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Sustainable energy infrastructure siting: an agent based approach

可持续能源基础设施选址:采用基于个体的方法

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Abstract - **Technical, environment, social, economic and political constraints are critical barriers to the development of new renewable energy supplies. This paper is an agent-based, predictive analytics model of energy siting policy in the techno-social space that simulates how competing interests shape siting outcomes to identify the beneficial policy for sustainable energy infrastructure. Using a high voltage transmission line as a case study, we integrate project engineering and institutional factors with GIS data on land use attributes and US Census residential demographics. We focus on modeling citizen attitudinal, Community Based Organization (CBO) emergence and behavioral diffusion of support and opposition with Bilateral Shapley Values from cooperative game theory. We also simulate the competitive policy process and interaction between citizens, CBOs and regulatory, utility and governmental stakeholders using a non-cooperative game theory. In addition, our model simulates the complexity of infrastructure siting by fusing citizen attitude and behavior diffusion, stakeholder bargaining and regulatory decision-making. We find CBO formation, utility message and NGO messaging have a positive impact on citizen comments submitted as a part of the Environmental Impact Statement process, while project need and procedure have a negative impact. As citizens communicate and exchange political opinions across greater distances with more neighbors, less CBOs form but those that do are more effective, increasing the number of messages citizens send. Our results also indicate that despite the money spent on assessing the engineering aspects of major infrastructure projects, citizen participation and political power can be more important to stakeholder bargaining outcomes than the level of local disruption that project causes.**

Keywords –**infrastructure siting, game theory, agent-based model, Bilateral Shapely Values, community-based organization**

摘要－技术、环境、社会、经济和政治约束是新的可再生能源供应发展的主要障碍。本文介绍了一个基于个体的预测分析模型，重点分析在科技社会空间中的能源选址政策，模拟利益冲突如何影响选址的结果来确定可持续发展能源基础设施的有理政策。使用高压输电线路为例，我们结合项目工程和制度因素，并采用土地使用属性的 **GIS** 数据和美国住宅人口普查数据。使用夏普利值及合作博弈理论，我们的模型专注于公民态度，基于社区的组织(**CBO**)的出现，和支持与反对的行为扩散。使用非合作博弈理论，我们还模拟市民、当地监管部门、公用和政府利益相关者之间的竞争政策过程和互动。此外，我们的模型还融合了公民的态度和行为扩散，利益相关者的交涉，和监管部门的决策来模拟基础设施选址的复杂性。我们发现**CBO**的形成、公共部门信息和非政府组织信息对环境影响声明过程中的公民的信息提交产生积极影响，而项目需要和过程对公民信息提交产生负面影响。随着公民沟通和交流的政治观点跨越更大的距离并联系更多的邻居，**CBO**的数量减少但是以更有效的形式呈现，增加公民提交信息的数量。我们的研究结果还表明，尽管有大量的钱花在评估重大基础设施项目的工程方面，相较于项目对当地造成的破坏，公民参与和政治力量对于影响利益相关者的交涉结果可有更大的作用。

关键词－基础设施选址，博弈论，个体为本模型，夏普利值，基于社区的组织

I. INTRODUCTION

Technical, environment, social, economic and political constraints are critical barriers to the development of new renewable energy supplies. This paper reconceptualizes how we “get to yes” by encouraging public participation and shifting opposition to the “other” side’s proposals. In this agent-based model of energy siting policy, we focus on how competing interests shape siting outcomes and identify actionable strategies to help build energy infrastructure in a more timely and less conflictual manner that current processes typically allow.

In this article, we investigate the effect of public participation on agency decision-making. Public managers must balance citizen demands, business interests, and the public interest, conceived of as public policy goals. While the relative influence of citizens versus interest groups in administrative decision-making is one of the enduring questions in political science and public administration, investigations of relative citizen influence often rely on case-based methods that typically focus on macro-level issues such as institutional rules, problem severity, as well as the attributes of the decision-making outcome. Yet, to estimate the independent effects of public participation, the other micro-level contextual variables must be, or are assumed to be, held constant. As Collins [14] states, if research were to include the effect of the complex interactions between individual actors, then the development of generalizable theories would be limited by our scholarly resources to investigate the population of cases. Our computational modeling approach compliments, rather than substitutes for, empirical research and literature reviews, and can offer a method for generating novel theoretical insights into citizen influence [13].

Using a high voltage transmission line as a case study, we integrate project engineering and institutional factors with GIS data on land use attributes and US Census residential demographics. We focus on modeling citizen attitudinal, Community Based Organization (CBO) emergence and behavioral diffusion of support and opposition with Bilateral Shapley Values from cooperative game theory. We also simulate the competitive policy process and interaction between citizens, CBOs and regulatory, utility and governmental stakeholders using a non-cooperative game theory. In addition, our model explores the complexity of infrastructure siting by fusing citizen attitude and behavior diffusion, stakeholder bargaining and regulatory decision-making.

