generated from the data
- GAM uses a link function to establish a relationship between the mean of the response variable and a smoothed function of the explanatory variables
- The general form is:

$$y = \alpha + \varphi + \sum_{i=1}^{n} f_i(X_i)$$

- The usual linear function of a covariate, $\beta_i . X_i$, is replaced with f_i - an unspecified smooth function
- Non-parametric nature means that it doesn't assume a rigid form for the dependence of y on the predictors

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Methodology: Generalized Additive Models

- Replaces the parameter "values times the predictor values" with a cubic spline smoother for each predictor
- Natural cubic spline smoothing functions of exposure variables and income were used
  - Removes the small variation while maintaining the major trend of each variable
  - Aim is to increase the efficiency in estimating the model
- Strength of GAM is its ability to deal with highly non-linear and non-monotonic relationships
  - GAM assumes additivity between predictors but allows for local nonlinearity in each predictor

Construction of Humidity Smoothing Terms

- Since only extremes matter - maximum and minimum humidity are transformed as:

$$H_{TR.Max} = H_{Max}/H_{Mean}$$
$$H_{TR.Min} = H_{Min}/H_{Mean}$$

  - Estimates the effect of the extremes as multipliers of the average effect
  - The transformed smooth splines are bounded on (-∞, 1) and (1, ∞)

- Separating out the conditional impact of the multiplier at any point on the mean spline

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Methodology: Variables

- γ_{iwy} is the natural logarithm of weekly per capita mortality in city i
- T and H are weekly temperature and humidity in city i
- I is the natural logarithm of the real income per capita of the Metropolitan Statistical Area that city i belongs to
- μ is a set of unrestricted time fixed effects and φ is a set of unrestricted city fixed effects
  - Control for unobserved confounding factors such as vaccination campaigns or the virulence of influenza strains

Results

- The variables are stationary
  - Im, Pesaran and Shin test
- We use Maximum Likelihood (ML) estimation method as its covariance parameters is more stable
- BIC test shows Min Temp and Transformed Min Humid regression to be most robust
- All the smooth terms are statistically significant
- The chances of influenza related mortality is higher at low income cities

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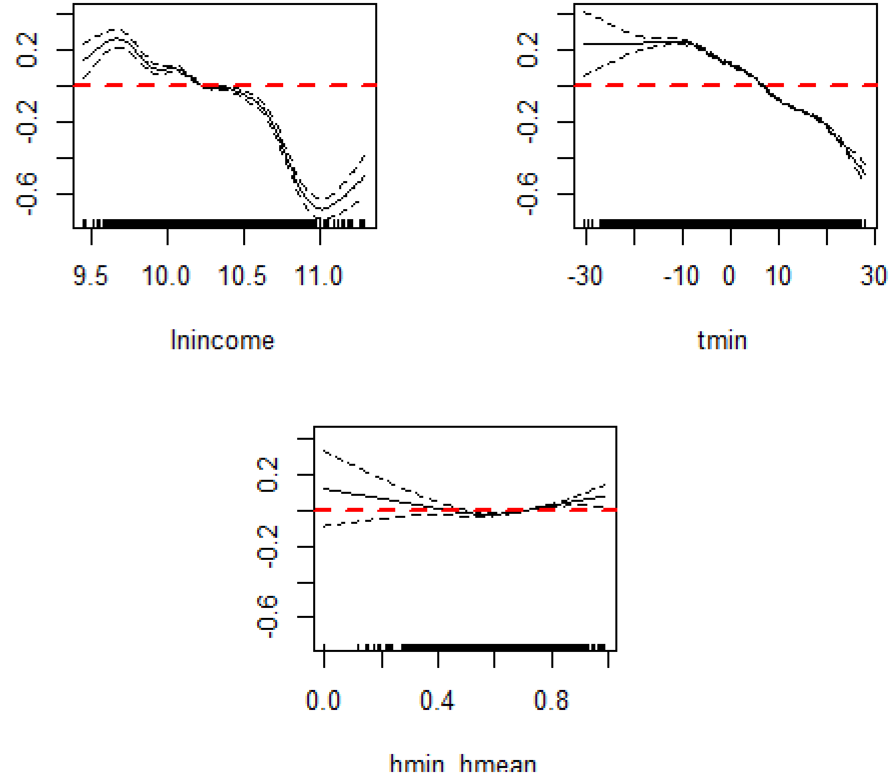
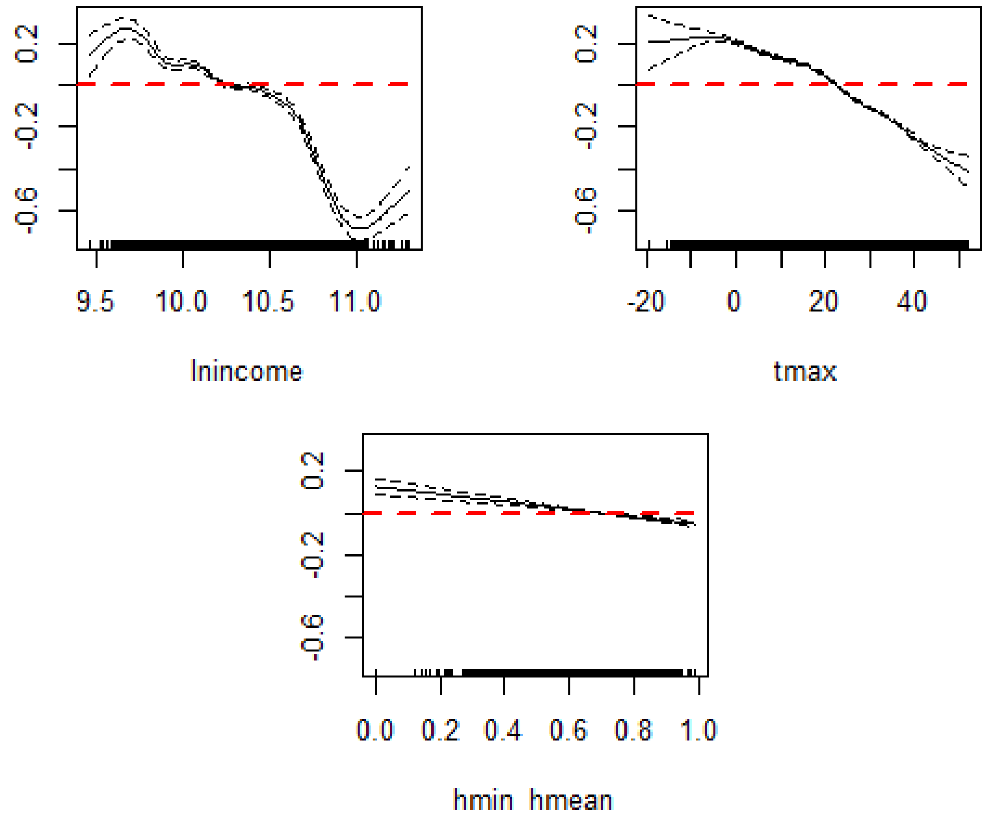
Results: Minimum Temperature and Humidity



