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# Editors & Editorial Board

# Editor's Letter

This issue of JPCS touches upon a broad set of topics. The first two papers focus on the topic of forecasting the outcome of interactions in a network. The first paper in this group, authored by Scheinert, Zia, Koliba, and Merrill, is addressing the changes in partnership networks using a bottom-up approach. The second paper, authored by Johnson, Lemasters, and Bhattacharyya, is using a network science approach to understand the changes in complex environments as diverse as classroom interactions and climate change.

The second group of papers is related to decision making in complex systems. The first paper in this group, authored by Sissa, Girdinio, and Terna uses agent-based modeling to devise plausible policies for sustainable energy policies. The paper by Givel, however, takes a theoretical approach to complex systems behavior in democratic policy theory, thus addressing the aspects of decision making in democratic political processes. Finally, the paper by Udell completes this group of papers by providing a meta-level analysis of complex systems through its "four dimensions." This meta-level analysis is exemplified in the context of the proper framing for resolving wicked problems.

The last paper of this issue, authored by Simoyama, offers a systematic literature review of complex systems applications. Review papers are often useful for newcomers into the field, offering a good starting point for further explorations of topics, ideas, theories, achievements, and challenges of the field under considerations.
We hope you will enjoy the issue.

Mirsad Hadzikadic

Editor, JCPS

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*Editor's Note: No issues were published in 2016.*

# Growing Collaborations: Forecasting Changes in Partnership Networks using a Bottom-Up Approach

Steve Scheinert, Asim Zia, Christopher Koliba, and Scott Merrill[A]

**Both social and organizational networks change over time. Previous research has examined and documented the change in social networks using dynamic network analysis. However, limited research has examined mechanisms of change, leaving the mechanisms in a proverbial "black box." We show how exponential random graph models can be used to measure the influence of some of the mechanisms that drive network development. Our mechanisms are derived from network theory and applied to a goal-directed organizational partnership network, the Vermont Farm to Plate Network. Our method uses an agent-based model to induce bottom-up network change. This approach allows us to offers some explanation of the underlying mechanisms for network change. Implications for forecasting network growth in a governance and policy context are discussed.**

**Keywords: network growth, organizational partnership networks, governance, networked governance, agent-based model, exponential random graph models, policy implementation**

Interpersonal professional social networks change over time. Friendships grow and fade and new friendships emerge. That this change occurs is well established in studies that document changes in scientific collaboration among individual researchers (Barabasi et al, 2002; Perc, 2010; Tomassini & Luthi, 2007). The links between professional researchers help to facilitate and describe the flow of research funding, allowing for the tracking of ideas, and financial resource flows, among networks of individual researchers. Such interpersonal links exist between professionals in all fields. When professionals collaborate as representatives of organizations, the unit of analysis of a node shifts from the individual to the organization. Instead of networks of individual collaborators, these may be viewed as inter-organizational networks of partners, or "partnership networks." Inter-organizational partnership networks have now been observed in many places, including environmental and water quality management (Weible & Sabatier, 2005; Lubell & Fulton, 2007; Henry, Lubell, & McCoy, 2010; McGinnis, 2011; Imperial, 2005), healthcare (Isett & Provan, 2005), and emergency management (Kapucu & Demiroz, 2011; O'Toole, 1997), and thus can be considered a common structure in policymaking and implementation. Since partnership networks are built from the same individual collaborations and professional social networks, partnership networks are also subject to the same forces that drive

[A] University of Vermont

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change in professional social networks. The literature on professional social network growth applies a top-down approach to drive changes in the network's dyadic structure by relying on mathematically simulating changes in network statistics. Networks often form through bottom-up processes, with the network becoming an emergent property of agents' individual decisions (Axelrod & Cohen, 2000; O'Toole, 1997). By simulating the actions of organizations in a partnership network, we develop a bottom-up approach to generating the kind of evolving change in inter-organizational partnership networks that has been studied in professional social networks.

Both inter-organizational partnership and interpersonal social networks are an emergent property of organizational and individual agents making their own decisions and taking their own actions to forge or sever links (Axelrod & Cohen, 2000; O'Toole, 1997). Current methods for forecasting change in social networks rely on reproducing observed variation over time in whole network measures, such as clustering coefficients and node degree distributions. Simulation models add nodes and links to an existing network such that the observed patterns in network measures are reproduced. The evolution is treated as cumulative, with nodes and links remaining in the network once they have been added (Barabasi et al, 2002; Kossinets & Watts, 2006). Since networks emerge from the accumulation of individual actions by the separate agents that form the network, efforts to model the growth of networks should take seriously the need replicate that emergence. Exponential random graph modeling (ERGM) measures the influence on the final network structure of the differing reasons that agents may use to select collaboration partners, such as finding new partners through existing partners or seeking out particularly well-connected agents (Goodreau, Kitts, & Morris, 2009). Therefore, in extending the research on changing social networks to apply to inter-organizational networks, we propose using the results of an ERGM to parameterize an agent based model for bottom-up network growth. This approach provides additional insight into the mechanisms of network change and how the mechanisms of network change can be harnessed to forecast future network growth.

We demonstrate our approach using data from the Vermont Farm to Plate Network.[1] The Vermont Sustainable Jobs Fund organizes and operates the Farm to Plate Network to promote closer interaction between food producers, professional food service, food sellers, and consumers, from government, industry, and the non-profit sector. Members take part in a range of working groups and task forces. Members are free to choose their level of involvement and may enter and exit the Farm to Plate Network at their discretion. The Farm to Plate Network pursues and measures increasing interaction between participants. This effort by the Farm to Plate Network provides the opportunity to study the growth of partnerships by providing data that identify changes in an inter-organizational partnership network over a short period.

[1] Details on the Vermont Farm to Plate Network are online at <<http://www.vtfarmtoplate.com/>> and <<http://www.vsjf.org>>.

# Literature Background

## Change in Social Networks: Scientific Coauthorship and Email Communication Networks

The study of social network evolution has so far focused on networks of coauthors of scientific papers and email communication networks. Scientific coauthorship networks are formed by linking researchers who have coauthored published research into a broad network that can either cover a wide range of scientific disciplines (Barabasi et al, 2002), be limited to a specific scientific field (Tomassini and Luthi, 2007), or be limited to a certain geographic area (Perc, 2010). Kossinets and Watts (2006) build a network by linking individuals who exchange emails on a university email system, creating an email communication network. Both the coauthorship and email communication networks are social networks since they link people together through inter-personal interactions.

Barabasi et al (2002), Tomassini and Luthi (2007), and Perc (2010) all seek to describe in detail how the structures of coauthorship networks change. Barabasi et al (2002) study the role of preferential attachment, where agents prefer to add new links with already well-connected agents. Tomassini and Luthi (2007) also use preferential attachment while adding in four whole-network measures: mean degree centrality, clustering coefficient, average path length, and the network's degree distribution. Perc (2010) uses preferential attachment, small world networks, the clustering coefficient, and the network's diameter. In all three studies, the researchers examine how their measures change over time and draw conclusions from the pattern of change of each measure without attempting to explain why or how the observed patterns emerged. This kind of analysis is known as dynamic network analysis (Carley, 2003; Abbasi & Kapucu, 2015). Kossinets and Watts (2006) use the same approach to show how network-level measures stabilize over time in the email communication network, reaching what Kossinets and Watts label as an equilibrium, while individual-level measures remain unstable. All of these studies saw the measurements of their network statistics change over time, but none of these studies examined why. They only examined what the pattern of change was, not what mechanisms generated the observed patterns of change. This leaves an important gap between in our knowledge of network evolution, between how agents choose new partners and how specific network structures emerge from those agents' choices.

## Agent-Level Link Selection

*Network Link Accretion: Homophily, Heterophily, Transitivity, and Preferential Attachment*

Whether networks develop organically (Axelrod & Cohen, 2000) or through the direction of policy and planning (Koliba, Reynolds, Zia, & Scheinert, 2015), they follow a set of rules for link selection that is now well recognized among network scholars (Wasserman & Faust, 1994). Network agents will sometimes seek partners who are similar to themselves, leading to existing groups drawing themselves closer together through increased bonding social capital (Burt, 1992). Network analysis refers to this behavior as homophily. Conversely, agents will sometimes seek partners who are different from themselves as those agents gain leverage by linking unconnected agents in the network (Granovetter, 1973 & 1983), where that lack of a link is known as a "structural hole" (Burt, 1992).

Network analysis refers to this behavior as heterophily. Every agent in a network can be associated with a set of attributes that can be used to define homophily and heterophily. The choice to forge links in a network is labeled as either homophily or heterophily, depending on how an agent utilizes the relationship between their attribute values and those of the prospective partner (Goodreau et al., 2009). Simply put, homophily is when ‘like attracts like’ and heterophily is when ‘different attracts different.’ When agents apply homophily, they will share a link with another agent who shares the same value on an attribute, such as when two non-profit organizations choose to interact. When agents apply heterophily, they will share a link with another agent who has a different attribute value, such as when a public program and a non-profit organization choose to interact.

An organization may choose homophilic pairings for one attribute, such as their jurisdiction, by preferring to work with other organizations in the same city or state. That same organization may simultaneously prefer a heterophilic pairing for another attribute, such as their sector. An example of this choice is when governmental programs partner with private business or non-profit organizations, due to the assets that private partners can bring to government, such as differing resource bases and constituencies (Koliba, Meek, & Zia, 2010).

Network structure can also drive partner selection. Agents will sometimes find new partners when their current partners introduce them to potential new partners (Wasserman & Faust, 1994). Network analysis refers to this behavior as transitivity. Transitivity occurs when agents select partners who share links to a common third agent, forming a complete triangle in the network (Wasserman & Faust, 1994). For organizations, this could be the result of business referrals or public events that promote mixing, for example. Agents may also desire links to well-connected agents, finding value in the access to resources that a well-connected partner can provide, such as information or money, that the links direct, or in the influence that links provide, for example. When agents place intrinsic value in having links, they will seek to collaborate with other agents who already have a large number of links. This forms a pattern of preferential attachment, where a small number of agents are very highly connected while most of the agents have relatively few links. Networks that display preferential attachment are referred in network theory as “scale free” networks (Albert & Barabasi, 2002).

*Network Link Decay: Attributes and Bridges*

Burt (2000, 2002) identified that the probability that a link will cease to be present from one period to the next is related to the homophilic and heterophilic relationships between the nodes who share the link (Burt, 2000). He has also determined that the probability is related to whether or not the link is a network bridge (Burt, 2002) defined as a link that connects two otherwise unconnected components of a network (Wasserman & Faust, 1994). In identifying bridges, researchers typically look for those components to contain many agents and links, though a bridge still exists if one or both of the agents would otherwise be an isolate node without the bridge. Burt (2002) operationalizes a bridge such that it is synonymous with Granovetter’s (1973, 1983) definition of a weak network link, which is any link between two nodes in a network when those nodes do not link to any common third node. Burt (2000, 2002) offers independent formulas for each decay process. As links age, they generally become less likely to decay while homophilic pairings are slower to decay than heterophilic pairings (Burt, 2000). Network bridges are more likely to decay than non-bridge links for the first three years that the link exists and are less likely to decay than non-bridge links after three years (Burt, 2002). Additional research would be needed to combine decay based on attribute pairings with decay based on network bridges; Burt does not offer any conclusions about how these formulas could be used together.

**Exponential Random Graph Models**

ERGM is designed to elicit the varying influence of, among other potential model terms, attribute values, homophily, transitivity, preferential attachment in a network's formation but is sensitive to specification (Handcock et al., 2014), meaning that its results are dependent on which of these possible model terms are included when the ERGM is estimated (Hunter & Handcock, 2006; Hunter, 2007; Hunter, Handcock, Butts, Goodreau, & Morris, 2008; Hunter, Goodreau, & Handcock, 2013). Heterophily is treated as a reference case to homophilic pairings. ERGM estimation calculates a logistic regression that measures the influence that attribute value, attribute pairings, transitivity, and preferential attachment have on the set of observed ties, using the following functional form (Goodreau et al., 2009):

$$P(Y = y \mid n) = \frac{e^{\left(\sum_{k=1}^{K} \theta_k z_k(y)\right)}}{c}$$

where:

| *Term* | *Meaning (Goodreau et al, 2009)* |
|---|---|
| $P(Y = y \mid n)$ | the probability the empirical network is the one observed, given a network of *n* agents |
| $\theta_k$ | the set of *k* attributes and their influence |
| $z_k(y)$ | the set of network structural influences such as transitivity as applied to node *y* |
| $c$ | a control parameter that constrains the formula to be between 0 and 1 |

Estimation platforms provide terms for non-paired attribute values, homophilic pairings, and transitivity (Hunter et al, 2008).[2] The influences of attribute values, homophily, and transitivity, measured as logit coefficients, may then be used in a logistic formula to produce estimates (Kennedy, 2003) that can be interpreted as the probability that each potential network link is observed.

