A Model of Policy Formation through Simulated Annealing:

The Impact of Preference Alignment on Productivity and Satisfaction

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Abstract We are interested in how preference correlations can impact policy-maker productivity and their satisfaction with resultant policy. We applied a simulated annealing process as a model of revising draft legislation in peer and committee reviews before submission to a floor vote. Results indicate that having exogenous, common issue priorities is required for productivity but that some structures inhibit productivity, particularly where preference schedules are uncorrelated. Our model also demonstrates lower system efficiency, and lower overall satisfaction, as policy is negotiated through compromise to achieve higher production.

Key words: simulated annealing · policy formation · organizational theory · preference alignment · network structure

1 Introduction

It is a trope of Western democratic ideals that a democracy—governance by vote—produces the greatest happiness for its citizenry, or the least unhappiness for a majority of it. Our intuition is that diversity and divides in policy preferences can result in legislative deadlock and lower overall satisfaction with legislative outcomes. We were motivated to this research wishing to understand the unproductive $112^t h$ and $113^t h$ U.S. Congresses. Political science often models congressional ideology backward from voting decisions [13, 9], party influence [4, 5, 1, 11, 12], and committee dynamics [17, 6, 14]. Our

* We wish to thank Maksim Tsvetovat who introduced us to applications of simulated annealing to Organizational Theory and inspired us to extend it, adapt it, and to think about organizations and processes where it seems to fit especially well. We also thank an anonymous reviewer for helpful feedback provided on a previous draft of this paper.

research complements other studies by developing a computational model of policy development through draft legislation, working forward from arbitrary ideological foundations. Viewing bill revision as a process that optimizes legislative body satisfaction within a system of competing legislator preferences, we judged simulated annealing (SA, hereafter) to be the non-deterministic optimization method most suited for modeling this.

As a generalized model of policy-making, the results are broadly applicable to a wide range of policy-making organizations: legislative bodies at the national or local level, regulatory bodies, standards organizations, and conference committees, for example.

Our simulation model enables quantitative analysis of the productivity and satisfaction of three typified legislatures: with unified, bi-modal (bipartisan), or completely uncorrelated sets of preferences. Results indicate that party partisanship alone does not explain a Congress's inability to produce legislation.

2 Model and Methods

2.1 Model Overview

In this section, we describe implementation of a model of policy formation through simulated annealing. We initialize each case by generating a legislature and its internal social network. Legislators have preferences on a set of issues, prioritizing some issues over others. They take turns sponsoring bills, which get reviewed and revised through two rounds of SA before the entire legislative body votes on the bill. We captured productivity, satisfaction, and amount of compromise as the relevant metrics for each simulation run. We describe the initialization and simulation processes and experimentation methods in more detail below. [1].

2.2 Model Initialization

The first step in the simulation initializes the model by generating a `State` object, which realizes the parameters of that run scenario:

[1] In the interest of brevity, we have omitted some detail descriptions of the initialization and simulation; however, these details,as well as the model itself, may be found in the online supplement at https://github.com/strangeintp/garbage-can-congress/wiki

a heterogeneous set of 100 legislators, each with priority-ranked positions on a set of 75 issues, assigned stochastically but correlated through State- and party-provided seed vectors. The `State` object then organizes the legislators into a social network making a realistic number of connections between the most similar legislators.

Initializing the Model Environment For our model, we assume that several core issues represent powerful, crystallizing factors that differentiate our simulated parties. Thus, party "platforms" consist of vectors of positions and priorities on a set of issues that includes both `State_Priorities` and a random sample of high-priority `Ideology_Issues`. These vectors are used as "seeds" for the stochastic generation of individual legislator preferences.

Legislator Initialization Each legislator's issue priorities are assigned with a stochastic preferential attachment method to the seed values provided by the `State` object. This generates a power law distribution of priorities for that legislator and provides some correlation in legislator priorities to the extent that seed vectors are similar (as determined by state priorities and party ideology).

We assume that party-affiliated legislators adopt the positions of their party; for all other issues (and all issues for unaffiliated legislators), positions are assigned uniform randomly from the range of allowed position values (2^4 for our model). The end-result of this process is a set of legislator agents with heterogeneous but correlated policy preferences as conditioned by party ideologies and state priorities, and with the strength of correlation determined by party-alignment.

Network Generation The final step of initialization generates a social network, using both homophily [15, 3] and preferential attachment [2], based on preferences assigned in the previous step. Preferential attachment is as described in Barabasi and Albert (1999), with $m = 5$ new edges selected randomly from a *pdf* distribution of degree in the sub-network of potential allies of each legislator. The set of potential allies is selected using a preference-weighted likelihood over all issues. The typical outcome of this procedure is a network among legislator agents with "small-world" properties [18], consistent with existing research on social networks in the U.S. Congress [7] [2].