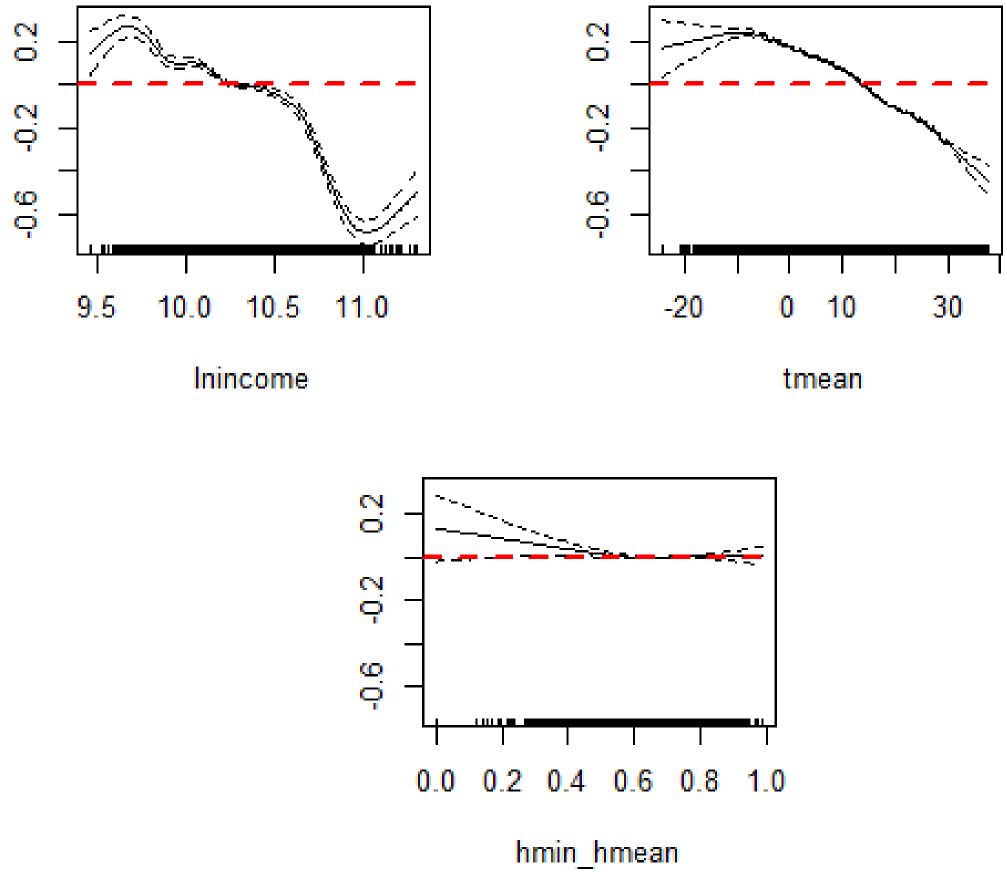
- Non-linear effect is evident
- More influenza mortality occurs at low temperature
  - Supports enhanced shedding theory at temperature of around -10°C
- Both very low and very high humidity are significant - *U shaped*
- BIC Test - This is the most robust specification