## Modeling Network Development in the Vermont Farm to Plate Network

We test the effectiveness of an algorithm parameterized by the results of an ERGM for forecasting network growth. We build an agent-based model (ABM) that executes this algorithm to forecast change in the Farm to Plate Network and then compare our forecast growth to empirical changes that occurred at the same time. We calculate an error rate for our algorithm by measuring

[2] Every pairing between two nodes can be described as either heterophily or homophily. Since ERGM estimation uses terms for homophily and each node's own attribute values, the influence of heterophily is included in the ERGM's intercept term.

the differences between the forecast and observed networks, as seen in Figure 1. Finally, we review the performance of our algorithm to see how its forecasts could be improved. The model is described in this section, according to the Overview, Design Concepts, and Details (ODD) protocol (Grimm et al., 2006). We developed our ABM using AnyLogic 7 (AnyLogic University Edition 7.0.3).

## Overview

### *Purpose*

The purpose of this model is to test an algorithm for building a network based on agent decisions, with the agents in this model being organizations. If validated, then an agent-based model that uses our algorithm can provide accurate forecasts of the network's future growth and development through modeling agents' decisions to add or remove links.

State Variables and Scales

The model comprises three hierarchical levels: network links, organizations, and a "main object" or modeling environment. Network links operationalize our networks within the model and allow for managing the network when the model is adding and removing links. Network links are formulated in two different manners. First, AnyLogic's Java libraries offer a state variable for organizations, by which the organizations can be directly connected via a network link and the presence of this connection directly tested. The model uses this form of link object to maintain active network links in memory. A population of networks links also exists within each organization and records both active and non-active links. These network links include five state variables: *fromID, toID, toAdd, toCut,* and *startTime.* The variables fromID and toID record the organizations that a given network link connects. The variable startTime records the model time for when a link is created. The variables toAdd and toCut record whether this link should be added or removed from the list of links maintained in memory, respectively.

Organizations contain seven state variables: *orgID, orgName, orgAcronym, capacity, sector, jurisdiction,* and *jurisLevel*. These state variables allow us to link the organizations to the ERGM and then use the ERGM to drive agents' decisions to add or remove links. The first three of these, are identifiers that link to the empirical Farm to Plate network data. *orgID* records an integer number identifier, which is also used in the *fromID* and *toID* state variables for network links. *orgName* and *orgAcronym* contain the full name and unique text identifier for each organization in the Farm to Plate Network. The other four variables record the attributes used in the ERGM, matching to capacity, sector, jurisdiction, and jurisdictional level, respectively. The attributes which we use and their application to governance networks, like the Farm to Plate Network, are defined and developed in existing literature (Koliba et al., 2010; Scheinert & Comfort, 2014; Koliba et al, 2015). Capacity is defined as an organization's ability to influence its environment and operationalized through organizational staff sizes and budgets (Scheinert, 2012). Sector records an organization's sector, including public, private, and non-profit organizations, but, in this case, also separates out federal-, state-, and municipal-level public agencies as well as educational/research organizations (Koliba et al, 2015). Jurisdiction records an organization's basic geographic area of operation, based on political boundaries. Values used to distinguish levels of jurisdiction in this specific case include areas such as Vermont, New York, and Quebec, as well as the United States and Canada (Koliba et al, 2015). Jurisdictional level records the extent of an organization's geographical reach, indicating whether its operations are relevant throughout a local municipality, the entire state, a sub-state region of the state, including watersheds and regional planning commission districts, or if the organization's reach extends beyond state or national borders (Comfort, Oh, Ertan, & Scheinert, 2010). Appendix A lists the attributes, their conceptual values, and the numeric labels assigned to each.

The main object serves as the Java modeling environment that provides the modeling space for the agent populations. The main object contains a range of state variables, all designed to link the model's settings menu to the model's main algorithm for adding new network links. This includes a separate state variable for each of the estimated ERGM terms (see appendices B and C), state variables to determine whether or not the model should run the link accretion algorithm, whether or not the model should run the link decay algorithm, whether or not the model should run the different control experiments described below, which subnetwork to use in the growth and decay algorithms, and how many times the accretion and decay algorithms should be run before comparing the modeled results to the empirically observed results (see figure 1).

*Process Overview and Scheduling*

The model is built around two central processes, as depicted in figure 1. In the first processes, a network is updated by adding some new links and removing some old links. This process is labeled as "Model Operation" in figure 1. The model starts by reading in the list of organizations to be found in the network and an initial set of empirically observed links, forming a network. Our data contain multiple types of interactions, forming separate networks. These subnetworks are discussed in more detail below, under *Initialization*. One subnetwork is chosen and read into memory in the model. The model runs link

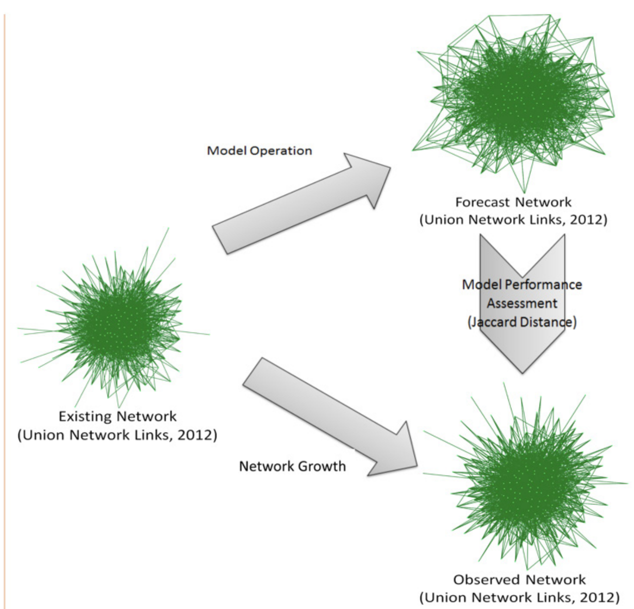


**Figure 1: Networks in the Agent Based Model**

accretion and link decay algorithms on the subnetwork to be updated. Accretion is run first and decay is run second. New links to be added and existing links to be cut are recorded using the population of network links contained in each organization. Once the links to be added and the links to be cut are determined and recorded, the model updates the network by adding and deleting the appropriate links to the population of active links. This newly updated network is referred as the forecast network. Since no links are actually added to or deleted from the network until after both the accretion and decay algorithms are run, changing the order to run decay before accretion would not influence the results; all accretion and decay decisions see the same network when organizations make their accretion and decay decisions.

In the second process, the forecast network is compared to a new network that is empirically observed update to the existing network. This empirically observed update is labeled as "Network Growth" in figure 1 and this second process is labeled as "Model Performance Assessment." A survey of the members of the Farm to Plate Network asked respondents to identify whether the links in the three subnetworks were "new," meaning that the links had been formed in the last year and as part of the responding organization's activities within the Farm to Plate Network. Those links that were not marked as "new" are treated as "existing." This survey was conducted twice, in 2012 and 2014, and is discussed in detail, under *Initialization*. The existing network, which provides initial conditions, and the observed network are constructed in two different ways. Each way of constructing these networks uses a different combination of new and existing links: 1) using the networks of existing 2012 links to forecast the networks of new and existing 2012 links, and 2) using the networks of new and

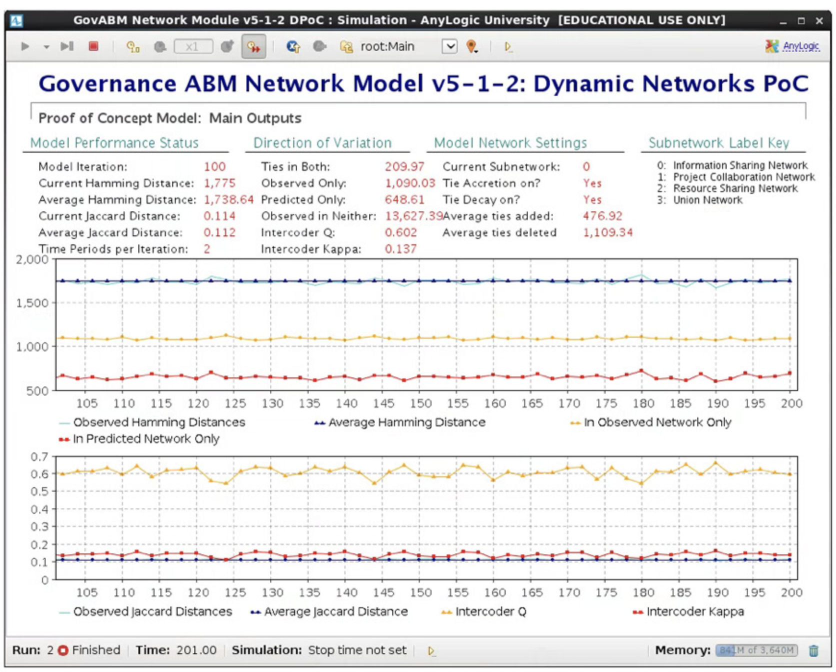


**Figure 2: Example of ABM Output (Forecasting the 2014 Information Sharing Subnetwork from the 2012 Information Sharing Subnetwork)**

existing 2012 links to forecast the networks of new 2014 links. Figure 2 contains an example of the model's output, showing one model run, using the 2012 existing links to forecast the 2012 new links in the information-sharing subnetwork. We used twelve model runs, each producing a similar figure. The full results from each run are recorded in tables 4 and 5. Model runs comparing existing and new links within the 2012 data do not apply link decay, as the data did not provide information for link decay between existing and new links in the same year. Analysis also considered whether to use two iterations of the model in each model repetition for forecasting the 2014 new and existing links from the 2012 new and existing links. This means that we ran the model's accretion and decay algorithms twice before performing comparisons between forecast and observed networks, based on the assumption that model output represented an annual process that would be repeated twice between 2012 and 2014.

Links can be observed in either: 1) both the empirically observed and forecasted networks; 2) neither the empirically observed network nor the forecast network; 3) the forecast network only; or 4) the observed network only. Counts of the links that fall into each of these four categories are reported in the model output under the Direction of Variation heading (Figure 2). The counts are used to determine if the model is accurately placing new links within the forecast network. A perfectly performing model will match all forecasted links to all the observed links; the model will only show links that are either in both networks or in neither network. A count of the links that only occur in either the observed network or the forecasted network will indicate the degree of difference between the observed and forecasted networks, quantifying the forecast error. This measure is what is referred to as a Hamming distance (Hamming, 1950), which is simply the count of differences between two strings, vectors, or matrices. The shortcoming of using a Hamming distance to measure the variation between two networks is that networks vary in size. Networks with more nodes can drastically increase the number of possible links; while the Hamming distance is a very common approach to measuring the difference between character strings, vectors, and matrices, it does not account for potential variation. A Jaccard distance (Jaccard, 1912) does account for the possible variation by dividing the Hamming distance by the maximum number of differences that are possible, which, in a network, is the number of possible links. Therefore, we can interpret the Jaccard distance as the model's error rate, reporting the percentage of incorrectly forecast links. Keeping counts of how many links appear in either the observed or the forecasted network, but not the other allows for determining whether the forecasted networks are over- or under-estimating the number of links in the observed networks.

We use two control models that compare our model's performance with two plausible alternatives. The first control assumes no changes in the modeled network; the existing network (Figure 1) is read into the model and then compared directly to the observed network (i.e., ties cannot be created or decay). This control is referred to as the fixed initial conditions control. The second form of control uses an approach based on a common random network generator. Comparing empirical networks to random networks is a common metric in network analysis for determining if certain network phenomena are present in the empirical network. For example, Watts and Strogatz (1998) use a random network, typically modeled as an Erdos-Renyi random graph of similar size and density (Erdos & Renyi, 1959), to define small world networks. In this control for testing our model's performance, new ties are assigned randomly throughout the network with a fixed probability, equal to the network's density. This control is referred to as the Erdos-Renyi control, since it approximates the method used to calculate an Erdos-Renyi random network. Use of these two controls, the Erdos-Renyi control and the fixed initial conditions control, allows performance to be measured not just by error rates but also by whether or not our model out-performs the controls.