Our simulation results provide strategic advice to users about how to reach consensus on sustainable energy infrastructure siting issue given its dynamics, offer insights about policy levers, issue linkage strategies, bargaining positions, scenarios analysis to explore key uncertainties, and can identify equitable solutions supported by communities.

II. LITERATURE

Sustainable energy infrastructure development can be seen as a mixed motive social dilemma where public goods provision is in conflict with private interests. There have been a lot of attentions paid to environmental sustainability and new regulatory rules, have so utilities, stakeholders, and government officials are under the pressure to find new and creative solutions to the complex problems of sustainable resource use. We focus on the Environmental Impact Assessment (EIA) decision-making processes because they are common and the EIA process structures agency decisions. EIA processes require and notice and comment period like the Administrative Procedures Act. [1]EIA's involve analyzing the likely environmental and social impacts of a project in a multidisciplinary fashion, presenting the information to the public and decision makers, and taking public and stakeholder comments into account in the final decision. The siting of an energy project usually begins with the project sponsor developing a detailed and substantial review of social and environmental impacts, typically prepared by the project proponent, which gives it significant advantages in determining the alternatives and the initial assessment of costs and benefits of the project design. The EIA process involves public notification of the project proposal, public involvement in scoping, preparation of a draft EIA, public review and comment on the draft EIA, and the preparation of a final EIA that takes public comments into account [31].

There is substantial evidence in the planning and political science literature that ensuring robust public participation and making use of collaborative planning approaches can significantly reduce conflict [8, 9]. A study of planning in the Great Lakes region find that an open and fair participatory process is associated with greater trust and better policy outcomes. Many public participation practices reduce conflict and develop accountability [8]. Increased public participation can include building trust, developing "buy-in", provide objectively superior decisions, and lead to a more healthy democratic society [8].

The second type of theoretical and empirical support for the model development is industry impact in administrative decisions. Although stakeholder participation in general has elicited great expectations for power sharing among diverse interests and individuals, public consultation can just legitimize decisions that have already been made [20]. Other researchers have been concerned that stakeholder processes simply reproduce the power relations already present in a jurisdiction [6][16]. Public participation has been conceived as a means to check power of the state and market [44].

The third body of literature that contributes to the model comes from lobbying and administrative decision making. Agency decisions are subject to lobbying by industry groups who can more easily overcome barriers to collective action than consumers [34]. Industry groups have greater lobbying resources compared to public interest groups. Other studies suggest that powerful industry groups manage to manipulate state energy policies [37]. Evidence suggests that environmental groups have been skeptical of participation mechanisms because of the perceived power of pro-development interests to influence the outcomes [18][30].

III. THE MODEL

Given this review of citizen and industry influence administrative decisions, simulating this process requires the

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[1] After the US systematized EIAs in the National Environmental Policy Act (NEPA) of 1969, some form of assessment has been required by all US states, and in a growing number of nations around the world (Wathern, 1988, p. 3). The European Union requires EIA for public and private infrastructure projects that are thought to have significant environmental impacts (European Commission, 2012). Most nations in Asia, including China, Korea, Japan, Indonesia and India require some form of EIA before major projects can proceed. EIA's are typically required for these large infrastructure projects involving government funds or lands.

integration of both citizen and industry preferences into modeling efforts. Our agent based model of siting preferences, called SEMPro, simulates bargaining dynamics amongst stakeholders as well as decision makers in the decision process using a spatial bargaining model.

Bargaining models date back to Condorcet's voting paradox [15], and Black [11] and Downs [17] trying to frame a positivist approach to analytical politics. More recently, McKelvey and Ordershook [29] as well as Feldman [19] outline four fundamental assumptions for spatial stakeholder bargaining models: actors are instrumentally rational, with the choice set of feasible political alternatives modeled as a space with complete, ordered and transitive properties. The spatial bargaining approach naturally lends itself to agent-based modeling as stakeholders possess decision agency as well as attributes of preferences over issue spaces, with varying influence and salience [22]. ABM instantiations of spatial bargaining models include Abdollahian and Alsharabati [3] and Abdollahian et al [4].

SEMPro is part of a new class of techno-social [42] and complex adaptive systems' models[1, 2], simulating the interactive effects and feedbacks between human and institutional agency, engineered physical elements, and geophysical systems. SEMPro makes two contributions to our understanding of citizen impacts on agency decisions. First, SEMPro is one of only a handful of multi-agent agent-based models that uses geographical information system (GIS) and detailed census survey data which instantiates real-world dynamics into simulation modeling. Second, SEMPro is the first planning model we are aware of that integrates an ABM with cooperative and non-cooperative game theory models of stakeholder and regulatory decision-making.

SEMPro utilizes the ABM approach as it generates emergent, large-scale system phenomena from the micro-motivations and behavioral interactions of multiple agents. ABM results can then be validated against observed patterns of behavior to analyze what percent of the variation in real-life events that can be explained by the modeling. ABMs are used in techno-social modeling for three primary reasons.

