

Mathematical Model of Legislating Climate Policy

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Background

Policy defines both domestic and global climate action. Action regarding climate change relies on elected officials working together on green legislation. Interactions between officials and agreements play a vital role in the dynamics of elected officials. This research is a formal exploration of the nonlinear dynamic of congressional voting in the U.S. Government. We aim to model the impact of interactions between the members of the House and Senate. The model assumes people who change position largely do so through interactions and negotiations made with parties, allowing for a mass action term to moderate their movement. We begin this exploration by looking at the American Clean Energy and Security Act of 2009.

The decision to base our analysis and model off of the American Clean Energy and Security Act is deliberate due to its relevance as the most recent climate bill to pass in the House of Representatives. The American Clean Energy and Security Act consists of five main titles: clean energy, energy efficiency, reducing global warming pollution, transitioning to a clean energy economy, and agriculture and forestry related offsets. The bill specifically focused on implementing a cap-and-trade system for seven greenhouse gasses. The goal was to cap emissions and over a forty-year period reduce greenhouse gas emissions by over 80%.

This is the simulated impact that the American Clean Energy and Security Act, otherwise known as the Waxman Markey bill, would have had on carbon emissions had it been passed.

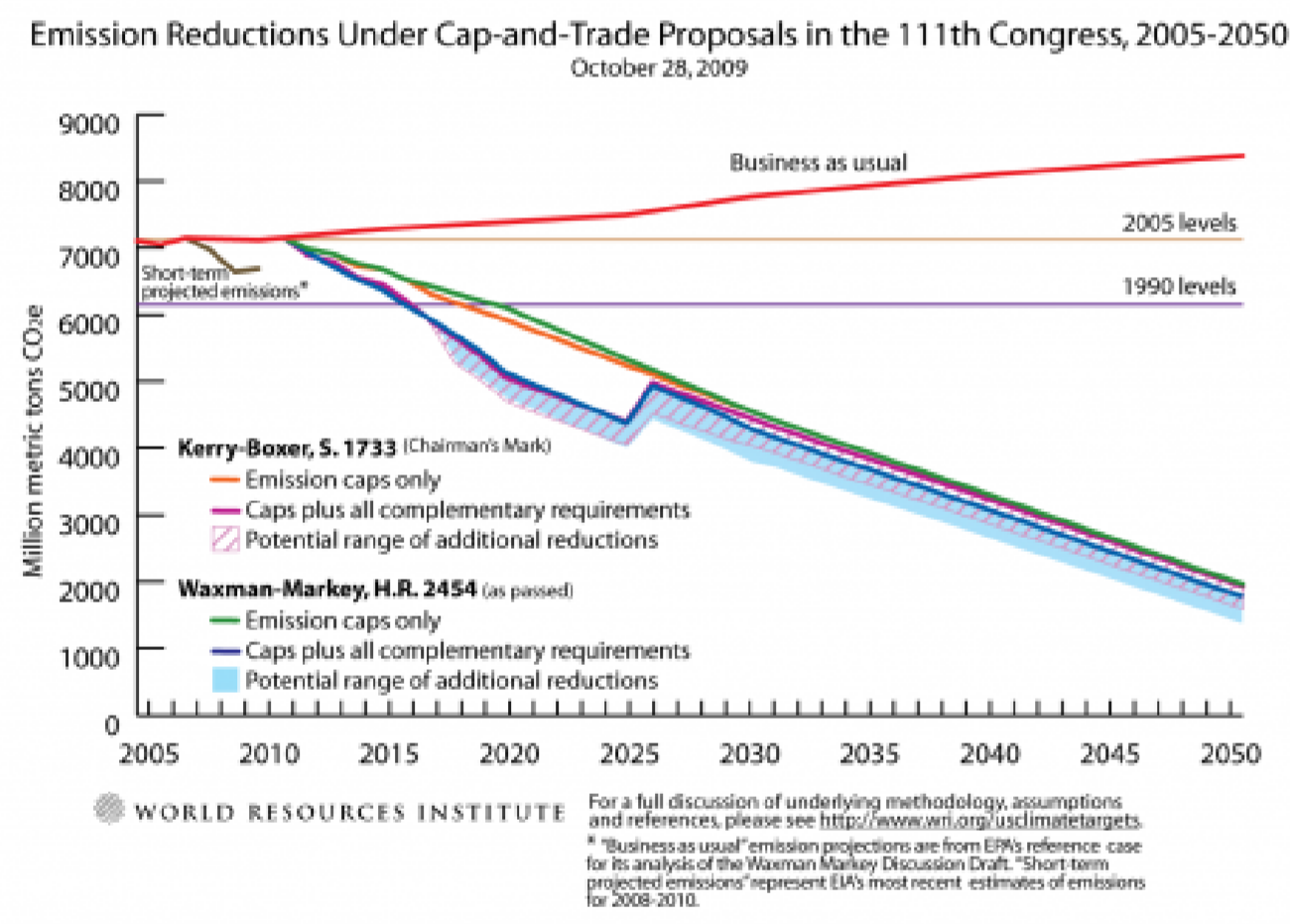


Figure 1. Projected impact of American Clean Energy and Security Act on Carbon Emissions

The massive potential impact of the American Clean Energy and Security Act points to the question of why it failed in the Senate.

Research Objectives

- Construct a mathematical model consisting of a compartmental system of nonlinear differential equations to effectively simulate the process of a bill moving through Congress and predict if it will become a policy
- Define and calculate the parameters for this model