## Design Concepts

*Emergence:* Homophily, heterophily, transitivity, and preferential attachment can be viewed as the measureable outcomes of the underlying decisions that agents make, regardless of whether or not the agents are thinking in terms of networking with similar, dissimilar, multiple acquaintances, or particularly well-connected partners (Goodreau et al., 2009). All four can be expected to have had an influence on the network's observed structure. ERGM can be applied to measure the influence that each concept had on network formation (Goodreau et al., 2009). Our approach to preferential attachment differs from Barabasi et al.'s (2002) in that, Barabasi et al. (2002) seek to recreate a specific, observed degree distribution, while we measure the influence that the degree distribution has on agents' decision making. With the correct set of attributes, agents' decisions regarding the selection of interaction partners throughout the network, measured using an ERGM, can reproduce the observed network and forecast the development of new links in that network.

*Stochasticity:* The model uses a stochastic method to determine which specific links are to be added and deleted. The algorithms, described under *Submodels*, determine the probability that any given link will be added or deleted. A random draw then determines whether that link is added or deleted. We repeat the model's algorithm for updating network links 100 times in each model run, with each repetition's results recorded and averaged to produce the model's output. This repetition prevents random outlier cases where the model randomly determines to add a particularly large or small number of links from dominating the model's results. Such dominance would falsely indicate particularly good or particularly poor performance. We then take the average each distance measurement across these process repetitions. The graphs in Figure 2 record the performance of the Hamming and Jaccard distances over a model run.

## Details

*Initialization*

The model is initiated using empirical data from a survey of the members of the Vermont Farm to Plate Network. Our research team, in partnership with the Vermont Sustainable Jobs Fund, conducted two network surveys of the organizations that participate in the Farm to Plate Network. These surveys were conducted in 2012 and 2014 and the structure of the survey did not change significantly between the two editions. Links are collected using an alter roster approach where respondents are asked to identify interaction partners from a comprehensive list of potential partners (Marsden, 2005; Pustejovsky & Spillane, 2009). The list of network agents does vary between the two editions.

To ensure computational comparability between the networks in both periods, separate versions of the networks in each period are constructed using only the organizations that appear in both periods, identified as the intersection networks. Since the intersection networks are limited to only the organizations that appear in both periods, they have the same number of nodes, as seen in table 1. The 2012 and 2014 editions of the survey collected data on three kinds of interaction within the Farm to Plate Network: information sharing, project collaboration, and resource sharing. Each of these forms a separate subnetwork, as defined by Scheinert, Koliba, Hurley, Coleman, and Zia (2015), where a network with multiple types of interaction can be disaggregated into the separate types of interaction. The separate types of interaction then form networks of their own referred to as subnetworks. A union network for each year was formed by including the links found in at least one subnetwork for that year. Each subnetwork was analyzed and modeled independently to provide additional testing space for our model. Table 1 provides a summary of the intersection subnetworks that we use in this study.

| **Subnetwork function** | **Number of Nodes** | | **Number of Ties (New and Existing)** | | **Density** | |
|---|---|---|---|---|---|---|
| *Intersection Networks* | *2012* | *2014* | *2012* | *2014* | *2012* | *2014* |
| Information Sharing | 176 | 176 | 1,708 | 2,600 | 0.056 | 0.084 |
| Collaboration | 176 | 176 | 733 | 1,520 | 0.024 | 0.049 |
| Resource Sharing | 176 | 176 | 246 | 738 | 0.008 | 0.024 |
| Union | 176 | 176 | 1,877 | 3,146 | 0.061 | 0.102 |

**Table 1: Profiles of the Subnetworks in the Vermont Farm to Plate Network**

*Input*

The model uses two data sources for inputs. First, as discussed under *Initialization*, the model uses the network data collected in the Farm to Plate Network survey for initialization. This same data is used at the beginning of each repetition of the accretion and decay algorithms, such that the model is re-initialized for each repetition of the algorithms.

Second, the model uses estimated ERGM results to parameterize the accretion algorithm. Doing so ensures that our estimated ERGM drives agents' decisions about forming new links. The ERGM is estimated using the *ergm* (Hunter et al, 2008; Handcock et al, 2014) and *statnet* (Handcock, Hunter, Butts, Goodreau, & Morris, 2003) packages in R (R Core Team, 2014). The model uses one parameter for each of the terms in the ERGM, meaning one parameter for each value of each attribute and for each homophilic pairing of each value of each attribute, along with a term for the influence of the network's density and transitivity. The results of estimation are discussed below and the chosen results are included in Appendices B and C. When existing 2012 links are used to forecast new and existing 2012 links, the ERGM results in appendix B are used. When new and existing 2012 links are used to forecast new and existing 2014 links, the ERGM results in appendix C are used.

*Submodels*

Link Accretion: The accretion algorithm cycles through all 30,800 organizational pairs seeking structural holes, where links can be added. When the model finds a structural hole, it uses the following formula to determine the probability that an agent will fill that structural hole:

$$P(link\ is\ added) = 0.5\left(\frac{e^{d + \beta_1 C + \beta_2 S + \beta_3 J + \beta_4 L + \beta_t t + \beta_p p}}{1 + e^{d + \beta_1 C + \beta_2 S + \beta_3 J + \beta_4 L + \beta_t t + \beta_p p}}\right)$$

where:

| *Term* | *Meaning* |
|---|---|
| $d$ | the ERGM-calculated influence of the network's density on the probability of a link existing |
| $\beta_1 C$ | organization's capacity and the ERGM-calculated influence of that capacity on the probability of a link existing |
| $\beta_2 S$ | organization's sector and the ERGM-calculated influence of that sector on the probability of a link existing |
| $\beta_3 J$ | organization's jurisdiction and the ERGM-calculated influence of that jurisdiction on the probability of a link existing |
| $\beta_4 L$ | organization's jurisdictional level and the ERGM-calculated influence of that jurisdictional level on the probability of a link existing |
| $\beta_t t$ | whether or not the link being considered for inclusion would close at least one transitive triangle and the ERGM-calculated influence of transitivity on the probability of a link existing |
| $\beta_p p$ | the influence of preferential attachment on the probability of a link existing |

Calculation of the formula produces a threshold probability for the link to be added, calculated between 0 and 1. Both organization of the pairing could act to add the link and the model calculates the probability twice, once from each member of the pairing, but ERGM only considers attribute values and pairings based on observed dyads and structural holes. To prevent this double counting, we halved the threshold. A random draw between 0 and 1 determines if the model adds the link. If the random draw value falls below or equal to the threshold, then the link is added. If the random value falls above the threshold, then the link is not added.

*Link Decay*: Burt's (2000, 2002) processes for link decay are calculated independently, so only one or the other should be applied at a time. We chose to use decay rates of network bridges, without factoring the influence of homophily and heterophily. Use of decay based on homophily and heterophily would create collinearities between accretion and decay while using bridge decay rates would allow the decay algorithm to remain independent of the accretion algorithm and the ERGM. Rates of decay for both bridge and non-bridge links are a function of the link's age such that older links are less likely to decay (Burt, 2002). Rephrased, the older a link is, the more likely it is to persist. When a link is either created through accretion or included in the model's initial conditions, the model records the time. A threshold value is calculated for removal, using the values listed in table 3. Just as with link accretion, the threshold is halved to prevent double counting and a random draw between 0 and 1 determines whether the model removes the specified link. Draw values equal to or below the threshold result in the link being removed, while draws above the threshold result in the link being retained.

| Integer Link Age | Bridge Decay Threshold Values | Non-Bridge Decay Threshold Values |
|---|---|---|
| 1 | 0.475 | 0.3625 |
| 2 | 0.375 | 0.325 |
| 3 | 0.2 | 0.2875 |
| 4 | 0.075 | 0.25 |
| 5 | 0.025 | 0.2125 |
| 6 | 0.0125 | 0.175 |
| 7 | 0.005 | 0.1375 |
| 8 | 0 | 0.1 |

**Table 2: Link Decay Thresholds (Based on Burt, 2002)**

# Results

## Estimated ERGM Specification

We reviewed 22 potential ERGM specifications to find the best-fit model. ERGM fit is determined through calculated AIC and BIC values, which are reported in the estimation output. The lower the value the better the ERGM's fit to the data. We selected the ERGM specification with the lowest AIC and BIC goodness of fit values, using the structure of the information-sharing subnetwork as the dependent variable. This specification was then applied to ERGM estimations using the other three subnetworks as dependent variables. We utilized a geometrically weighted edgewise pair term (*gwesp*) with a non-fixed alpha for transitivity and a geometrically weighted degree distribution term (*gwdegree*), reviewed with a wide range of potential *alpha* values, for preferential attachment. Estimation terms available for ERGM allow for a consideration of whether homophilic pairings within any given attribute have a different influence on the probability of a link occurring (Hunter et al, 2013). For example, estimation terms allow the researcher to determine if two state-level public agencies are more likely to form a partnership than two non-profit organizations that operate throughout Vermont. We determined that the best specification allowed for the probability of forming a link to vary by an organization's individual attribute values, homophilic pairings by attribute, and transitivity. Estimation using this specification reported the lowest AIC and BIC values for the information-sharing subnetwork. Models using preferential attachment did not perform as well as those that used transitivity while models including both transitivity and preferential attachment failed to run due to excessive correlation between model terms.

## Error Rates in Network Forecasts

We performed nine model runs in each phase of analyzing our network growth algorithm. This includes four runs of our proposed algorithm, four runs of the fixed initial conditions control, and one run of the random change control. The AIC and BIC goodness of fit measures from the selected ERGM analyses for each run are included in tables 3 and 4. The results from phase 1, which forecasted new and existing links in the 2012 data from existing links in the 2012 data that are presented in table 3. The results from phase 2, which forecasted new and existing links in the 2014 data from the new and existing links in the 2012 data, are presented in table 4. The results show that our model did not perform as well as the fixed initial conditions control but did perform better than the Erdos-Renyi control. A pattern emerges in the results that shows that our model tended to produce twice the

**Table 3: Results of Forecasting 2012 New and Existing Links from 2012 Existing Links**

| Model Run | Model Output | Information Sharing | Collaboration/ Coordination | Resource Sharing | Multiplex/ Union |
|---|---|---|---|---|---|
| ERGM Fit | AIC | 11,771 | 7,097 | 3,312 | 12,529 |
| | BIC | 11,964 | 7,286 | 3,486 | 12,723 |
| Model Algorithm | Average Hamming Distance | 527.90 | 257.92 | 136.00 | 512.98 |
| | Average Jaccard Distance | 0.021 | 0.010 | 0.005 | 0.020 |
| Fixed Initial Conditions Control | Average Hamming Distance | 222 | 121 | 48 | 242 |
| | Average Jaccard Distance | 0.009 | 0.005 | 0.002 | 0.009 |
| Erdos-Renyi Style Random Change Control | Average Hamming Distance | 785.3 | --- | --- | --- |
| | Average Jaccard Distance | 0.031 | --- | --- | --- |

**Table 4: Forecasting Future Links: 2012 New and Existing Links to 2014 New and Existing Links**

| Model Run | Model Output | Information Sharing | Collaboration/ Coordination | Resource Sharing | Multiplex/ Union |
|---|---|---|---|---|---|
| ERGM Fit | AIC | 12,509 | 8,271 | 3,347 | 13,381 |
| | BIC | 12,703 | 8,462 | 3,524 | 13,575 |
| Model Algorithm | Average Hamming Distance | 1,738.64 | 903.68 | 563.73 | 1,862.89 |
| | Average Jaccard Distance | 0.112 | 0.058 | 0.036 | 0.120 |
| Fixed Initial Conditions Control | Average Hamming Distance | 1,575 | 873 | 434 | 1,645 |
| | Average Jaccard Distance | 0.101 | 0.056 | 0.028 | 0.106 |
| Erdos-Renyi Style Random Change Control | Average Hamming Distance | 1,966.73 | --- | --- | --- |
| | Average Jaccard Distance | 0.126 | --- | --- | --- |

amount of error as the fixed initial conditions control across all four subnetworks in table 3. The Jaccard distance values in table 4, which can be read as a percentage, show a smaller difference, 1.6 percentage points different in the union subnetwork and less in the other three subnetworks. These initial results, with error rates only slightly worse than one type of control and better than another type of control, indicate that our method is plausible though the algorithm requires further refinement to improve its performance.