First, agents can be assigned attributes based on stochastic distributions to represent noise or errors in human communication in the model that is reflective of the dynamic, adaptive and strategic nature of human behavior, especially in real-world political and social processes [5]. Introducing stochasticity in agent relationships can dramatically affect networks structures that in turn drive different behaviors [35].

Second, unlike most top-down economic models, agents in ABMs can be assigned heterogeneity in preferences, attributes, or goal-orientation objectives. Brown and Robinson [12] have shown how variations in preferences predict divergent land use outcomes. Finally, the interaction of these heterogeneous agents can lead to non-monotonic outcomes stemming from social mimicry, cooperation and competition in human systems [27]. Thus, ABMs can represent, anticipate and shape the complexity of socio-technical systems better than equation-based models and are more transparent [7].

SEMPro was developed using a system's perspective and parameterizes the project and policy levers that enable scenario analyses required of an effective decision support system [26]. Decision support systems (DSSs) like SEMPro allow users to simulate trade-offs and alternatives to improve energy planning outcomes [35]. DSSs are intended to improve the quality of decision making and need to be generalizable to a wide range of cases [24]. SEMPro can be applied to a wide range of infrastructure siting technologies such as oil pipelines, highways, high speed rail, electricity generation stations, and the subject of this article, electricity transmission lines. In addition to varying project level variables such as engineering attributes in SEMPro, we can also estimate the impacts of changes in risk communication strategies by project stakeholders.

We fuse geophysical and social elements to understand the interactive effects and feedbacks between individual human agency, engineered physical elements and the geophysical environment. Our model is implemented in NetLogo [45], with three different sequential modules, a citizen/CBO formation module, a stakeholder lobbying module and a regulatory decision making module. The citizen agents, stakeholders, and regulators in the model are all trying to maximize their own utilities, given the assumption of bounded rationality. Figure 1 depicts the high level process and multi-module architecture. It runs for up to 25 time steps, with each time step representing 1–2 months of calendar time consistent with regulatory decision time frames in some instances.

