A Bayesian Analysis of Carbon Dioxide Emissions in States Under the Regional Greenhouse Gas Initiative

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Introduction

Cap and trade systems are an attempt at using a marketplace with as few government restrictions as possible in order to reduce emissions of an undesirable pollutant. A hard cap of the amount of permissible pollutants is set, and pollution permits allowing the holder to legally pollute are distributed in a variety of ways. Each year, the cap is lowered and fewer permits are distributed, forcing firms to be more efficient so that they will need to purchase fewer permits each year. One such system that has been adopted in the Northeastern United States is the Regional Greenhouse Gas Initiative. I apply Bayesian modelling techniques in which we incorporate prior information about data in order to arrive at posterior distributions for RGGI carbon dioxide emission data to monitor whether or not there is a decreasing trend in emissions levels. If it is ultimately determined to be successful in reducing carbon dioxide emissions, the RGGI may provide a template for other states to design their own cap and trade programs.

RGGI Program Design

RGGI is a cap and trade program that seeks to lower emissions of carbon dioxide from electric power plants and covers Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont. There are three key components to the program design of RGGI. The first is the carbon cap, set at 91 million tons and lowers by 2.5% each year until 2020 when it will be re-evaluated. The second is the allocation of pollution permits. RGGI has chosen to distribute most permits through an auction system, in which pollution permits are put up for bid and power plants must outbid each other for them. The auction system is an attempt to keep free market conditions while still imposing a carbon cap. The third and final element is the monitoring of the individual power plants. At the end of every three year control period, plants must be able to show that they have purchased the requisite number of permits or face penalties. In 2013, the average auction clearing price for one pollution permit was $2.92.

Methods

In order to determine whether carbon emissions have been decreasing during the years in which the RGGI has been active (2009-2014), several methods were employed. First, carbon emissions from the 172 separate power plants in RGGI member states were plotted as profile plots. Next, a possible model for the trend of the data was proposed: due to the data's complex trends (increase, decrease, then flatten, a cubic polynomial trend of the form $Y_{it} = \beta_{0i} + \beta_{1i}t + \beta_{2i}t^2 + \beta_{3i}t^3 + \varepsilon_{it}$ is proposed. In the equation, Y_{it} represents the emission at site i (1, 2, …, 172) and year t (1, 2, …, 6). The beta parameters are site-specific random parameters that we are trying to estimate in order to construct an appropriate model. To conduct the analysis, a Bayesian model is constructed when I define the following prior distributions for the model:

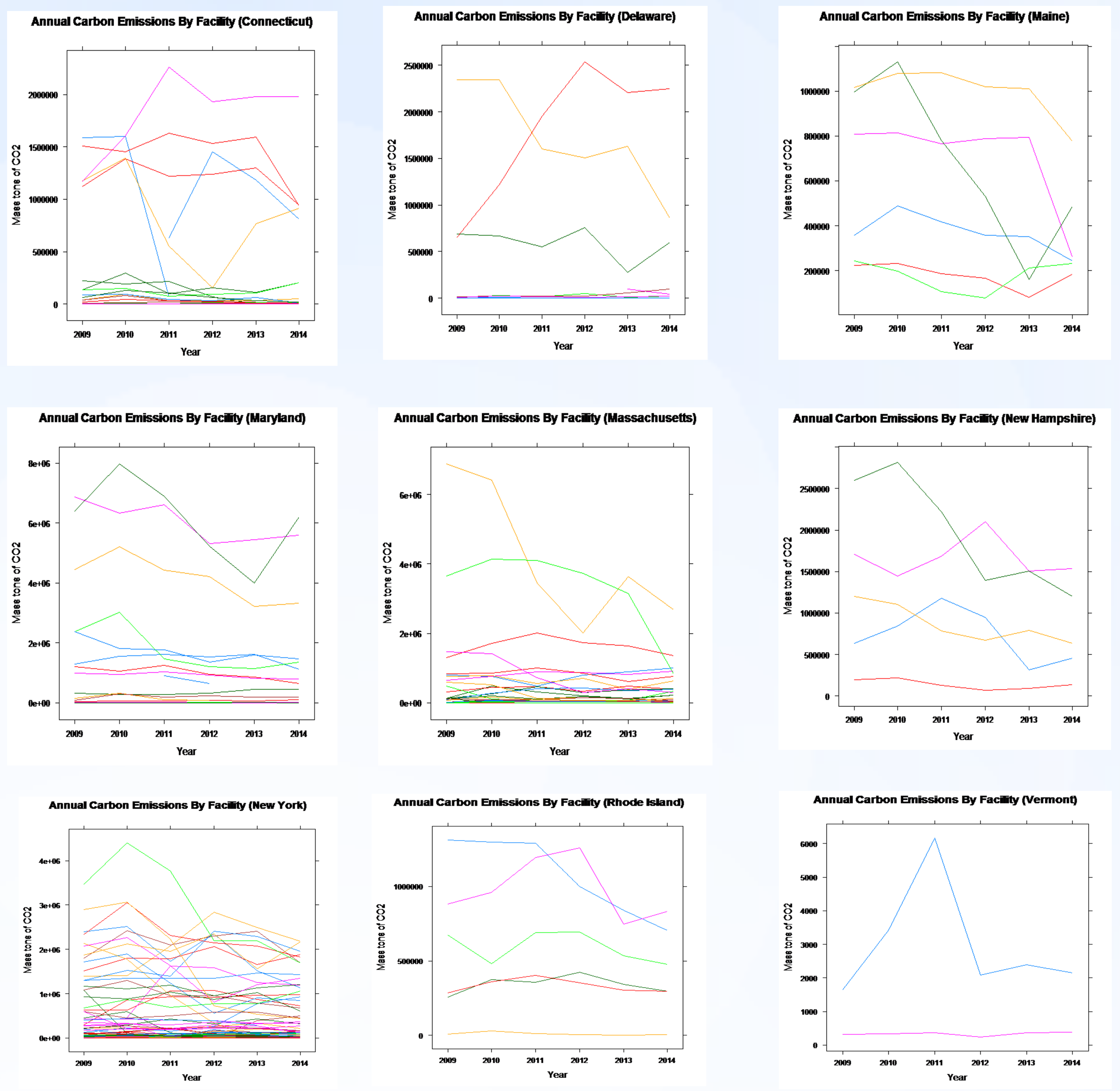
$$\beta_{0i} \sim N(\theta_0, \tau_0^2)$$
$$\beta_{1i} \sim N(\theta_1, \tau_1^2)$$
$$\beta_{2i} \sim N(\theta_2, \tau_2^2)$$
$$\beta_{3i} \sim N(\theta_3, \tau_3^2)$$
$$\varepsilon_{it} \sim N(0, \tau^2)$$