Comparing the results in tables 3 and 4 with the statistics in table 1, error rates and network density appear correlated. The model runs with the highest error values also have the highest network densities. This pattern continues to hold between the highest and lowest values. There are too few values to confirm a correlation, but this result does suggest that our algorithm performs best on less dense networks.

## Rates of Link Accretion and Link Decay

Phase 1 of our modeling analysis allows for a closer examination of the performance of algorithm for adding network links. Each execution of our algorithm, for accretion and for decay, can be expected to add additional error, so that higher rates of error are expected for the phase 2 analysis. These higher rates are seen, but the difference between control runs and algorithm runs is decreased. Seeing this convergence, it is worth asking how many links the accretion algorithm is adding and how many links the decay algorithm is removing. Table 5 records values for expected and observed values of both link accretion and decay, as well as a ratio of observed accretion and decay to

| Subnetwork | Accretion | | | Decay | | |
|---|---|---|---|---|---|---|
| | Expected | Average Observed | Ratio (Obs./Exp.) | Expected | Average Observed | Ratio (Obs./Exp.) |
| Existing Information Sharing | 222 | 312.08 | 1.41 | --- | --- | --- |
| Existing Collaboration | 121 | 138.60 | 1.15 | --- | --- | --- |
| Existing Resource Sharing | 48 | 88.32 | 1.84 | --- | --- | --- |
| Existing Union | 242 | 277.44 | 1.15 | --- | --- | --- |
| New Information Sharing | 692 | 476.92 | 0.69 | 883 | 1,109.34 | 1.26 |
| New Collaboration | 489 | 144.67 | 0.30 | 348 | 480.67 | 1.38 |
| New Resource Sharing | 290 | 228.86 | 0.79 | 144 | 199.05 | 1.38 |
| New Union | 900 | 368.65 | 0.41 | 845 | 1,181.72 | 1.40 |

**Table 5: Link Accretion and Removal**

expected accretion and decay, respectively. Expected values are drawn from the fixed initial conditions control; the count of links only in the observed network for the control output provide the expected accretion while the count of links only in the forecast network provide the expected decay. Our model tracks the count of links added and deleted in each algorithm repetition, takes averages across all the repetitions in each model run and reports that average (see Figure 2). For the existing subnetworks, used in phase 1, the expected decay is not measured for either the control runs or model algorithm runs since decay is not permitted in phase 1. The ratio values in table 5 allow for determining the rate of either over- or under-forecasting both accretion and decay. Our results show that our model over-forecasts decay at a consistent rate, while the ratio is less consistent for accretion.

## Discussion

### An Agent Based Method for Forecasting Network Growth

Network theory recognizes homophily, heterophily, transitivity, and preferential attachment as bases for agents' link selection (Wasserman and Faust, 1994). Though it cannot be assumed that these are the only factors driving network formation, networks do form from individual agents, whether organizations or persons, applying these four decision criteria. The results in tables 3 and 4 show that ERGM can provide not only a careful assessment of how a network developed from these four criteria but that that assessment can be repurposed to forecast future change. In forecasting the 2014 subnetworks from the 2012 subnetworks, we achieved error rates comparable to those of the fixed initial conditions control and better than achieved by the Erdos-Renyi control. The stochastic elements of our algorithm will require multiple runs for any real forecast, but the stochastic elements will also allow for both serendipitous change and the calculation of confidence intervals for how different a forecasted network will be from an existing network.

The ratios calculated in table 5 can provide a weighting parameter to the model that offers a means of calibration for an ABM that applies our forecasting algorithm. After applying our algorithm for accretion and either of Burt's (2000, 2002) algorithms for decay, any threshold value could be weighted by this ratio to improve the fit of the general algorithm to the specific network. This process would require at least two periods of network data to execute. Sufficiently rich network data can be difficult to obtain; dynamic network analyses of the growth of scientific collaboration networks have been successful due in part to the ready availability of dynamic network data from databases of published works that, as of the time of Barabasi et al.'s (2002) publication, contained almost 71,000 scientific articles from around 210,000 different authors (Barabasi et al., 2002). Dynamic network analyses have been unable to address mechanisms of change due at least in part to the lack of readily available data about the scientists whose research is cataloged in the databases. We sought a method that would support forecasting using a single period of data. We found a single period of data to be sufficient to prove only that our algorithm could make plausible forecasts but that more data are needed to make accurate forecasts.

## Towards an Agent Based Model of Network Growth

ABMs provide a means for a researcher to direct agent behavior while still allowing for emergent properties, like networks. This makes an agent based model a natural match for bottom-up forecasting of network growth. ABMs give space to each agent to make independent decisions. The researcher is left to determine how the agents makes those decisions, including how dependent, independent, or interdependent the agents' decision rules are. The strength of ABM approaches is that they allow for examining situations with a complex set of interdependent agents and rules (Ostrom, 2005). Their weakness is that ABMs require extensive amounts of high-quality data to build, validate, and calibrate. Data that meet the needs of an ABM are often difficult to acquire in any social scientific context, including organizational partnership networks (Janssen & Ostrom, 2006).

Consistent standards and protocols for using empirical data in ABMs are in short supply, particularly among social scientific applications of ABMs (Janssen et al., 2008), though some, such as the ODD protocol, are beginning to gain wide acceptance (Grimm et al, 2006; Grimm et al, 2010; Janssen et al, 2008). While the ODD protocol helps in communicating model design, it does not speak of the challenges of linking the model's structures, processes, and outputs to empirical data (Grimm et al., 2010). Janssen and Ostrom (2006) identify two sets of trade-offs for how to use data that a modeler must consider when designing an ABM: 1) context-specificity versus generalizability, and 2) few subjects versus many subjects (see table 6). Under the first trade-off, the modeler either designs the model to apply to many cases broadly or designs the model to recreate a specific case with high fidelity to that case's nuance. Under the second trade-off, the model chooses either to gain detailed data on decision-making processes from a few subjects or to acquire broad data on many subjects, but without the depth that is possible when the subjects are few in number. For Janssen and Ostrom (2006), these trade-offs create a foursquare typology that identifies four means of data acquisition and usage, shown in table 6. ERGM analysis provides a version of stylized facts that can be transformed into an algorithm for forecasting network growth; ERGM provides network analysts with a means to measure the relative influence of each behavior for selecting partners, thereby providing the rules for how a network developed (Goodreau et al., 2009). Examining the influence that each decision rule has on link selection provides insights to how specific networks formed.

**Table 6: Approaches to Empirical Data Use in ABMs (Adapted from Janssen & Ostrom, 2006)**

| | Context-Specific | Generalized |
|---|---|---|
| Many Subjects | Case Studies | Stylized Facts |
| Few Subjects | Role Games | Laboratory Experiments |

## Modeling Networked Governance with ABMs

The Vermont Farm to Plate Network plays a governing role with a list of 25 goals and a strategic plan for harnessing the network and its membership to achieve those goals (VSJF, 2015a, 2015b). Increasingly ABMs are being employed to study multi-scale, multi-sector governance arrangements (Pahl-Wostl, 2005; Janssen & Anderies, 2007; Janssen, et al., 2008; Ostrom, 2010a, 2010b; Veldkamp et al, 2011; Grimm et al., 2006; Zia & Koliba, 2015). These ABMs rely upon ethnographically derived institutional rule structures extracted through extensive comparative case studies (Pahl-Wostl &

Ebenhoeh, 2004; Janssen & Anderies, 2007), source document analysis (Zia & Koliba, 2015) and available databases (Zia & Koliba, 2015). A growing arm of policy research is now applying ABMs to examine both policymaking and policy implementation (Axelrod, 1997; Lempert, 2002; Janssen & Ostrom, 2006; Zia & Koliba, 2013; Choi & Robertson, 2014; Maroulis, & Wilensky, 2014). The outputs of these governance ABMs have focused on local level irrigation management decisions (Janssen, 2007; Janssen & Anderies, 2007) and the prioritization of transportation projects at the regional scale (Zia & Koliba, 2015). To date, no ABM of governance configurations has led to the generation of a predictive capacity to anticipate changes in governance arrangements over time and as the result of intentional interventions. While, ABM population models of civilizations (Epstein, 2006) and urban centers (Campbell, Kim, & Eckerd, 2014; Kim, Campbell, & Eckerd, 2014) have been used to regenerate historical settlement patterns in existing populations or forecast future patterns in simulated populations, these population models have not focused on predicting the evolution of present time, empirically observable social structures.

The ability to simulate the emergence of new arrangements for networked governance has been elusive. Policy systems operate as complex networks (Weible & Sabatier, 2005; Lubell & Fulton, 2007; Henry et al., 2010; McGinnis, 2011; Ingold, 2011; Provan & Lemaire, 2012), meaning they often feature extensive sets of human agents who apply complicated and varying decision rules, are subject to path dependency, and are continuously changing as agents review and revise decisions (Axelrod & Cohen, 2000; Ostrom, 2005; Koliba et al., 2010). Networks between individuals and organizations provide structure to policy systems. This structure then influences the policy choices and social impacts that emerge from the policy systems (Provan & Milward, 1995; O'Toole, 1997; Koliba et al., 2010). This relationship between structure and outcome gives governance networks two venues for change: the underlying network structure and the policy decisions and social impacts that are the consequence of that network's functions. Our algorithm speaks to the changes in underlying network structures. As this structure evolves, so too will how the network behaves, such as in how financial resources and information flow through the network. Altering these flows can alter the outcomes for service delivery. However, no accurate measurement of how an intervention alters the network and its behavior can be made without accounting for the network's organic growth and development. By capturing the processes of this organic growth, as measured through homophily, heterophily, transitivity, and preferential attachment, our algorithm provides the baseline necessary to being measuring the impacts of policy interventions to the network's structure and behavior.

## Study Limitations and Future Research

Our work is built from an analysis of one governance network that operates in a food systems context. In a strict sense, this places potentially severe limits on the external applicability of our results; since our analysis is built on one type of network in one context, the results only apply to that type of network in that context. However, none of our research is based on the idiosyncrasies of food systems or governance networks. We parameterize our model using the ERGM from one, specific context. ERGM is applicable for any network context, making our approach flexible enough to apply to any network context to which ERGM can apply. Future research should repeat the modeling process in other contexts, such as other policy problems, like energy and water, as well as outside of policy implementation. We demonstrate that an ABM that grows a network from the bottom up can forecast that network's growth in one context. Future research should consider if our conclusions hold for ABMs built outside of a food systems or policy context.

The primary building block of an ABM is its agents and their decision mechanisms (Axelrod, 1997; Pahl-Wostl & Ebenhoeh, 2004; Janssen & Anderies, 2007; Grimm et al. 2006; Zia & Koliba, 2015). Our algorithm's weakness is that the algorithm cannot recreate agents' true decision processes, only their outcomes. ABMs that apply even simple decision processes can produce complex results, often with unexpected emergent patterns (Campbell et al., 2014; Epstein, 2006; Janssen & Ostrom, 2006). Researchers may then encode the decision processes of relatively simple agents to create effective forecasting models in those contexts. Models using more complex agents, including human beings and organizations are usually limited in their scope since the full decision processes, including the capacities for learning and adaptation (Axelrod & Cohen, 2000; Choi & Robertson, 2014; Comfort, Boin, & Demchak, 2010), are often difficult, if not impossible, to anticipate in the scope of a pre-programmed ABM. This limitation is what has led to the use of ABMs in theory building but limited their application in theory testing and forecasting (Epstein, 2006). Advanced modeling methods, including artificial neural networks (ANNs) are now emerging (Zhang, Patuwo, & Hu, 1998; Schmidhuber, 2015), but have to see wide application in social scientific contexts. Future research should consider integrating ANNs and ABMs.