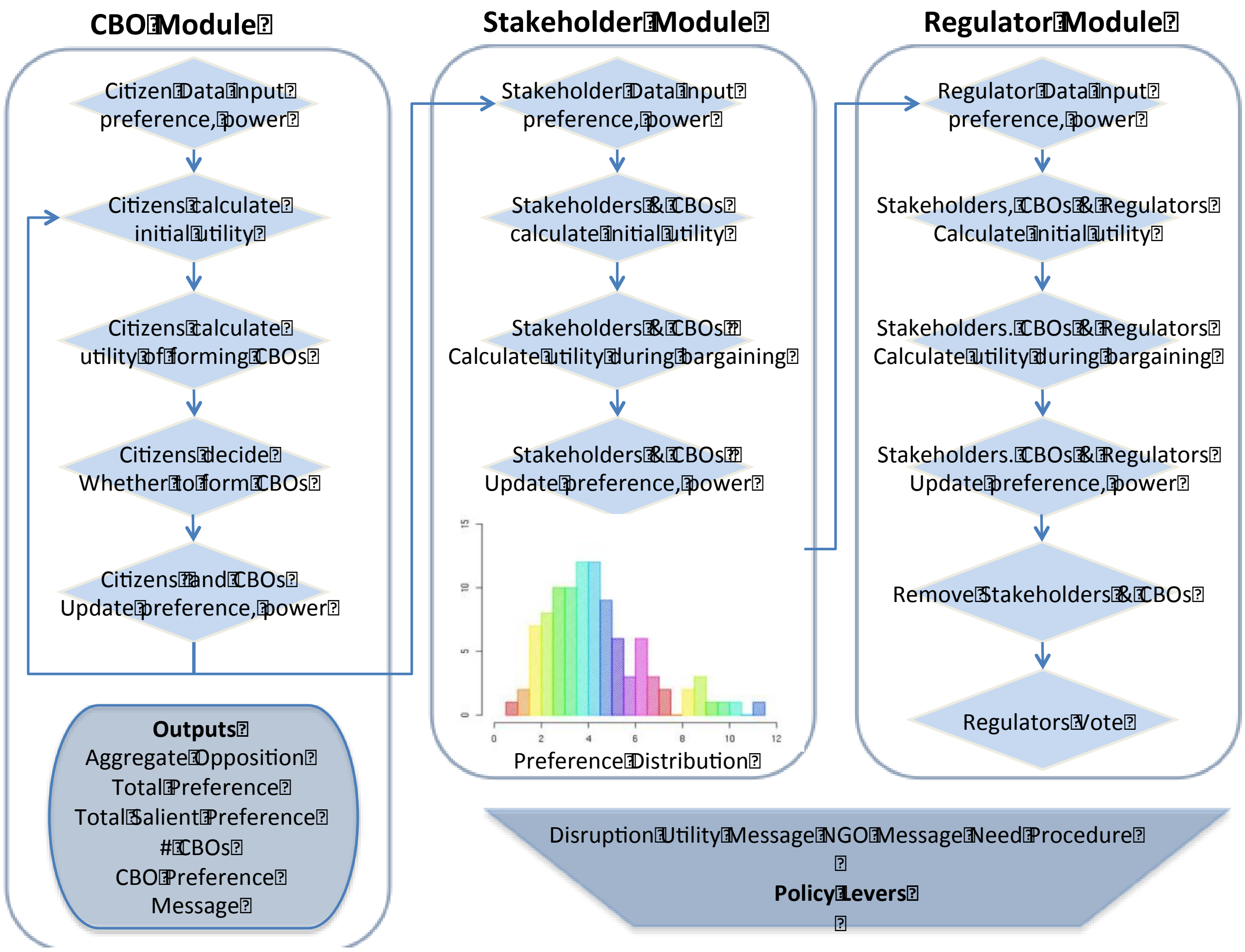


Fig. 1. Three model modules [2]

In the first module, citizens react to energy infrastructure siting projects by forming opinions, interacting with each other, and forming Community Based Organizations (CBOs) that either support or oppose such projects. To simulate this process, citizen agents are queued and processed according to their patch or grid location. GIS-based data on the project size and route, on land use, and on the location of residents informs agent-based simulations of individual interactions. US Census block-group population density data is used to locate citizen agents in the model. Data on education and income by block-group are instantiated as attributes of the agents in the model and provide initial heterogeneity for simulated citizen behavior. Higher values are associated with greater levels of influence in affecting project outcomes and imbue citizens with "power." Wealthier and more educated individuals tend to have a stronger sense of self-efficacy and more resources available for advocacy [33].

In this module, the following is based on calculation of Bilateral Shapley Values (BSVs) of all citizen agents. BSV is a concept in cooperative game theory for explaining coalition formation, and thus a natural modeling strategy to use in CBO formation [25]. Each citizen agent is assumed to be autonomous, with bounded rationality, maximizing it's own utility subject to the geophysical, engineering and social constraints of its environment [46]. BSV computes all combination of all possible coalitions that citizens can join that maximize citizen utility, and then compares all possible coalition utilities in deciding whether or not to join or form a larger CBO. BSV dynamics thus focus on the permutations of individuals in different coalitions based on the marginal utility gained from CBO formation. Expected utility has been described as the "major paradigm in decision making" [38], and our CBO formation is based on cooperative game theory [40].

We also incorporates Social Judgment Theory in each citizen agent's objective function. This theory describes how the positions of two agents can be conceived along a Downsian continuum where the distance between their positions affects the likelihood of one accepting the other's position. A message that is far from a receiver's position is likely to be rejected [39]. For decades, social psychology research has documented that not only do people resist changing their own positions in relationship to new information, but that they might also adopt even more extreme beliefs than before. Social judgment theory finds support in the literature on risk perceptions and social trust. Citizens are unlikely to change their preferences about the project if they distrust the source of risk communications

[23]. In spatial bargaining, trust can be operationalized as the distance between two stakeholder's positions and again is operationalized in the SEMPro model structure.

In the second module of stakeholder bargaining, against this backdrop of political and social opinion formation and risk communication processes, organized stakeholders seek to lobby not only citizen opinions but also other stakeholders to maximize their specific, organizational interests. Berlo's Communications Penetration Model describes how these messages may not be received or accepted because the receiver is not exposed to the message, does not pay attention to the message or does not accept the sentiment of the message [10]. The stakeholder bargaining module takes the emergent CBO formation into consideration in determining stakeholder bargaining outcomes using non-cooperative game theory. Stakeholders will form coalitions if it increases their power to potentially influence the regulatory process as long as the coalition's position is acceptable given the stakeholder's initial position [32].

In the third module, regulators join the bargaining process in the end of the stakeholder module, taking into account CBO formation and public opinion, then bargain among themselves in the regulator module to vote either in support or opposition to the project. Each module updates at each time step. This parallel, linked module processing sequence then iterates. In two continuous time steps, if no new coalition is formed, or no CBOs, stakeholders and regulators change their preference, then the model reaches its steady state equilibrium and will stop.

Actionable policy levers for shaping the transmission siting process include the disruption engineering of the project, utility and NGO messaging outreach, as well as perceived project need and procedure surrounding the process. SEMPro users can simulate changes in the engineering, social, and political attributes of each project as explained in Abdollahian, et al [2]. Each policy lever parameter is normalized along Downsian issue continuum on a 1-10 scale to calibrate the model's internal validity.

The variable that describes the engineering attributes of the project in the model is the level of *disruption* that the project imposes on the community. Disruption is defined as impacts to public health and safety, viewshed impairment, impacts to property values, or other externalities from the infrastructure project (0-1 scale).

Utility-Message is a stakeholder variable that represents the number of pro-development messages the project sponsor sends to citizens to shape public attitudes in each time step.

NGO-Message is the final project level variable that represents the number of anti-development outreach risk communications that non-governmental organizations (NGO) such as the Sierra Club sends to citizens. Our approach propagates utility and NGO messages according to the parameter settings for each simulation in each time step.