2.3 Simulation Algorithm Overview

Having defined a population of legislators and their relationship to each-other, we next establish a procedure for legislators to engage in the business of law-making.[3] In our model of law-making, the simulation sequentially repeats the following process for 200 proposals (or halts if all issues are passed into law):

1. Proposal:
   (a) A random legislator is chosen to sponsor a bill.
   (b) The sponsor proposes a draft bill on any issue that has not already been addressed by law. This initial draft reflects the sponsor's position on that issue.
2. Draft circulation among cosponsors:
   (a) All legislators connected to the sponsor in the social network are selected as cosponsors.
   (b) The cosponsors revise the draft using SA; new issues may be added to the bill during the revision process and solutions on existing issues may change.
3. Committee review:
   (a) The draft is referred to a committee, reflecting committee agenda-setting powers [4, 5]. Legislators for whom the main issue of the bill is a high priority are assigned to the relevant committee.
   (b) The committee revises the bill by SA; again, new issues may be added and existing solutions changed.
4. Floor vote:
   (a) The bill is referred to the floor for a vote.
   (b) A legislator votes 'yes' to a bill when her satisfaction with it is greater than the model parameter `satisfaction_threshold`.

[2] We verify "small-worldness" of the networks produced by the model using the Humphries and Gurney metrics [8].

[3] One might argue that this is a departure from realism, as the current Congress does not appear to do this. However, we are attempting to generalize a model of law-making in legislatures. Some legislatures do periodically legislate.

(c) If the bill passes by simple majority (>50% votes), the bill is made into law; *i.e.*, the solutions addressed by the bill are recorded and the issues may not be revisited for the remainder of the realization.

Simulated Annealing Bill revision is implemented by the Metropolis algorithm for simulated annealing [16, 10]. Our energy function is the cumulative dissatisfaction of all reviewers over all dimensions of the bill. Increases of 0.1 in dissatisfaction were accepted with probability ½ at the maximum temperature. Higher satisfaction energy states are automatically accepted. [4]

2.4 Model Calibration

We calibrated legislators' *satisfaction thresholds*—the point at which they vote "yes" on legislation—to achieve a 4% pass-rate, comparable to passage rates in the actual US Congress (between 2% and 7% in recent history).[5]

2.5 Experiments

Table 1 identifies key parameters used in the model for the suite of experiments. The experiment suite was designed factorially, exercising all combinations of values shown in the table – excepting `Green_Fraction` variation when `Unaffilitated_Fraction` = 1.0, which is a degenerate case – resulting in 28 unique experiments. 30 simulations were realized per experiment.

For each realization, we recorded: the number of laws passed, the number of issues addressed by law (i.e. provisions), and legislative body satisfactions over all bills before and after SA revisions. To keep the data set manageable, we recorded a sample run history for only a single realization of each experiment. Aggregate statistics (averages and standard deviations) were also calculated and recorded for the output metrics of all realizations of an experiment.

[4] The online supplement provides more detail.

[5] Pass rates are equal to the total number of bills passed in a given Congress divided by the total counts of introduced legislation for that Congress. Data to calculate pass rates was collected from Civic Impulse LLC (http://www.govtrack.us).

Table 1. Simulation Parameter Space

Parameter	Description	Value [Variation]
`Unaffilitated_Fraction`	Fraction of the legislative population with no ideological party affiliation.	[0.05, 0.5, 1.0]
`Green_Fraction`	Fraction of the party-affiliated population belonging to the *Green* party. Remainder belong to the Yellow party.	[0.5, 0.75, 1.0]
`Ideology_Issues`	Ideological platform issues for the parties.	[0, 5]
`State_Priorities`	High-priority issues for all legislators, regardless of affiliation.	[0, 5]

3 Results and Findings

Fourteen of the 28 experiment combinations were uniformly unproductive (produced no laws), as follows:

1. All four cases with no party structure,
2. Scenarios with 50% unaffiliated, 25% Green, and 25% Yellow,
3. Scenarios with no external priorities (an additional 5), and
4. One case with 5% unaffiliated members, 50% Green members, and no ideology-based priorities.

For the remaining productive cases, Figure 1 presents run results across the three aggregate metrics captured for each run (total satisfaction and number of laws passed, plotted against number of provisions added.)

Interpreting these results, our main findings are:

1. Higher correlation of preferences results in higher productivity.
2. Higher productivity requires increased provisions.
3. Partisanship is not necessarily an impediment to productivity (see cases 2 and 4).
4. Bipartisan networks (even division of party-affiliated legislators) with more external priorities can be more productive than majorities or super-majorities (with fewer external priorities). Compare case 4 to cases 11, 18, 19, and 23.
5. Despite higher productivity, overall satisfaction decreases with increased provisions (note negative trend lines in the "Satisfaction" row of Figure 1).