## Conclusions

Understanding how networks change can provide insights into how those same networks will behave. Goal-directed inter-organizational partnership networks, by definition, seek to obtain some kind of goal, whether setting a policy agenda, raising public awareness, providing information and education, implementing policy, or any combination of these goals, as well as many other potential goals. The Vermont Farm to Plate Network pursues 25 different stated goals. Its ability to pursue its goals is dependent on the voluntary efforts of its members and the resources that the members devote to their efforts within the Vermont Farm to Plate Network. If we wish to understand how network structures influence performance, we will need to understand not just how to measure those structures at a single period, but how to measure their change.

Network theorists have been studying this change (Barabasi et al, 2002; Perc, 2010; Tomassini & Luthi, 2007), but, so far, their efforts have largely been limited to documenting how network measures have changed within a single network over time, using dynamic network analysis. This approach has paved the way for understanding network growth and provided a solid basis for documenting this change. However, this approach has not yet been able to offer insights into the mechanisms that drive network growth and development. Our research shows that ERGM provides insights into these mechanisms by measuring the influences of different agent strategies in selecting collaborators and that these insights can be applied to forecast growth. Our algorithm, when paired with an algorithm for network decay (Burt,

2002) within an ABM, produces plausible forecasts of network growth. However, our algorithm does still struggle to forecast the correct amount of link accretion and link decay. Using two periods of data allows for measuring forecast error. The measured forecast error, the amount of over- or under-forecasting of link accretion and link decay, could then be used to calibrate our algorithm to a specific network. Measured error from initial model runs could be repurposed as a new parameter that either increases or decreases the amounts of accretion and decay. This more refined version of our algorithm could then be expected to produce more accurate forecasts of network growth and development.

## Appendix A: Attribute Coding Rules

List numbers indicate the assigned ordinal value for each attribute. Homophily in one attribute occurs when two organizations who share a link also share the same value on that attribute.

*Capacity Attribute (Scheinert, 2012)*

- 1: very small organizations (all jurisdictions)
  - o Those with expected staffs of around 10 members or less
  - o Groups of insufficient size to maintain a website or web presence
- 2: small organizations (all jurisdictions)
  - o Organizations that would staff up to about 50 people or budgets in thousands to 10s of thousands of dollars, annually
  - o Includes local-level government offices
  - o Small staff state-level organizations
  - o INGO's that only function or can only function in one location at a time
- 3: medium sized organizations (all jurisdictions)
  - o Staffs between 50 and 100 or budgets at or exceeding $500,000/year
  - o Includes state-level political parties
  - o State-level agencies
  - o INGO's working in a limited number of countries
- 4: large domestic organizations and large international organizations (not government backed)
  - o Large staffs or budgets exceeding $5,000,000/year
  - o Organizations backed by a single foreign government
  - o INGO's working in many countries
- 5: large international organizations (public only) that draw on resources of multiple governments, allowing for budgets of many millions of dollars per year

*Sector Attribute (Koliba et al., 2015)*

1. Federal Governing Agents
2. State/Provincial Governing Agents
3. Regional/Geo-governing Agents
4. Local/Municipal Governing Agents
5. Private (For-Profit) Enterprise
6. Non-Governmental and Non-Profit Organizations
7. Citizen Agents
8. Research Agents
9. International Governing Agents

*Jurisdiction Attribute (Koliba et al., 2015)*

1. Vermont
2. New York
3. Quebec
4. US
5. Canada
6. International

Last resort codes:

7. (Aggregate Sector-Identified Agents (Identifiable Sector but no jurisdiction))
8. (Unclear or otherwise unusable jurisdiction information)

*Jurisdictional Level Attribute (Comfort et al, 2010)*

1. Village/Sub-town
2. Town/Municipality
3. County
4. Sub-state regions (example: RPCs)
5. Watershed
6. State
7. National
8. International

## Appendix B: ERGM Results for Phase 1: Forecast 2012 New and Existing Links from 2012 Existing Links

| Model Terms | | | Information Sharing | | Collaboration | | Resource Sharing | | Union | |
|---|---|---|---|---|---|---|---|---|---|---|
| Term | Attribute | Attr Value | Estimate | P-Value | Estimate | P-Value | Estimate | P-Value | Estimate | P-Value |
| edges | | | -3.95 | 0.00 | -5.05 | 0.00 | -4.55 | 0.00 | -4.36 | 0.00 |
| factor | Capacity | 2.00 | -0.04 | 0.28 | 0.03 | 0.41 | -0.05 | 0.48 | 0.20 | 0.00 |
| factor | Capacity | 3.00 | -0.01 | 0.85 | 0.04 | 0.52 | -0.03 | 0.77 | -0.01 | 0.84 |
| factor | Capacity | 4.00 | 0.27 | 0.00 | -0.15 | 0.03 | 0.03 | 0.79 | 0.00 | 0.98 |
| factor | Sector | 2.00 | 0.29 | 0.01 | 0.05 | 0.70 | -0.12 | 0.64 | 0.37 | 0.01 |
| factor | Sector | 3.00 | -0.70 | 0.00 | 0.32 | 0.01 | -0.04 | 0.83 | 1.01 | 0.00 |
| factor | Sector | 5.00 | 0.29 | 0.00 | 0.06 | 0.53 | 0.02 | 0.91 | 0.39 | 0.00 |
| factor | Sector | 6.00 | 0.32 | 0.00 | -0.03 | 0.75 | 0.03 | 0.85 | 0.57 | 0.00 |
| factor | Sector | 7.00 | 1.08 | 0.00 | -1.22 | 0.03 | 0.32 | 0.42 | 0.09 | 0.81 |
| factor | Sector | 8.00 | -0.26 | 0.28 | -0.10 | 0.61 | 0.14 | 0.75 | 1.01 | 0.00 |
| factor | Juris | 4.00 | -0.22 | 0.07 | 0.01 | 0.90 | -0.40 | 0.01 | -0.36 | 0.00 |
| factor | Juris | 6.00 | 0.03 | 0.85 | 0.06 | 0.70 | -0.23 | 0.54 | 0.53 | 0.00 |
| factor | JurisLevel | 2.00 | -0.10 | 0.16 | 0.10 | 0.20 | 0.04 | 0.65 | -0.10 | 0.10 |
| factor | JurisLevel | 3.00 | 0.32 | 0.00 | 0.09 | 0.23 | -0.05 | 0.48 | -0.45 | 0.00 |
| factor | JurisLevel | 4.00 | 0.09 | 0.09 | 0.14 | 0.02 | 0.02 | 0.73 | -0.28 | 0.00 |
| factor | JurisLevel | 6.00 | 0.18 | 0.00 | 0.24 | 0.00 | 0.04 | 0.55 | -0.08 | 0.15 |
| factor | JurisLevel | 7.00 | -0.32 | 0.00 | 0.28 | 0.00 | 0.03 | 0.75 | 0.27 | 0.00 |
| factor | JurisLevel | 8.00 | -0.18 | 0.14 | 0.37 | 0.01 | -0.23 | 0.58 | -0.43 | 0.00 |
| match | Capacity | 0.00 | 0.07 | 0.24 | -0.13 | 0.01 | 0.07 | 0.44 | -0.15 | 0.02 |
| match | Sector | 0.00 | -0.11 | 0.06 | 0.00 | 0.93 | -0.12 | 0.09 | 0.01 | 0.81 |
| match | Juris | 0.00 | -0.31 | 0.03 | 0.20 | 0.03 | -0.51 | 0.00 | 0.01 | 0.94 |
| match | JurisLevel | 0.00 | -0.06 | 0.45 | -0.10 | 0.07 | -0.30 | 0.02 | 0.05 | 0.53 |
| gwesp | | | 0.24 | 0.00 | 0.71 | 0.00 | 0.55 | 0.00 | 0.21 | 0.00 |
| gwesp.alpha | | | 1.79 | 0.00 | 1.44 | 0.00 | 1.75 | 0.00 | 1.87 | 0.00 |
| density | | | 0.05 | 0.00 | 0.02 | 0.00 | 0.01 | 0.00 | 0.05 | 0.00 |

## Appendix C: ERGM Results for Phase 2: Forecasting New and Existing 2014 Links from New and Existing 2012 Links

| Model Terms | | | Information Sharing | | Collaboration | | Resource Sharing | | Union | |
|---|---|---|---|---|---|---|---|---|---|---|
| Term | Attribute | Attr Value | Estimate | P-Value | Estimate | P-Value | Estimate | P-Value | Estimate | P-Value |
| edges | | | -3.71 | 0.00 | -4.77 | 0.00 | -3.95 | 0.00 | -4.35 | 0.00 |
| factor | Capacity | 2.00 | -0.04 | 0.30 | 0.05 | 0.14 | 0.11 | 0.02 | 0.18 | 0.00 |
| factor | Capacity | 3.00 | 0.13 | 0.02 | -0.01 | 0.76 | 0.08 | 0.18 | -0.05 | 0.26 |
| factor | Capacity | 4.00 | 0.63 | 0.00 | 0.07 | 0.15 | 0.04 | 0.61 | -0.01 | 0.87 |
| factor | Sector | 2.00 | -0.10 | 0.42 | 0.14 | 0.11 | 0.05 | 0.80 | 0.43 | 0.01 |
| factor | Sector | 3.00 | -0.21 | 0.15 | 0.13 | 0.19 | -0.39 | 0.00 | 1.18 | 0.00 |
| factor | Sector | 5.00 | 0.05 | 0.63 | 0.04 | 0.56 | -0.22 | 0.03 | 0.46 | 0.00 |
| factor | Sector | 6.00 | 0.01 | 0.89 | 0.06 | 0.31 | -0.19 | 0.07 | 0.70 | 0.00 |
| factor | Sector | 7.00 | -2.89 | 0.00 | 0.09 | 0.61 | -0.61 | 0.00 | 0.14 | 0.72 |
| factor | Sector | 8.00 | 2.48 | 0.00 | 0.24 | 0.08 | -1.09 | 0.07 | 1.25 | 0.00 |
| factor | Juris | 4.00 | 0.77 | 0.00 | 0.00 | 0.99 | 0.14 | 0.05 | -0.34 | 0.00 |
| factor | Juris | 6.00 | 0.63 | 0.00 | 0.09 | 0.44 | 0.27 | 0.29 | 0.65 | 0.00 |
| factor | JurisLevel | 2.00 | 0.55 | 0.00 | -0.12 | 0.03 | -0.10 | 0.23 | -0.09 | 0.24 |
| factor | JurisLevel | 3.00 | 0.28 | 0.00 | -0.02 | 0.64 | -0.19 | 0.01 | -0.42 | 0.00 |
| factor | JurisLevel | 4.00 | 0.10 | 0.15 | 0.00 | 0.94 | 0.02 | 0.72 | -0.31 | 0.00 |
| factor | JurisLevel | 6.00 | 0.19 | 0.01 | 0.00 | 0.97 | -0.18 | 0.01 | -0.07 | 0.25 |
| factor | JurisLevel | 7.00 | -0.71 | 0.00 | -0.18 | 0.00 | -0.28 | 0.00 | 0.30 | 0.00 |
| factor | JurisLevel | 8.00 | -1.47 | 0.00 | -0.20 | 0.02 | -0.37 | 0.12 | -0.57 | 0.00 |
| match | Capacity | 0.00 | -0.01 | 0.90 | -0.02 | 0.72 | -0.18 | 0.00 | -0.14 | 0.02 |
| match | Sector | 0.00 | 0.08 | 0.19 | 0.02 | 0.80 | 0.01 | 0.87 | -0.02 | 0.75 |
| match | Juris | 0.00 | 0.00 | 0.98 | -0.13 | 0.27 | -0.04 | 0.61 | 0.05 | 0.69 |
| match | JurisLevel | 0.00 | 0.08 | 0.30 | -0.11 | 0.12 | -0.45 | 0.00 | 0.06 | 0.35 |
| gwesp | | | 0.14 | 0.00 | 0.58 | 0.00 | 0.62 | 0.00 | 0.17 | 0.00 |
| gwesp.alpha | | | 2.12 | 0.00 | 1.46 | 0.00 | 1.62 | 0.00 | 1.89 | 0.00 |
| density | | | 0.06 | 0.00 | 0.02 | 0.00 | 0.01 | 0.00 | 0.06 | 0.00 |

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# A Complexity Context to Classroom Interactions and Climate: ABM Forecasting Achievement

Liz Johnson[A], Corresponding Author, Linda Lemasters[B],
Prasun Bhattacharyya[C]