Two institutional level variables are included in the model: *Perceived Need* is perceived to be needed by the community. Need can be coded higher when project has been approved by the state regulator and is perceived to provide local system reliability or economic benefits. *Procedure* is an indicator of procedural justice, or to what extent the citizens think their preferences will be included in regulatory decision-making. Experimentalist research confirms that people want to be treated equitably and "other-regarding" equity considerations are a primary driver of citizen behavior.

The primary community level variable is *Talk-Span*, defined as is the distance across which citizen agents talk to each other and make decisions on whether to form CBOs. This can be conceived as the social connectivity of citizens (Putnam, 2001).

IV. VERIFICATION AND SIMULATION

Unit tests were employed in the development of the three modules to verify code functionality. Next, the model outputs were validated against what it claims to be representing. The general goal of validating ABMs is to assess whether the micro-level behavior of the agents generate the expected macro-level patterns [21]. Following Taber and Timpone [41] we employed a two-step validation process. The first was a process validation assessment that tests the model's mechanisms against real-world processes. Our process validity assurance began with selection of appropriate micro-level theories about attitude and behavior diffusion, including social judgment theory [39] and spatially structured (rather than random) interactions [30]. Subsequently, the model's assumptions underlying the model's algorithms were validated against survey data of citizens for a Southern California Edison siting project of Tehachape and Chino Hills. The analysis of the survey data indicated that citizen preferences are moderated by their proximity to the project, their communication networks, and the disruption posed by the project. The effect of trust in the project sponsor on citizen preferences is moderated by distance [33]. Abdollahian et al [2] report other validation tests performed on the model outputs and how the survey data support the model.

After validation and verification, we conducted a quasi-global sensitivity analysis by varying all input parameters across their entire range in three steps (min, mean, max) resulting in 729 runs with up to 25 time steps each, for a total of 14,576 observations. We then pool all the simulations together for a pooled time series regression design estimated with ordinary least squares (OLS) regression with standardized β coefficients for input parameter comparability and model performance.

V. RESULTS

5.1. CITIZEN PREFERENCE

Table 1 contains the results of the OLS modeling of the simulation results. Model 1 in Table 1 is our baseline model for detailing the impact of input parameters on number of citizen messages sent to regulators regarding the siting project. The dependent variable is the interaction term of total messages and median preferences of citizens, which captures not only the number of messages but also the direction of messages—opposition or support for the project.

TABLE 1, POOLED OLS ESTIMATIONS OF CITIZEN MESSAGES AND CBO PREFERENCES

	(1)	**(2)**	**(3)**	**(4)**
	message	**message**	**cbopref**	**cbopref**
disruption	0.109***	0.109***	0.003	0.003
	(0.000)	(0.000)	(0.244)	(0.244)
talkspan	-0.018***	-0.018***	0.909***	0.909***
	(0.000)	(0.000)	(0.000)	(0.000)
ngomessage	0.019***	0.019***	0.010***	0.010***
	(0.000)	(0.000)	(0.000)	(0.000)
utilitymessage	0.016***	-0.005	-0.002	0.051***
	(0.000)	(0.624)	(0.479)	(0.000)
need	-0.014***	-0.014***	-0.013***	-0.013***
	(0.000)	(0.000)	(0.000)	(0.000)
procedure	0.022***	0.022***	-0.004	-0.004
	(0.000)	(0.000)	(0.186)	(0.189)
step	0.959***	0.959***	0.245***	0.245***
	(0.000)	(0.000)	(0.000)	(0.000)
utilitymessage2		0.022*		-0.055***
		(0.025)		(0.000)
N	14556	14556	14556	14556
adj. R-sq	0.933	0.933	0.886	0.886

Standardized beta coefficients; p-values in parentheses
* p<0.05 **p<0.01 *** p<0.001

First, let us examine the effect of project attributes on citizen opposition. In our simulations, the disruption posed by the project has a very large impact on citizen messages (β = .109) as expected. A one standard deviation decrease in disruption results in a decrease of .109 standard deviations in negative citizen messages. Modifying the project engineering design to reduce disruption by 35%, for instance by increasing the width of the right-of-way, is predicted to result in 11% less citizen opposition.

Project need in model 1 is negative and significant (β = -.014), but is much less important than disruption in explaining outcomes. The results are consistent with observation that citizens express less opposition when the project siting brings significant benefits and is needed by the community. Similarly, perceptions of the procedural justice of the project are negative but not significantly different from zero, suggesting that in these simulations, increasing citizens' perceptions of the procedural fairness of the EIA process is not likely to have an impact on citizen opposition. As expected from the model design, time (β = .959) is positive and significant as the number of messages grows over time. Community attributes also have a large impact on citizen advocacy and activism. Talkspan has a negative impact (β = -.018) on citizen comments, suggesting that citizens express their opinion less frequently in well-connected communities, as they can express the opinion through CBOs.