Results: Max Temperature and Min Humidity



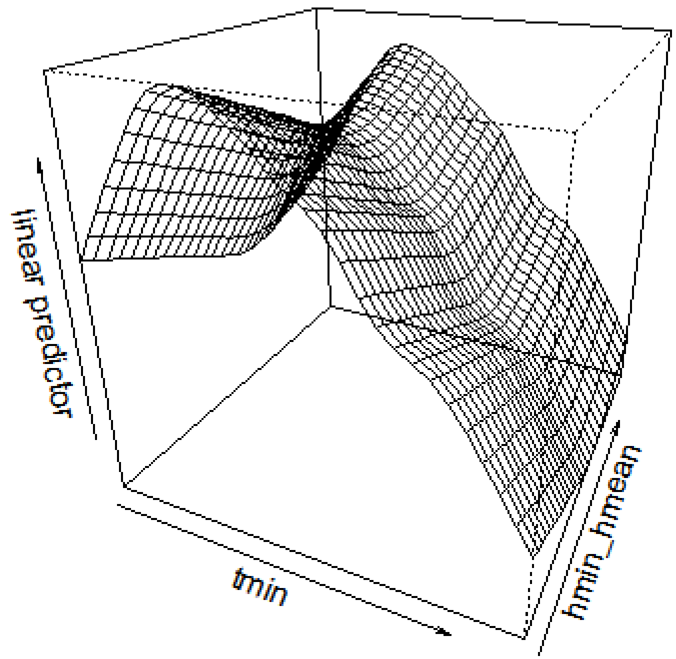
- Probability of influenza mortality is higher at low temperature and humidity levels

Results: Mean Temperature and Min Humidity



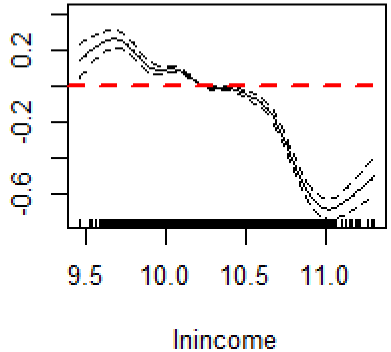
- Non-linear effect – specifications are robust
  - Do not change with mean, max, min

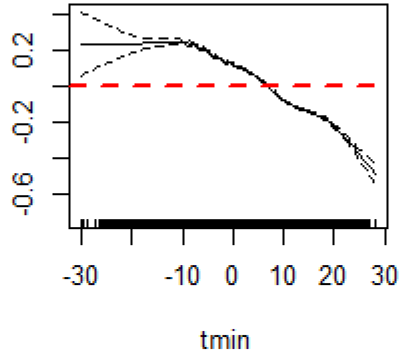
Results: Wireframe – Looking Beneath

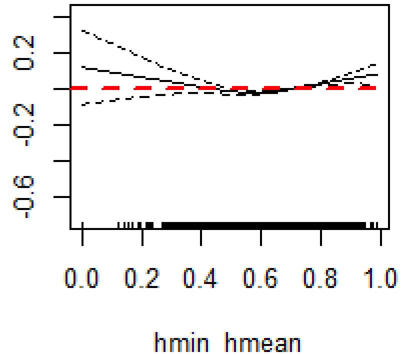


- Smoothing the marginal smooths of temperature and humidity
- Highest mortality risk at low temperature and low humidity

Results: Spatial Serial Dependence







- One issue with GAM is serial dependence
- Assuming spatial serial dependence - we include
  - A bi-variate smoothing factor with latitude and longitude
- Response functions to not change

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Discussion

- Different lag structures have no impact
- Data truncated for flu season do not change the shape of the response functions
- Neither does including a seasonal cyclical smooth term
- GAM results confirm the non-linear nature of the relationship

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Conclusion

- Probability of influenza mortality is highest at the lowest temperature levels
  - Supports works unider laboratory condition by Cannell et al., (2008) and Lowen et al., (2007)
- *U-shaped* specific humidity curve
  - Providing support for medical/epidemiological theory
- Influenza mortality declines as income rises
- Comprehensive evidence linking low *T* and extreme *H* to influenza mortality
- Next step is to use the results for projections
  - GCM data is being processed

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