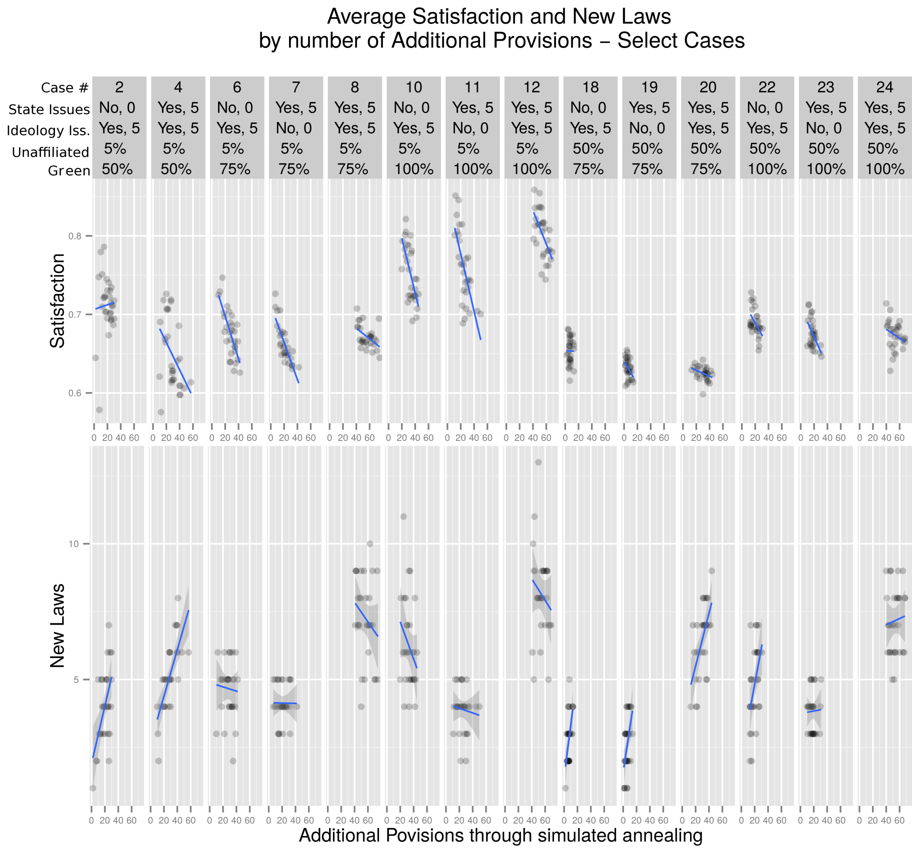

Figure 1. Experiment suite results for productive scenarios. The trend lines indicate a best fit linear correlation to the number of additional provisions.

4 Discussion

Based on our results and findings, we can generalize about the importance of having external priorities for self-tasking organizations, such as the U.S. Congress, that undertake complex tasks (law generation) requiring group approval.[6] Having at least some priorities established externally seems to be required for self-tasking organizations to be productive. As a rule, the cases with more externally-defined priorities are more productive than the cases with fewer externally-defined priorities. The cases with no externally-defined priorities were con-

[6] Note that production of an academic paper with multiple authors may fit this generalized formulation, as well.

sistently unproductive. It is tempting to say that this points at the role of leadership—both from within organizations (ideology issues) and from above them (state priorities)—but this will be a question for future research.

Our initial motivation for this research was consideration of the common assertion that a dysfunctional Congress (if measured by ability to pass law) is caused by tensions between the two major political parties in the U.S. Our results – in particular, findings 3 and 4 – do not support the assertion that polarization of preferences alone leads to an unproductive legislature; other factors such as manipulation of the political process are more likely causal.

Finding #2 demonstrates that higher productivity requires increased provisions. In a legislative context, these provisions (or "riders") represent effort diverted to individual interests that are not [necessarily] focused on the task at hand. These riders are commonly recognized as the "cost of doing business". Abstracting from a legislative context, we may generalize by saying that higher productivity comes with the cost of lower system efficiency.

Finally, finding #5—that satisfaction decreases with increasing provisions—captures the social aspects of negotiation and compromise. In other words, policy makers are willing to cede adverse positions on their lower-priority issues as a cost of attaining higher satisfaction with the total law, and total satisfaction decreases as these issues are added. Conversely, bills start off in a low-satisfaction state and gather provisions as a way of garnering votes. In either case, more issues are needed to retain or attain sufficient satisfaction to pass new legislation.

4.1 Implications for future research

Further research might vary the network-structure generating parameters with finer resolution to identify the tipping points in the outcomes: How much of a majority is needed for compromise to yield satisfaction and productivity? How much leadership intervention (ideology) is required to overcome inherently unproductive structures? How many state priorities are required to ensure sufficient preference correlation, for a given legislature?

We are also interested in understanding the effects of party affiliation on proposals and productivity. This paper reviewed aggregate results from our experiments with the model. The model could be extended to produce additional detail data about how much compromise is needed, given the characteristics of a bill's sponsor. We suspect that the sponsor's peer network, if they are in the minority, may modify an otherwise popular proposal with unpopular issues, such that it fails to garner votes at the committee or floor. If a bill's sponsor were to intentionally include members from the majority party, or conversely, exclude close connections who may be adverse to a proposal, the annealing process might produce more laws.

5 Summary

We modeled policy-making as a simulated annealing algorithm to find solutions in a complex problem space with interdependent constraints. We chose the U.S. Congress and legislative process as a case study, but this research may be applied to other policy-making organizations. Results indicate that partisanship alone is not necessarily an impediment to productivity, provided that there is sufficient alignment of priorities and preferences. However, higher productivity comes at the cost of lower satisfaction and system efficiency. We conclude that simulated annealing is a useful method for computationally modeling policy-making, and recommend it for other research projects.

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