Turning to the effects of risk communications strategies by project proponents and opponents, NGO message is significant since credible NGO messaging can enhance citizen activism. However the impact of NGO messages is only modest (β = .019) showing effects on activism of about the same magnitude as perceived project need. Although utility risk communications reduce the number of negative messages sent to regulators, the average effect of this variable is not significant. The implications of this finding are discussed in more detail below.

In models 3 and 4, we look at the impact of input parameters on CBO preferences, a key emergent behavior from the first module. CBO preference is the weighted average of the number of CBOs times their preferences categorized by deciles in model output. A higher value for CBO preferences indicates more CBO opposition to the project. The R^2 of 88% in the models shows CBO preference variation explained.

We can see that talkspan is not only highly significant but has the largest impact (β = .909) on CBO preferences. As citizens are able to communicate and exchange opinions across greater distances with more neighbors, the number of citizens joining CBO increases, consistent with existing literature [1, 2]. The time step variable also shows a large and significant impact on CBO formation (β = .245), indicating CBOs opposition increases as time passes. The magnitude of this variable is significantly smaller than for citizen messages (model 1), indicating that CBO preferences are less time dependent than citizen messages.

Utility message and other policy levers like disruption, procedural justice and NGO message do not have significant impact on CBO preferences in the citizen module. Need is significant and positive, counter intuitively indicating greater project need increases CBO opposition. Further investigation of this finding is warranted to discover how project need is channeled through citizen preferences that might have a positive impact on CBO preferences.

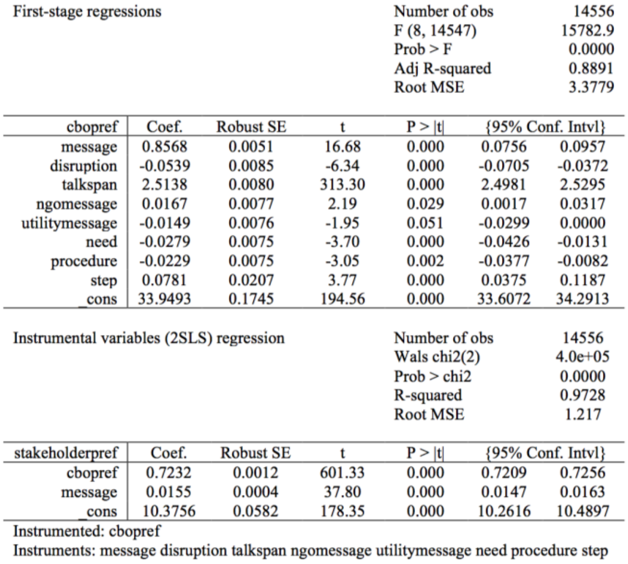
5.2. STAKEHOLDER PREFERENCE

Next, we turn to an analysis of stakeholder preferences in Table 2. We employ a two stage least square (2SLS) / Instrumental Variable (IV) regression technique for the model outputs for time steps 1-20. The error term from stakeholder preferences are likely to be correlated with

CBO preferences in any given time step. 2SLS is an appropriate econometric technique that uses the predicted value of CBO preferences created in the first stage to predict stakeholder preferences in the second stage regression. This controls for the simultaneous impact of CBOs on stakeholder preferences.

The first stage in model 5 results in an R^2 of .89, indicating 89% of the variation in CBO preferences is explained. Stage 1 in model 5 is very similar to model 3, but also includes negative messages. The inclusion of negative citizen messages truncates the coefficients for both time step and talkspan and makes the need coefficient negative. This is also consistent with model 1 and our theoretical priors. The second stage regression in model 5 indicates the number of citizen messages has a much smaller impact on stakeholder preferences than CBO preferences. This is consistent with observed behavior that citizens need a seat at the table to be heard. Organizational representation is critical to influence stakeholder bargaining in the model.

TABLE 2, 2SLS/IV ESTIMATIONS OF STAKEHOLDER PREFERENCES



First-stage regressions

Number of obs	14556
F (8, 14547)	15782.9
Prob > F	0.0000
Adj R-squared	0.8891
Root MSE	3.3779

cbopref	Coef.	Robust SE	t	P > |t|	{95% Conf. Intvl}	
message	0.8568	0.0051	16.68	0.000	0.0756	0.0957
disruption	-0.0539	0.0085	-6.34	0.000	-0.0705	-0.0372
talkspan	2.5138	0.0080	313.30	0.000	2.4981	2.5295
ngomessage	0.0167	0.0077	2.19	0.029	0.0017	0.0317
utilitymessage	-0.0149	0.0076	-1.95	0.051	-0.0299	0.0000
need	-0.0279	0.0075	-3.70	0.000	-0.0426	-0.0131
procedure	-0.0229	0.0075	-3.05	0.002	-0.0377	-0.0082
step	0.0781	0.0207	3.77	0.000	0.0375	0.1187
_cons	33.9493	0.1745	194.56	0.000	33.6072	34.2913