**This multimethod, multiphase study was developed to determine how classroom achievement could be forecasted, as well the impact of charter school reform policy on achievement gains in North Carolina. The study analyzed the relationship between classroom climate, interactions, and student achievement, through a complexity adaptive systems context. Combined qualitative, quantitative, network analysis, and agent-based modeling enabled capturing the simple, complicated, complex, and chaotic interactions in classrooms. The data were secured from eighth-grade mathematics teachers and students at four charter schools in a North Carolina urban area (n = 300). A more nuanced and detailed account of the relationship between classroom climate, interactions, and charter school achievement emerged suggesting that teacher control and second-semester math grades are statistically significant. Consequently, the higher the level of control teachers exercise, the higher students score on common core achievement. The results indicate that North Carolina charter schools have served as an effective reform strategy to address the achievement gap challenge in North Carolina, with school-specific strategies of high teacher support, students' teaching students, IAP/tutoring/online supplemental program, and small classrooms. On average, all schools scored 30.9% to 56.8% higher on grade-level proficiency (GLP) than the North Carolina 2014-2015 average. The network analysis demonstrated how classrooms can be complex in varying degrees and in different ways with instructional, emotional support, and behavior management interactions that fit into network structures of teacher to one-student, teacher to whole class, whole class to teacher, and student to student or students. The predictive agent-based model (ABM), which was based on qualitative, quantitative and network analysis demonstrated accuracy level from 93.6% to 100%. The ABM captured macroclassroom and microstudent outcomes, as well as with climate changes based on interactions that either increased or reduced positive climate. This is critical because teachers have limited resources and cannot control most influences from outside the classroom. Thereby, teachers have the power to create a positive or negative climate by their verbal and nonverbal interactions. Teachers' interactions in the classroom have consequences that impact students' achievement and students' lives, so every interaction matters.**

**Keywords: agent-based model, network analysis, multi-method, charter schools, achievement gap**

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[A] Institute for Economic Research (IRE), University of Lugano
[B] The George Washington University
[C] Prasun Bhattacharyya

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## Introduction

The purpose of this study was to develop a predictive agent-based model (ABM) to determine the relationship between classroom environment, teacher–student interaction patterns, and varying levels of teacher support in charter school eighth-grade mathematics classrooms to capture their combined impact on achievement. A major goal was to develop not only an effective predictive toot but also a visual simulation representation of the changes in classroom networks, teacher/student and student/student interactions, behavioral interaction markers that impact classroom climate, and corresponding environment. The topic is relevant because of the quick pace and number of charter schools are being opened, dramatically transforming the educational terrain in North Carolina. Charter schools vary extensively in philosophy, mission, and pedagogy and represent almost 4% of the enrollment in North Carolina public schools (Cheng, Hitt, Kisida, & Mills, 2015; NC Department of Education, 2015). Given the achievement gap's racial disparities that direct most American educational reform policy, many charter schools were established under the guise of lessening that gap (Cheng et al., 2015).

Assessing the success of charter schools as a reform has had mixed results (Eisen & Ladd, 2015; Guo, 2015). Assessment attempts in North Carolina have been replete with political posturing, accusations, misinformation, and lack of funding for comprehensive evaluation (Guo, 2015). Determining if and how charter schools impact achievement is important to determine whether or not charter schools are effective as an education reform. Though, achievement tests alone do not give the complete picture (U.S. Department of Education, 2007). Many critical factors, such as climate in charter schools, have not been examined. When school climate is considered, charter schools "appear to demonstrate a better attunement to student needs and greater success in meeting them" (U.S. Department of Education, 2007, p. 4).

When key variables in relation to achievement were researched, they were often studied in isolation without regard for the charter school systems as an integrated whole. Yet, classrooms operate as complex adaptive systems (CAS). A school classroom, characterized as a complex adaptive system depends on the environment and contingency, subsumed by "the nature of the ever-changing interactions among the constituent parts" (Hadžikadić, O'Brien, & Khouja, 2013, p. 11). Investigating classroom interactions by merely reducing them to mere constituent parts contributes to minimum understanding the cointeraction of classroom elements and the environment, as well as implications resulting from the fact that the classroom interactions give rise to aggregate system-level outcomes of achievement scores in charter schools (Johnson, 2016). A complexity context and corresponding simulation methodological approaches allow for more intricate investigation of nonlinear classroom interactions in relation to achievement score outcomes, in order to better grasp the nature, magnitude, and nuances of the inherent complexity unique to charter schools (Hadžikadić et al., 2013, p. 15).

In the literature, no studies were found that utilized a complexity context with a methodological approach involving qualitative, quantitative, and network analyses, as well as ABM, as used in this research. The literature revealed that complex educational systems, like classrooms, can be accounted for and accommodated by mixed-methods approaches inclusive of complexity methodologies, which can add to education research in novel ways (Miles & Huberman, 1994). Classrooms are complex and dynamic adaptive systems, whereby interactions give rise to the aggregate system level of classroom achievement score outcomes. "The nature of the ever-changing interactions among the constituent parts" are linked to classroom climate, as well as climate's being linked back to the student and teacher agents (Hadžikadić et al., 2013, p. 11). The increased understanding of the nature, magnitude, and nuances of the inherent complexity in classroom networks, as in this research, can provide educators with accurate predictions of average classroom mathematics achievement scores and provide timely feedback to improve classroom-level learning environments and, in turn, improve achievement scores (Johnson, 2016). Early educational complexivist theorists Davis and Sumara recognized that education, in the context of complexity, is not about preparing for the future but is about "participating in the creation of possible futures" (Davis & Sumara, 2008, p. 43).

## Research Problem

Researchers have yet to develop timely and effective tools to predict classroom achievement. Additionally, North Carolina's charter school movement, as a reform, has faced controversy over the great divide in relation to the hype and effectiveness about charter schools. In the opinion of some, the North Carolina Republican-dominated legislature has enacted a war on public education, with charter schools as a means to further weaken the public education system (Strauss, 2015). For example, the limit on charter school start-ups has been overturned and oversight has been weakened (Strauss, 2015). Concerning is the fact that there has been scant research on charter schools in North Carolina to substantiate claims about accountability, oversight, positive outcomes for students, and effect of charter schools on public schools. The often cited research is from Bifulco and Ladd (2006). They claimed that achievement gains in charter schools were less than gains in traditional school districts. Some researchers have considered this study to be flawed and outdated (Stoops, 2010).

## Research Questions

1. What are teacher and student interaction patterns in charter school classrooms and how do they impact student achievement?
Interaction patterns were based on data from the Classroom Environment Scale (CES) (see Appendix A) survey administered to both teachers and students and from Classroom Assessment Scoring Systems (CLASS) (see Appendix B) standardized interaction observations. The 2015 North Carolina Common Core end-of-grade mathematics achievement test was used to measure student achievement.

2. How do the experiences of students and teachers in the classroom climate or environment in charter schools impact prediction of student achievement?
Student and teacher experiences were based on data from the CES survey administered to both teachers and students and from CLASS standardized interaction observations.

## Research Sample

All charter schools in the North Carolina urban area were contacted for research recruitment; however, only 4 schools participated. The population sample of $n$ = 300 for the study included teachers and students from four charter schools from the same urban area in North Carolina for a total of 16 classrooms. Three schools completed the Climate Environment Scale (CES) survey for students and teachers in regard to their respective classrooms (see Appendix A). Two of the schools were randomly selected for Classroom Assessment Scoring System (CLASS) achievement markers observation sessions in addition to the survey administration. CLASS behavioral markers include instructional interactions, emotional supportive interactions, and behavioral management interactions (see Appendix B.

The charter schools that participated were all nonprofits and had been in operation for 4 years or more. In each of the four schools that participated, both regular and advanced mathematics classrooms were included as part of the sample. The schools were administered varied levels of interventions and diverse achievement boosting strategies:

1. School #1: Students and teachers were administered CES, CLASS observations, and research treatment intervention of pre-meeting directing teacher to implement high level of Teacher Support. CES definition of Teacher Support is the help and friendship the teacher shows toward students; how much the teacher talks openly with students, trusts them, and is interested in their ideas (.

2. School #2: Students and teachers were administered CES and CLASS observations. Exclusively gifted. High number of students teaching other students. Student seating was in table clusters with the teacher's desk located in the front of the classroom off to the side during observations.

3. School #3: Students and teachers were administered CES. Individual Accommodation Plan (IAP) for each student, tutoring, and required supplemental mathematics program online. Student and teacher seating was traditional.

4. School #4: No administration of CES or CLASS. Low teacher/student ratios; 1 to 7; 1 to 8; 1 to 10; 1 to 11; 1 to 16. Student and teacher seating was traditional.

Table 1. *Research Interventions.*

| Research Interventions | | | |
|---|---|---|---|
| Charter Schools From large NC urban area | Administered CES Survey on classroom environment to 8th grade math students & teachers | Twenty-minute Pre-meeting with 8th grade mathematics teacher to direct to be supportive & helpful to students | CLASS ½ hour Observations conducted the last two weeks of school |
| School #1 | ✔ | ✔ | ✔ |
| School #2 | ✔ | | ✔ |
| School #3 | ✔ | | |

## Research Methodology

Through the mixed-methods design the researchers studied interactions of eighth-grade charter school mathematics classrooms and impact on student achievement, from a complexity context perspective. The approach was used to capture simple, complicated, complex, and chaotic systems in classrooms. The multiphase approach, which incorporated a complexity conceptual frame, guided data collection strategies and analyses. Also the complexity context allowed for comprehensive integration of approaches, theories, data, methodologies, and analyses, facilitating an emergent synergy from all the phases.

Investigating the deeper levels of complexity of the research phenomena's comprehensive whole necessitated interrelated and sequential steps. First, the results from Phase 1 of the CES qualitative survey and classroom CLASS observations of behavioral markers, that impact achievement, set up Phase 2 of data collection for quantitative regression analysis. The results from Phases 1 and 2 set up the data collection for Phase 3, a network analysis. The results from Phases 1, 2, and 3 set up the data collection for a data-driven, predictive ABM. The results from Phases 1, 2, 3, and 4 set up the data collected for the overall analysis. Figure 1 provides an overview of the data sources, outputs, and analyses.

### Summary of Results

**Phase I results.** The results of Phase I are measures of central tendency. For the 16 classrooms from the four schools, the 2014-2015 achievement score mode was 4 and the mean score was 3.25. This average score represented a 91% increase since the common core was initiated in 2013-2014 (*n* = 271). The intervention classrooms scored, 22%, on average, higher than the other classes on CES Teacher Support and scored, 12%, on average, higher than nontreatment classes on CES Teacher Control.

**Phase II results.** The results of Phase II of the statistical regression analyses formed two models. The first model ran first-semester math grades as the primary independent variable against achievement scores for 2014-2015, the dependent variable of. Neither the first-semester math grades nor the treatment variable of Teacher Support measured significant. Teacher Control was significant in the model, suggesting that the more control a teacher exercises in the classroom the higher students will perform on achievement tests. The next model was run with second-semester math grades as the primary independent variable. The second model suggested that second-semester math grades were significant at the .001 level ($p < .001$) and Teacher Control was significant at the .05 level ($p < .05$). Teacher Support did not show statistical significance. The second model had an *Adjusted R Square* of .33 ($R^2 = .33$). Thereby, 33% of the variance in 2014-2015 achievement scores was explained by second-semester math grades, while controlling for gender, race, and CES classroom dimensions (Johnson, 2016).

**Phase III results.** Phase III provided network analyses. Classroom interaction patterns of classrooms were translated into network graphs to capture dynamism and temporal sequences of classroom interaction networks over half hour observation sessions. Figure 2 illustrates three novel approaches for capturing classroom structures of network of interactions:

1. Teacher-to-one student and student-to-student/s.
2. Students as a group to teacher.
3. Teacher-to-students as a group (Johnson, 2015).