- Numerically verify this model by simulating the American Clean Energy and Security Act and compare the results of the simulation with the actions of the 111th Congress

Model and Methods

Model Parameters

Parameter	Description	Value in House	Value in Senate
α_C	% of legislature that is a centrist	0.168	0.22
α_F	% of legislature that is in favor of the bill by party	0.449	0.41
α_A	% of legislature that is in favor of the bill by party	0.382	0.37
β_F	Rate Centrists move to vote yes by peer pressure	0.01	0.01
β_A	Rate Centrists move to vote no by peer pressure	0.0095	0.0095

Table 1. A table caption.

L represents the legislative body before contact with the bill. C is the group of centrists. Y is people who are in favor of and therefore vote yes on the bill. N is people who are against and therefore vote no on the bill.

$$\dot{L} = -(\alpha_F + \alpha_A + \alpha_C)L \quad (1)$$

$$\dot{C} = \alpha_C L - \beta_F C Y - \beta_A C N \quad (2)$$

$$\dot{Y} = \alpha_F L + \beta_F C Y \quad (3)$$

$$\dot{N} = \alpha_A L + \beta_A C N \quad (4)$$

This research is defined by two different steps.

- Singular Value Decomposition:** The first stage is breaking up the legislature into centrists, people in favor of the bill, and people against the bill. This is accomplished by scaling the ideologies of the 111th Congress by analyzing their voting records through a singular value decomposition. The singular value decomposition ranks the ideology from -1, the most liberal, to 1, the most conservative. The centrist group is defined as the legislators whose ideology is between -0.25 and 0.25. Next, based on the traditional values of each party, the legislature is divided into each category by the percentage of the whole body their ideology makes up.
- R simulation:** By taking the ideology categories from the singular value decomposition and using them as parameters for the compartmental system of differential equations and simulating it in R along with choosing 0.01 as ideology transmission rate for the majority party and 0.0095 as the ideology transmission rate for the minority party, the model can predict the results of a vote in a legislature.

Numerical Experiments

With these parameters, simulating the model in the house outputs:

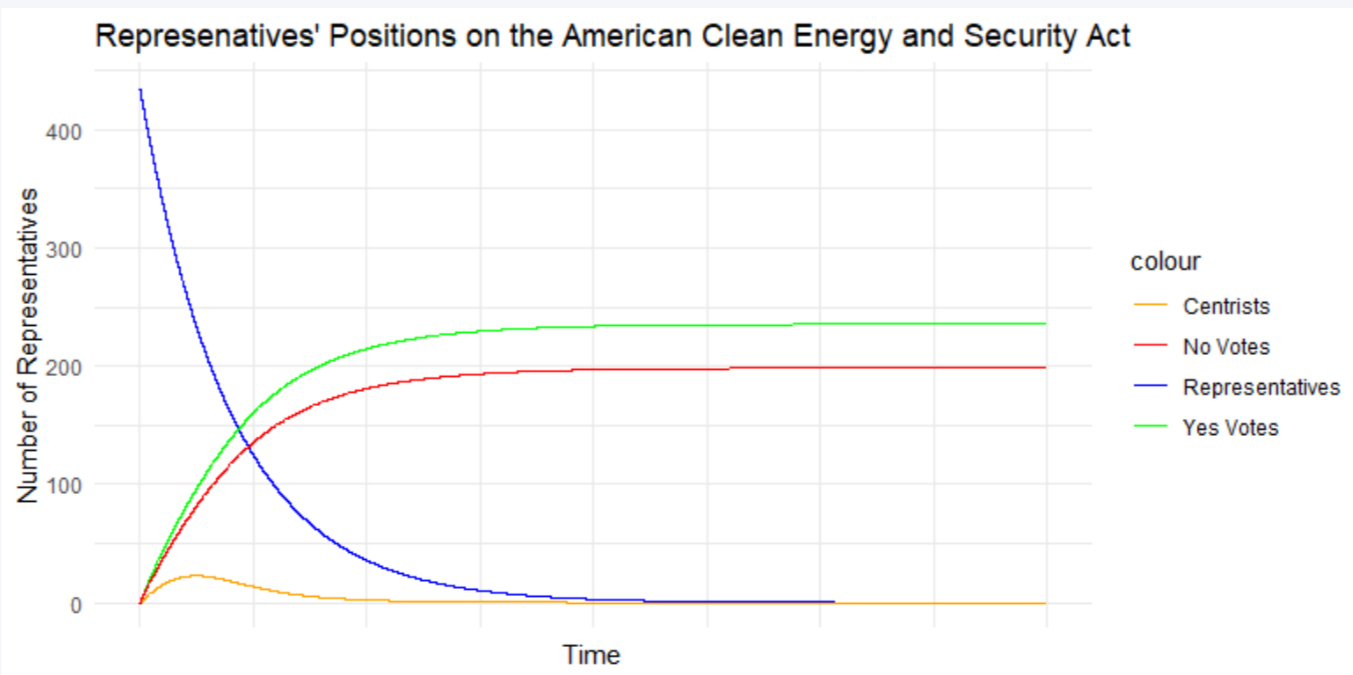


Figure 2. Projected House of Representative vote on the American Clean Energy and Security Act

Numerical Experiments Continued

In the Senate this outputs:

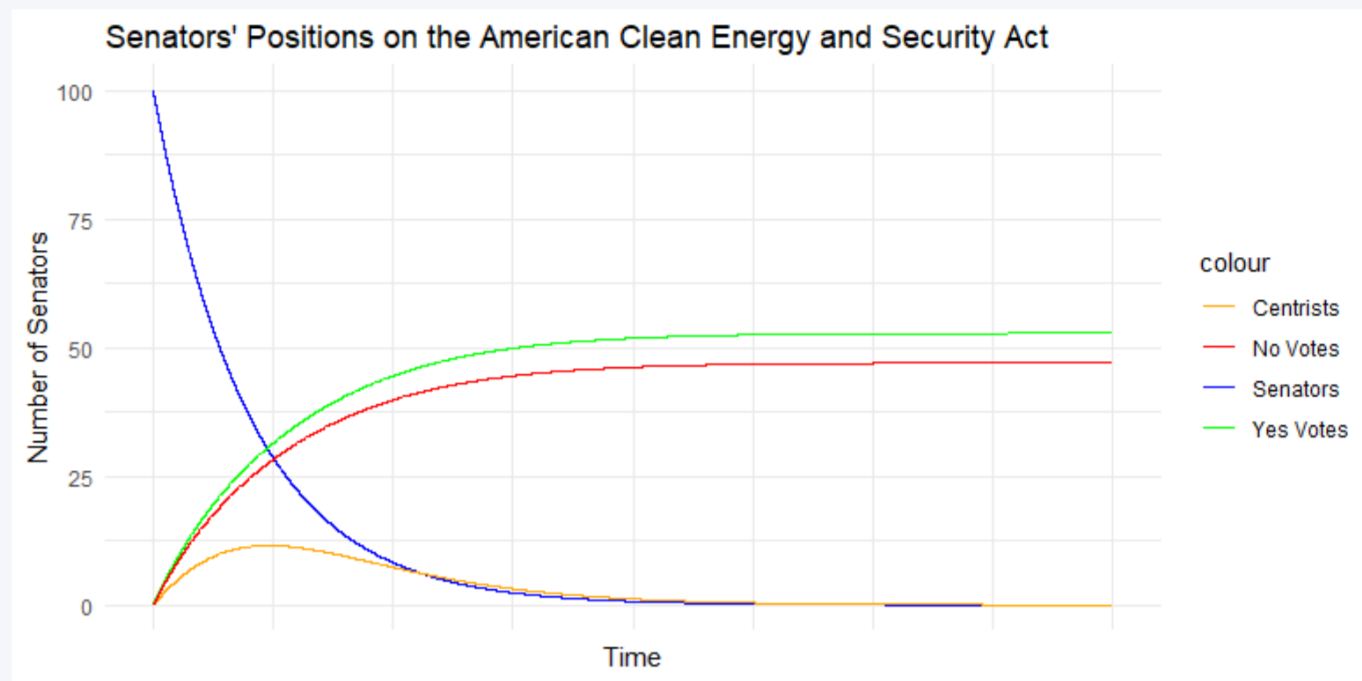


Figure 3. Projected Senate vote on the American Clean Energy and Security Act

After rounding the model's outputted values, the final tally comes to:

Branch of Congress	Votes in Favor	Votes Against
House	236	198
Senate	53	47

Table 2. Projected Votes in Each House

Conclusion and Future Research

This model acts as a baseline for simulating the way in which a bill is likely to move through the US Congress. In the case of the American Clean Energy and Security Act, it predicted a vote of 236-198 in the House, which is promising when comparing it to the actual vote of 219-212. The model misallocated <4% of the votes and correctly predicted the bill passing. It also correctly predicted that the bill would fail in the Senate, with a vote of 53-47, falling 7 short of making it past the filibuster. Consistent with this model's predictions, the American Clean Energy and Security Act never made it to a vote in the Senate because it did not have a chance of passing the filibuster. A nonlinear compartmental system of differential equations is a promising new approach to predict and analyze governmental action that has successfully been validated by the American Clean Energy and Security Act. This method can now be used to analyze other legislation. This model can be improved by taking into account the impact of lobbying and scaling the ideology of the bill in question.

Acknowledgement

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References

- Trevor Culhane, Galen Hall, and J. Timmons Roberts. Who Delays Climate Action? Interest Groups and Coalitions in State Legislative Struggles in the United States. *Energy Research Social Science*, 79:102114, 2021.
- Howard Rosenthal Adam Boche Aaron Rudkin Jeffrey B. Lewis, Keith Poole and Luke Sonnet. Voteview: Congressional Roll-Call Votes Database, 2023.
- Hem Joshi, Suzanne Lenhart, Sanjukta Hota, and Folashade B. Augusto. Optimal Control of an SIR Model with Changing Behavior through an Education Campaign. *Electronic Journal of Differential Equations*, 2015:1–14, 02 2015.
- John Larson. Emissions Reductions under Pollution Reduction proposals in the 111th U.S. Congress, 2010. Accessed: 10/28/2023.
- Isak Stoddard, Kevin Anderson, Stuart Capstick, Wim Carton, Joanna Depledge, Keri Facer, Clair Gough, Frederic Hache, Claire Hoolohan, Martin Hultman, Niclas Hållström, Sivan Kartha, Sonja Klinsky, Magdalena Kuchler, Eva Lövbrand, Naghmeh Nasiritousi, Peter Newell, Glen P. Peters, Youba Sokona, Andy Stirling, Matthew Stilwell, Clive L. Spash, and Mariama Williams. Three Decades of Climate Mitigation: Why Haven't We Bent the Global Emissions Curve? *Annual Review of Environment and Resources*, 46(1):653–689, 2021.