Instrumental variables (2SLS) regression

Number of obs	14556
Wals chi2(2)	4.0e+05
Prob > chi2	0.0000
R-squared	0.9728
Root MSE	1.217

stakeholderpref	Coef.	Robust SE	t	P > |t|	{95% Conf. Intvl}	
cbopref	0.7232	0.0012	601.33	0.000	0.7209	0.7256
message	0.0155	0.0004	37.80	0.000	0.0147	0.0163
_cons	10.3756	0.0582	178.35	0.000	10.2616	10.4897

Instrumented: cbopref

Instruments: message disruption talkspan ngomessage utilitymessage need procedure step

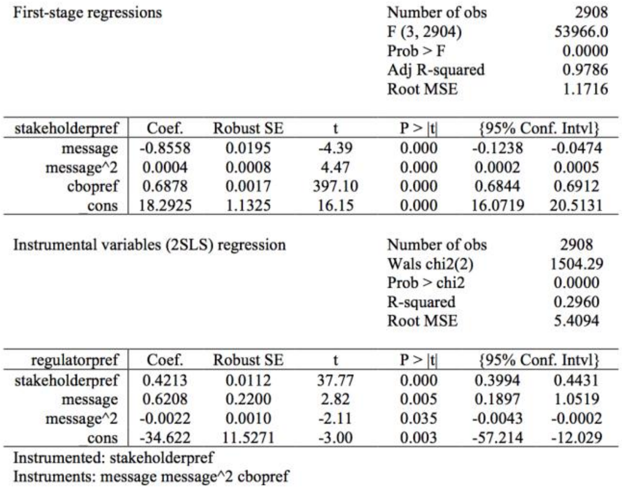
5.3. REGULATOR PREFERENCE

Table 3 shows the variables that impact regulator preferences using the same instrumental variable approach where we first predict stakeholder preferences and then use that value to predict regulator preferences. The R^2 indicates that 30% of the variation in regulator preferences is explained by the stakeholder preferences and citizen messages. We expect the R^2 for regulator preferences to be lower than that of the stakeholder equation as regulators have to balance additional considerations, such as competing policy goals and political issues, in their decisions. In addition, the R^2 is lower as regulators only interact with CBOs and other stakeholder from time step 16 to 20, and then decide amongst themselves from time step 21-25.

The table shows that negative citizen messages have a larger impact on regulator preferences than stakeholder preferences in the previous table. A one standard deviation increase in citizen messages results in a .621 standard deviation (β=.621) increase in regulator oppositional preferences.

This differential impact of citizen activism on stakeholder and regulator modules is critical. The impact of citizen messages on regulator preferences is over two times larger than their impact on stakeholder preferences. Citizen preferences impact stakeholder preferences through the efficacy of CBOs who bargain with other stakeholders. On the other hand, the modeling predicts that elected or appointed regulators are more balanced in their response to citizens and stakeholders' demands.

TABLE 3, 2SLS/IV ESTIMATIONS OF REGULATOR PREFERENCES



First-stage regressions

Number of obs	2908
F (3, 2904)	53966.0
Prob > F	0.0000
Adj R-squared	0.9786
Root MSE	1.1716

stakeholderpref	Coef.	Robust SE	t	P > |t|	{95% Conf. Intvl}	
message	-0.8558	0.0195	-4.39	0.000	-0.1238	-0.0474
message^2	0.0004	0.0008	4.47	0.000	0.0002	0.0005
cbopref	0.6878	0.0017	397.10	0.000	0.6844	0.6912
_cons	18.2925	1.1325	16.15	0.000	16.0719	20.5131

Instrumental variables (2SLS) regression

Number of obs	2908
Wals chi2(2)	1504.29
Prob > chi2	0.0000
R-squared	0.2960
Root MSE	5.4094

regulatorpref	Coef.	Robust SE	t	P > |t|	{95% Conf. Intvl}	
stakeholderpref	0.4213	0.0112	37.77	0.000	0.3994	0.4431
message	0.6208	0.2200	2.82	0.005	0.1897	1.0519
message^2	-0.0022	0.0010	-2.11	0.035	-0.0043	-0.0002
_cons	-34.622	11.5271	-3.00	0.003	-57.214	-12.029

Instrumented: stakeholderpref

Instruments: message message^2 cbopref

V. DISCUSSION

The results from the model simulations show important insights for planning processes as the linkages between emergent citizen behavior and stakeholder and regulator preferences are complex. First, citizen advocacy in institutional processes will be greater when threats to their communities are greater as evidenced by the positive impact of the disruption variable, which is consistent with the risk communication research.