The thickest network edges were teacher-to whole-class in relation to CLASS observation behavioral markers of instructional, checking-in, using names, and moving to students that improve achievement. The networks showed the teacher at the top of the hierarchy directing and controlling a majority of network interactions. The exception of School #2 Classroom #5, Observation Session #2 (see Figure 2) had the thickest edges not only from teacher-to-students with regard to the behavioral markers of checking-in, moving to student, and using names but also from student-to-student instructional interactions. Note Classroom #5 had the most interactions of 386 and network the graph captures the chaos of more than 73

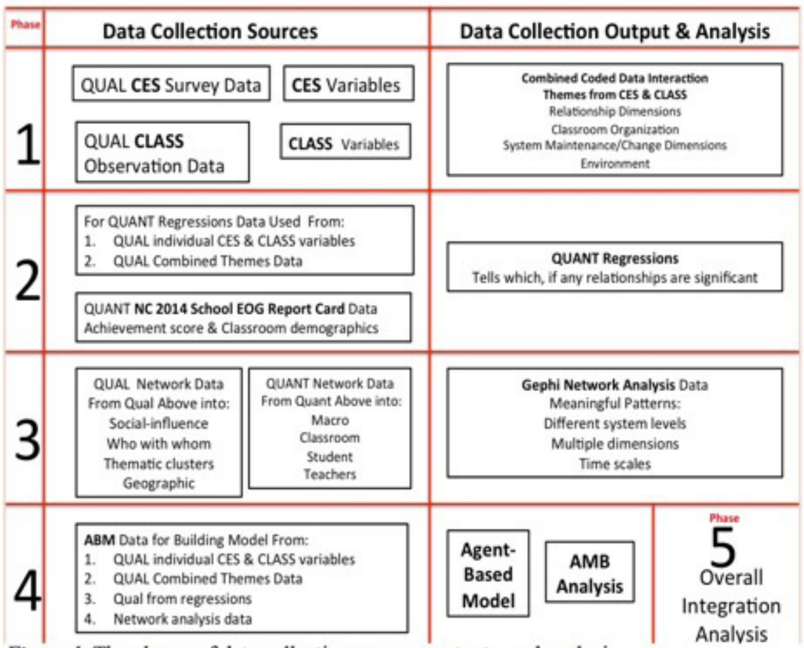



*Figure 1*. The phases of data collection sources, outputs, and analysis.

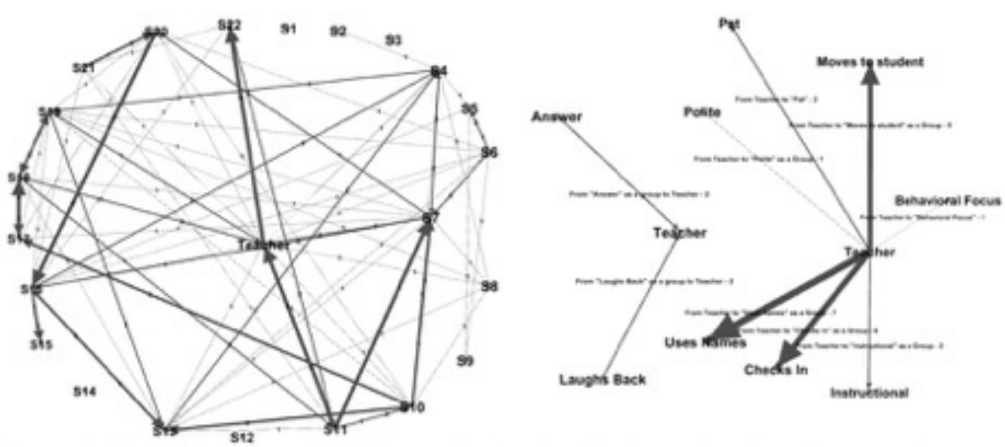
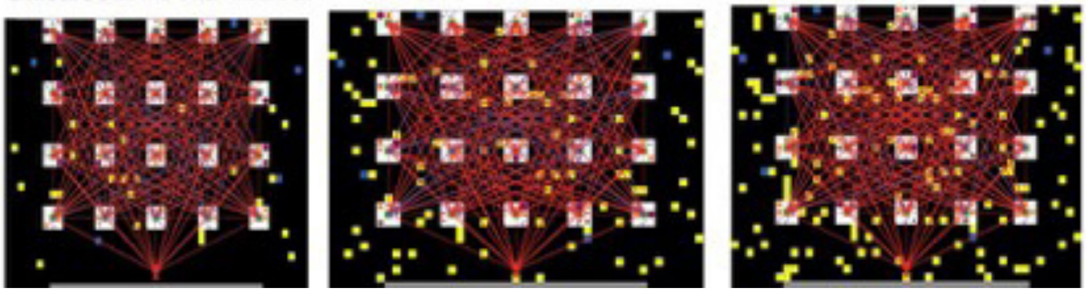



*Figure 2*. School #2 Classroom #5 Observation Session #2 advanced mathematics network analysis.

*Figure 3*. Phases of ABM Simulation for High Teacher Support High Teacher Control School #1 Classroom #1 Advanced.



The ABM predicted achievement scores versus actual scores are shown in Table 2.

Table 2. *2014-2015 ABM Predicted Achievement Scores Versus Actual 2014-2015 Scores*

| School | ABM predicted avg. ach. score for 2014-2015 | Actual CR scores 2014-2015 | Actual school ach. avg. 8th math | Difference + % accurate |
|---|---|---|---|---|
| 4#1 regular Treatment | 2.2 | 2.4, 2.06, 1.73 | 2.06 | 2.2 - 2.06 =.14 93.6% accurate |
| #1 advanced *limited data | 4 | 4 | 4 | None 100% accurate |
| #2 advanced gifted | 4.6 | 4.46, 4.85 | 4.65 | 4.6 - 4.65 =.05 99% accurate |
| #3 regular IAP, tutor | 2.1 | 2.0, 2.25, 2.1 | 2.1 | None 100% accurate |
| #3 advanced IAP, tutor | 3.55 | 3.41, 3.57 | 3.49 | 3.55 - 3.49 =.06 98.3% accurate |

Table 3. *Summary of Overall Achievement, Climate, Interactions, ABM, and Comparison to North Carolina Results*

| | School #1 | School #2 | School #3 | School #4 |
|---|---|---|---|---|
| Ach, increase 2013-2015 % & points | 59% or 6 | 11% or 11 | 10.5% or 11 | 77% or 8 |
| Phase I Positive Climate: | X | X | X | NA |
| Much higher norm Teach Support | X | X | | NA |
| Much higher norm Competitiveness | X | X | X | NA |
| Much higher norm Teacher Control | X | X | X | NA |
| Much higher norm Rule Clarity | X | X | X | NA |
| Teacher Climate Assess. Match Students | | X | NA | NA |
| Phase II Regression: | | | | |
| 2nd Sem. Math Grade .005 ($p < .01$) | | | | |
| Teacher Control .021 ($p < .05$) | | | | |
| Phase III Network Interactions: | | | NA | NA |
| High % Emotional Sup. | X | | | |
| Low behavior management | X | X | | |
| Phase IV ABM: | | | | |
| Predicted Ach. Score Average | 3.1 | 4.6 | 2.82 | NA |
| Actual Achievement Score Average | 3.03 | 4.65 | 2.79 | NA |
| Phase V Charter VS, NC Public School Av.: | | | | |
| Grade-Level Proficiency (GLP) | +30.0 | +56.8 | +52.5 | +44.1 |
| College Career Ready (CCR) | +25.4 | +64.2 | +1.9 | +46 |
| *Charter higher than NC average | | | | |

networks emerging and students actively instructing other students (Johnson, 2016).

**Phase IV results.** The results of Phase IV were developed from the data from Phase I, Phase II, and Phase III. The data-driven ABM measured and showed the changes in the types of interaction networks in classroom environments over half hour time periods and predicted average classroom achievement scores. The intervention School #1 exhibited the highest level of change in positive classroom environment. This can be seen in Figure 3 by the yellow squares that represented positive CLASS behavioral markers that contribute to improving achievement (CASTL, n. d.). Blue squares represent CLASS behavior markers that detract from a positive environment.

The data for predictions were drawn from the random selection of individual student achievement scores from 2013 (when the common core was initiated) through 2015. The ABM in Class #1 predicted the highest improvement in advanced mathematics classes at 110% or 11 points on a scale score for achievement (see Figure 3). School #2's prediction was a 3% improvement. For School #3 observational date and parameter ranges were substituted with similar profiles from previous research (Johnson, 2015) and had predictions of 67% improvement for regular mathematics classes and 83% for advanced (Johnson, 2016). The ABM adheres to the widely utilized overview design concepts and details (ODD) protocol by Railsback and Grimm (2012) and meets recommended ABM standards of validity and validation by Macal (2005) (see Appendix C).

**Phase V results.** The results of Phase V, based on the data from Phase I, Phase II, Phase III, and Phase IV, showed that the integrated methodology could account for the variety of systems such as instructional, emotional, behavioral, climate, structural, hierarchical, and even chaos in the network analysis. Further, the interaction patterns contributed to cocreating the classroom climate, which led to high Teacher Control, which led to effective teaching for Common Core second semester, which led to improvements that ranged from 11% to 130%. The ABM predicted scores for 2014-2015 from simulation runs ranged from 93.6% to 100% accuracy (Johnson, 2016). Table 3 shows a comparison of the results.

## Interpretations

This study presented multiphased robust results explicating fundamental classroom interactions, classroom climate, and a predictive achievement score model to help plan for a more active participatory role in the creation of more positive futures for students.

Fully comprehending a policy reform, such as charter schools, requires a systems approach contextualized within a theoretical complexity context, which was accomplished in this research (Lasky, 2004; Patton, 1990). The complexity context and methodologies allowed for capturing more and nuanced levels of system details. For example, results were presented on varied scales: individual students, groups of students, individual teachers, classrooms, and schools. These results are consistent with the claim by Kaput et al. (1999) that a complexity context facilitates understanding systems and changes in education in relation to a policy reform strategy (Johnson, 2016).

The ABM simulations enabled visual representations of classroom interactions, networks, and climate with aggregate classroom and individual agent outputs. The innovative combination of qualitative, quantitative, and network analyses, as well as ABM methodologies, extended and transcended the limits of traditional research, which Mason (2008) described as more concerned with inputs and outputs. Accordingly, school leaders and teachers must realize that actors in a CAS can influence almost everything but control almost nothing (Page, 2009). The role of school leaders, teachers, and policy makers should not be about making attempts to control outputs and outcomes. Their actions should be about cocreating and sustaining a facilitating and accommodating climate, whereby students are engaged and learn more (Johnson, 2016).

## Climate and interaction assessment

The recognition of effective teacher-to-student interactions also can further explicate classroom climate and achievement advancement (CASTL, n.d.; Rolland, 2012; Thapa, Cohen, Guffey, & Higgins-D'Alessandro, 2013; Trickett & Moos, 2002). Haggis (2008) argued that causalities of interactions may be intractable in classrooms. In opposition, this study showed, through a network analysis, which the teachers were at the atop of classroom hierarchies, initiating and directing a majority of interactions during six of the seven observation sessions. Carolan (2014) argued that educators know little of how the processes of change work and what form interaction patterns take. The CES and CLASS assessments provided evidence-based approaches to map interactions methodologically through the CES survey and CLASS observations. The results were then mapped into a network analysis and ABM simulations. Thus, more is known about interaction patterns and networks in these charter schools, but additional research is needed to further validate and expand the deeper meaning of these type of results (Johnson, 2016).

Through the network analysis and ABM simulations, the research made visible detailed representations of interactions usually hidden or unavailable to educators about relationships and the strength of them (Pianta, 2012). Given that the practice of teaching usually takes place in behind closed doors and with limited objective feedback, this study showed that the combined instruments and methodologies can provide effective feedback to improve practice and reinforce positive behaviors that are effective (Lampert, 2001). Lampert (2001) claimed that the practice of teaching is about working in relationships, building positive norms of interactions. Yet teaching requires more than norms; the practice requires cocreating a culture of learning with students. The teacher–student results in this study showed trusting relationships and positive interaction relational patterns and positive norms in the classrooms. This finding is important because an "emotionally and intellectually engaging environment" is linked to achievement increases in adolescence (CASTL, n.d., p. 3). The use of dual instruments and multimethods allowed for breaking down the complexity in classrooms and identifying effective interactions, as recommended by (Pianetta, 2012). (2013)

**Predictive ABM.** Combining the achievement factors through multimethods and multiphases that built upon each other contributed to developing a predictive ABM of classroom achievement averages. The ABM visually and symbolically displayed the density of instructional networks and emotionally supportive behaviors, as well as changes in classroom climate.