The theta parameters represent the mean of the posterior distribution for each beta, and the tau parameters represent posterior variances. I propose the following priors for these parameters:

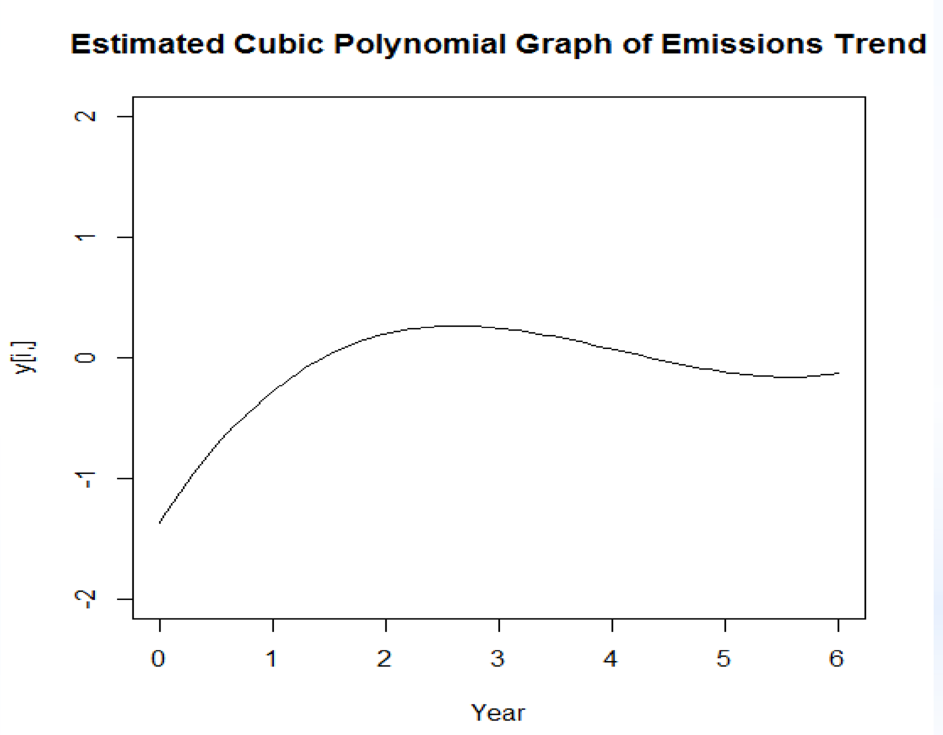
$$\theta_0 \sim N(0, 10^6)$$
$$\theta_1 \sim N(0, 10^6)$$
$$\theta_2 \sim N(0, 10^6)$$
$$\theta_3 \sim N(0, 10^6)$$
$$\tau_0^2 \sim Gamma(.1, .1)$$
$$\tau_1^2 \sim Gamma(.1, .1)$$
$$\tau_2^2 \sim Gamma(.1, .1)$$
$$\tau_3^2 \sim Gamma(.1, .1)$$
$$\tau^2 \sim Gamma(.1, .1)$$

After defining the model, code was written to use R to interface with JAGS, a Bayesian software that uses a technique known as Gibbs sampling to sample from the posterior distributions of the parameters we are monitoring. 100,000 random samples of each parameter's posterior distribution were taken. The output is presented in the Results Section of the poster.