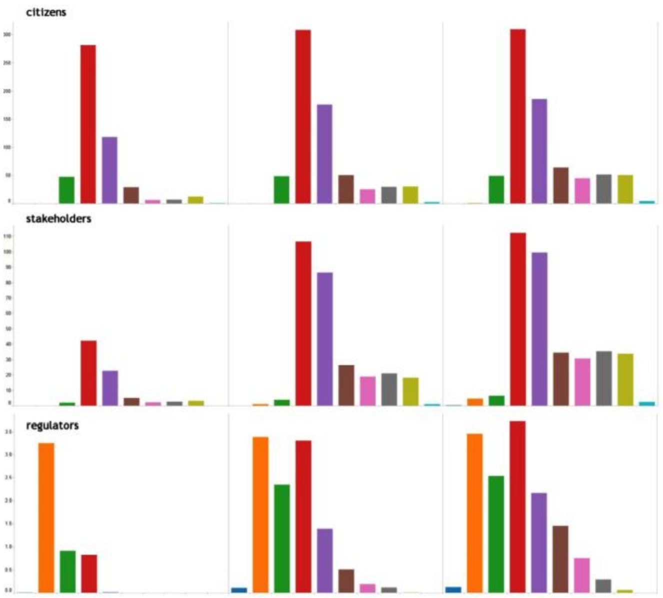
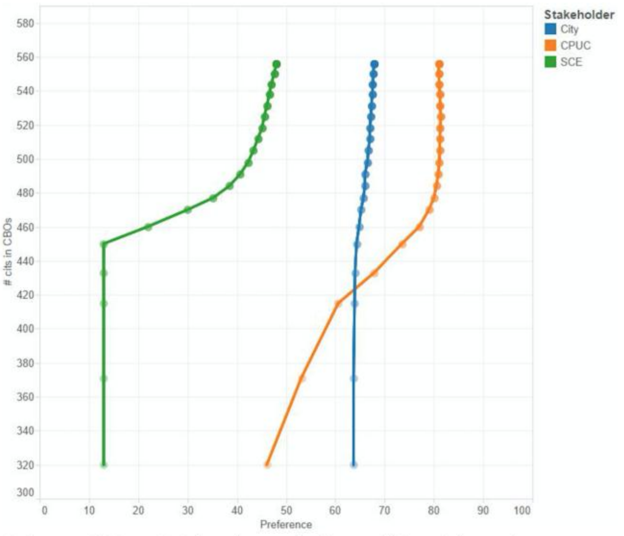


Figure 2 Agent Histogram Density for time step=1, 10 and 20



Preference vs. CBO Power. X-axis shows the range of preference, with 0 as actively supporting and 100 as actively opposing. Y-axis measures the power of CBO by number of citizens joining CBOs. Different color indicates different stakeholders.

Figure 3 Citizen CBO Size and Preference

Second, emergent citizen behavior can dramatically alter institutional outcomes over time. Figure 2 shows histograms of average citizen, stakeholder and regulator preferences in the first, middle and last time steps in all of the simulations. What is notable across all three categories is the shift towards greater project opposition over time across all three levels of analysis.

The third finding is communities with more well-connected citizens represented in the model by larger talkspan are more likely to be effective blocking or altering infrastructure projects. Talkspan implies citizens talking across a greater geographical distance in the model and predicts fewer CBOs as well as more citizen opposition messages. Talkspan can be conceived of as the level of betweenness in social network terms, with larger nodes being more socially connected to other individual citizens. For details, see Abdollahian et al. [2] analysis on betweenness and eigenvector centrality of the model's social network outputs.

Figure 3 above shows several simulations of citizen CBO representation and their resulting preferences for three groups, the city, one of the regulators the CPUC and the utility Southern California Edison (SCE). Here we can see the varying response elasticities of all three groups to increasing CBO size. While the city seems to be relatively inelastic to CBO sizes, both the regulator and the utility show marked change. The CPUC regulator here starts at an indifferent preference (approximately 50) but slowly moves towards project opposition (at 80) in a linear fashion as CBO participants move from 300 to around 450. Afterwards, there seems to be marginal returns for increasing opposition with more CBO participants. What is most interesting is the utility's staunch support for the project (at a preference of 10) in the face of increasing opposition, until a tipping point is reached where sharp, major concessions (shifting towards indifference at 50) are granted in order to maintain project viability. This seems to be consistent with many public agencies' past modus operandi of 'decide then defend' for works projects.

The results show several key emergent behaviors from infrastructure siting including citizen interaction and CBO formation. Our simulations explain why CBOs are effective in aggregating citizen preferences and altering stakeholder preferences. The finding that citizen messages are relatively more important to regulators than stakeholders is consistent with the institutionalized comment process. Our findings indicate that citizen comments are surprisingly influential in determining regulators' preferences, indicating a level of political responsiveness to social sustainability issues that supports the efficacy of institutionalized planning processes. At the same time, we also find that CBOs positions are important in determining stakeholder preferences.

We posit two important methodological advances from our current modeling approach. First, the SEMPro design that links an ABM with GIS data is critical for valid inferences about citizen participation as citizen interactions emerge from local conditions and attributes; all politics are local. Second, linking ABM with spatial bargaining models permits the analysis of the interactions and linkages between citizen emergent behavior and institutionalized decision-making modalities. By linking citizen behavior with stakeholder and regulator preferences, SEMpro explicitly simulates the impact of micro-level behavior on macro-level institutional outcomes, a fundamental challenge in social policy spaces.

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