Results



$$Y_{it} = -1.36612 + 1.47257t - 0.41247t^2 + 0.03357t^3$$



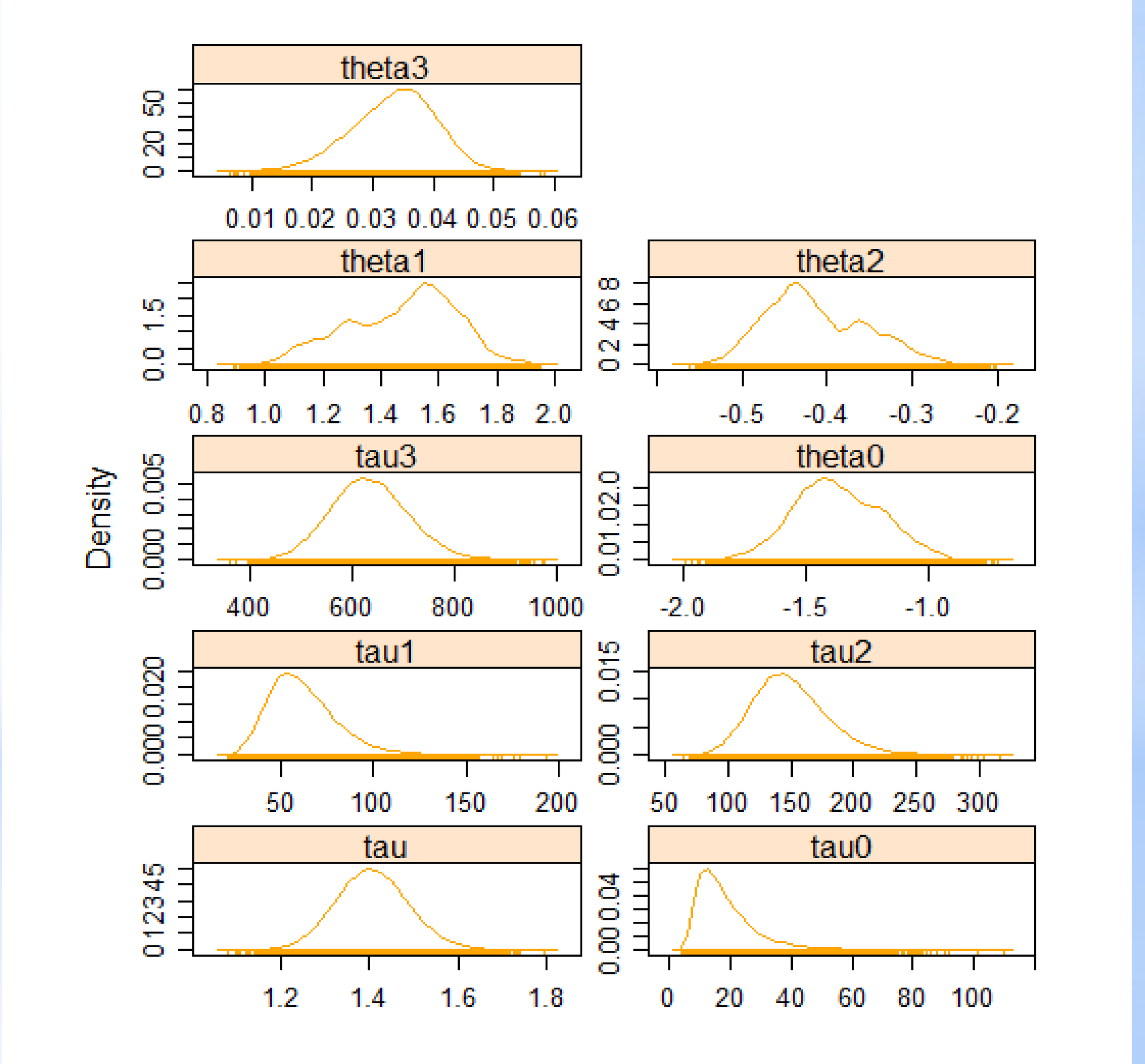
Conclusions

From the analysis, I derived a potential model that can describe the RGGI data trend. The graph of the trend shows a trend that first increases, then decreases slightly, then flattens out. Checking the density curves of the posterior distributions shows that they have converged to feasible distributions, and monitoring the tau parameters shows that they are desirably large, JAGS measures $^1/_{\tau^2}$ for the variance. Ultimately, while it cannot be concluded that the RGGI itself is entirely responsible for the trend, there is evidence that since the RGGI went into effect, there has been a reversal of the steadily increasing emission trend.

Posterior Distribution Means and Standard Deviations for the Nine Monitored Parameters

Monitored Parameter	Mean	Standard Deviation
τ	1.40725	0.080695
t_0	18.13165	9.375206
t_1	61.51307	17.858926
t_2	149.48072	28.858246
t_3	637.00078	75.272043
θ_0	-1.36612	0.176942
θ_1	1.47257	0.186335
θ_2	-0.41247	0.059559
θ_3	0.03357	0.006556

Density Curves for the Posterior Distributions of the Nine Monitored Parameters



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