The multiphase analyses in this research suggested that, based on the methodologies, there are simple, complicated, complex, and chaotic relationships between classroom climate and student achievement in North Carolina charter schools in an urban area. This finding was supported by qualitative, quantitative, and network analyses, as well as ABM. To more fully study the research questions, a data-driven ABM was developed from the preceding data to further investigate the dynamics of classroom climate with regard to achievement. The ABM captured microlevel and macrolevel interrelating networked systems from simple to complex. The goal of the ABM was to develop a model that can account for varied charter achievement strategies in regular and advanced math classes with individual student 2012-2013 scores, classroom climate, second-semester math grades, and 2014-2015 scores as part of the prediction formula. The formula predicted classroom averages based on the random selection of data parameters previously collected. The ABM accurately predicted achievement scores within 93.6% to 100% for the strategies of high Teacher Support, gifted students, and IAP/tutoring/online supplemental math for regular and advanced math students (Johnson, 2016).

An accurate predictive tool can provide invaluable feedback for educators to be more effective and for school leaders and policymakers to utilize resources more effectively for improved benefits to students. A predictive model based on second-semester math grades, however, leaves limited time to prepare for achievement score outputs. Therefore, an emphasis should be placed on what it takes for a class to be proficient or beyond in second-semester curriculum. An emphasis should be placed on what should take place for each individual student to be proficient or beyond in second-semester achievement curriculum. The ABM in the research could be strengthened considerably by additional classroom data and yearly data for generalizability; but, for now, it is a model that shows promise and accuracy. The ABM needs additional development to determine what other possible factors would be significant in addition to high Teacher Control and second-semester math grades, with which populations, and in which settings. Further, more observational data is needed on chaotic behaviors that disrupt a positive climate and transform it to a negative climate. This type of observational data over time could possibly contribute to lack of progress in achievement or even a major decline (Johnson, 2016).

To discern charter school effectiveness as a reform strategy, Betts and Hill (2006) recommended a variety of methodologies and approaches, which were used in this research. It seems unlikely that educators will know the full story about charter schools, as a reform in North Carolina, in the immediate future because there no centralized, controlling governing body with the power to force them to participate in any research. Hence, charter school research in North Carolina will continue to be piecemeal and subject to school leadership's willingness to participate in research and receive feedback (Johnson, 2016).

Yet no matter how the gap problem is conceptualized, the basic behaviors over which a teacher has control are the interactions in her or his classroom. Teachers do not exercise much control over factors outside the classroom that are contribute to the achievement gap, such as societal, community, home, and school factors (Barton & Coley, 2009; Kober, 2001). Over the decades, countless societal, community, home, and school policies have been unsuccessful in solving the gap problem. Consequently, it is imperative that educators know ***there is potential and power in each and every classroom interaction***. There is the potential with positive interactions to inspire and ignite student curiosity, for a lifelong of learning. There is also the potential that teachers and students can create a negatively escalating climate replete with disrespect, punitive control, and negative affect, which was not observed in this research (Pianetta, 20120). In a classroom, with time as a precious resource and mostly uncontrollable influences from outside, ***teachers have the power to create a positive or negative climate through their actions of verbal and nonverbal interactions with student.*** Teachers' actions have consequences that dramatically impact students' achievement and students' lives (Johnson, 2016).

## Conclusions

The achievement gap continues to be a challenge but complexity as a context can provide insight on varied scales. Given the inherent flexibility, charter schools are a reform solution that can work. To sustain and increase the achievement gains in charter schools, educators need to acknowledge the critical nature and potential of classroom climate and take advantage of predictive tools like the ABM in this research. Educators need to cooperatively strategize and implement plans to improve and sustain positive climates in of *all* classrooms.

The results are surprising on varied levels. This research provided novel methodological means and an integrated systems approach to study classroom climate, identifying critical classroom connections with the capacity to improve systems of learning and teaching. The results are important because positively transforming classroom environments has been shown to improve achievement scores on average up to 25% (CASTL, n.d.). The results are in contrast to previous results for traditional public schools in that Teacher Support in this study was not shown to be statistically significant (Eccles, Wigfield, Reuman, Mac Iver, & Feldlaufer 1993; Hattie, 2009; Rolland, 2012; Rueger, Malecki, & Demaray., 2008; Trickett & Moos, 2002). The results of this study suggest that high Teacher Control and high second-semester math grades are significant factors to improve achievement scores in charter schools in urban areas. Although the study's results are limited in generalizability, the results can be used foundationally to expand the models in the study with alternate types of schools, varied types of reform strategies, diverse demographics, and other subject areas to test whether or not the models potentially can contribute to solving the achievement gap. The methodological approach in the study can be recreated by following the Steps for Methodological Application and Replication in Different Settings as outlined in Appendix D. In a classroom every interaction matters. So as Bethune stressed, "we must have the courage to change old ideas and practices" (Bethune, 2000, p. 395).

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Appendix A. *CES SUBSCALES AND DESCRIPTIONS*

**Relationship dimensions**

1. Involvement – the extent to which students are attentive and interested in class activities, participate in discussions, and do additional work on their own
2. Affiliation – the friendship students feel for each other, as expressed by getting to know each other, helping each other work with homework, and enjoying working together
3. Teacher support – the help and friendship the teacher shows toward students; how much the teacher talks openly with students, trusts them, and is interested in their ideas

**Personal growth and goal orientation dimensions**

4. Task orientation – the emphasis on completing planned activities
5. Competition – how much students compete with each other for grades and recognition and how hard it is to achieve good grades

**System maintenance and change dimensions**

6. Order and organization – the emphasis on students' behaving in an orderly and polite manner and on the organization of assignments and activities
7. Rule clarity – the emphasis on establishing and following a clear set of rules and on students' knowing what the consequences will be if they do not follow them; the extent to which the teacher is consistent in dealing with students who break rules
8. Teacher control – how strict the teacher is in enforcing the rules, the severity of punishment for rule infractions, and how much students get into trouble in the class
9. Innovation – how much students contribute to planning classroom activities, and the extent to which the teacher uses new techniques and encourages creative thinking

## APPENDIX B: CLASS OBSERVATION & MAPPING SHEET

**Date__________ School____________________________ Teacher____________________ #Students_______**

***TEACHER***

**Emotional Support**
Moves to/away from Student
Smiling
Laughing
+ Comments
Respectful language: please, Thank-you
Checks in with students
Individual support
Reassurance & assistance

**Behavioral Support**
Attention to positive
Anticipates possible neg. behavior
Irritability
Anger
Yelling
Threats
Punishment
Physical control
Teasing
Bullying
Humiliation/sarcasm
Exclusionary behavior
Inflammatory/discriminatory/derogatory
    Language or behavior

**Instructional Support**
Open-ended questions
Follow-up questions
Assistance
Hints
Prompting
Expansion
Clarification
Specific feedback
Recognition & affirmation effort
Encouragement of persistence

Notes: on classroom context & time of day.

***STUDENTS***

1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
11.
12.
13.
14.
15.
16.
17.
18.
19.
20.

## APPENDIX C: MACAL (2005) ABM VERIFICATION AND VALIDATION ESSENTIAL TO USE MODEL FOR DECISION MAKING

**Verification:**

*Programmed correctly-model selects data randomly from 74 parameters
*Algorithms implemented correctly-test simulations checked against Excel
model has been tested hundreds of times

**Validation:**

*Does the model represent & correctly reproduce behaviors in the real world?
Yes: NW, CLASS, CES, video
*Does the model address the problem precisely? Yes: Addresses what is classroom climate & provides accurate information about the systems modeled
*Were data cross-checked? Yes: with all original, Excel, and research assistant
*Was ODD Protocol met for ABM and Network Analysis? Yes
*Did subject matter experts review? Yes: Dr. Hadzikadic, Dr. Simon
*Does model show participatory simulation ability to place self in position of agents in simulations? Yes
*Does model replicate special cases? Yes: shock, professional development side of model, IAP, high teacher control, small classroom, gifted students
*Was model independently verified and validated? Yes: Kris Tyte
*Models are based on human decision-making & assumptions, so is the model credible? Yes: produced sound insights, sound data used based on wide range of tests, model stands in for real systems

## APPENDIX D: STEPS FOR METHODOLOGICAL APPLICATION AND REPLICATION-DIFFERENT SETTINGS

The following steps serve as a flexible guide on how to apply and replicate the qualitative, quantitative, network analysis, and ABM from the study in different educational settings. Note that all methodologies may be useful for your research. Your research may require additional mythologies like data mining, system dynamics, or analytics. The steps should be taken as prompts to guide your thinking in what is possible with the research. All steps do not need to be taken.

1. Select the educational classroom research phenomena to be studied.

2. Determine the context of research phenomena to be studied by addressing the following questions.

    Does it involve systems?
    Does it involve open systems?
    Does it involve an interaction environment?
    Does it involve change over time?
    Does it involve evolutionary learning?
    Does it involve dynamics?
    Does it involve more than simple and complicated systems?
    Does it involve complexity and/or chaos?
    Is it nonlinear at times?
    Does it involve interactions?
    Does it involve feedback?
    Does it involve multiple scales like micro, meso, and macro?
    Does it involve emergence?
    Does it involve heterogeneous agents?
    Does it involve interdependence?
    Does it involve self-organization?
    Does it involve simultaneity?
    Does it involve patterns?
    Does it involve networks?
    Does it involve tipping points?
    Does it involve adaptation?
    Does it involve energy and the fitness function?

If so, then a complexity context can be used to base your selection of methodologies. A combination of traditional and complexity methods can account for simple, complicated, complex, and chaotic systems.

3. Familiarize yourself with traditional research criteria and complexity research criteria. Familiarize yourself with qualitative, qualitative, network analysis, and ABMs and how they can supplement each other.

4. What are the research questions and what methods can help answer the questions?
Traditional methods can answer research questions like what works?
Complexity methods can answer research questions like how does it work over time?

5. What are the ontological objectives that best fit your research goals and what methods can capture it?

 What is? qualitative, measures of central tendencies, statistical/regression analysis, network analysis, ABMs
 What could be? qualitative, ABM simulations, networks
 What was? qualitative, statistical/regression analysis, network analysis, ABM
 Probabilistic predictions of what will be? statistical/regression analysis, data-driven ABM based on related measures of central tendencies and on based related statistical/regression analysis, network analysis, based on related measures of central tendencies and on based related statistical/regression analysis
 What should be (adding values)? ABM simulations based on related measures of central tendencies and on based related statistical/regression analysis, network analysis based on related measures of central tendencies and on based related statistical/regression analysis
 What should have been (adding values)? ABM simulations based on related measures of central tendency, based on related statistical/regression analysis, networks simulations based on related measures of central tendency and/or based on related statistical/regression

6. What is the time frame you want to research and what methods can capture it?
 Past? qualitative, measures of central tendency, statistical/regression analysis, network analysis, ABM
 Current? qualitative, measures of central tendencies, statistical/regression analysis, network analysis, ABMs
 Future? qualitative, ABM simulations, networks, regression analysis
 Hypothetical? qualitative, ABM simulations, networks
 Iterative? qualitative, ABM simulations, networks

7. What data and proof sources do you need to support your operationalization?
 Empirical?
 Qualitative?
 Network analysis?
 Theory?
 Combination?

8. What educational setting will this research be applied to or replicated in and are there special considerations to take into account?

9. What is the starting point of the research and what is the rationale?

10. Given the starting point, how do students experience their current classroom climate? (Can be assessed from a variety of classroom climate instruments). How do teachers experience their classroom climate? What are the difference and how can the feedback from the results be used to improve the learning environment?

11. Given the starting point, what is the achievement/academic level of each student and measures of central tendency of the class?

12. Regression analyses can be run on the climate data (if adequate sample) to see if the climate variables impact achievement. What climate variables and demographic variables are statistically significant? What is the adjusted R square? The statistically significant climate variables can be included in your ABM as substantiating empirical evidence. If the regression analyses are run over time, those results can be used to parameterize your ABM.

13. What are school and/or classroom goals for achievement/academic improvement? (For example: Grade level proficiency, college/career ready)

14. What, if any, are special strategies to improve achievement? (For example: tutoring, supplemental online programs, small classrooms, remedial sessions)

15. What would be the ideal classroom climate for achievement/academic improvement based on those that cocreate the environment? (For example: this can be captured by a classroom climate survey like the CES Ideal version or by asking students)

16. What is the progress on the ideal climate and does the ideal change over time?

17. What is the narrative or story about classroom climate based on the experiences of teachers and students and does it add to further understanding of the research phenomena?

18. What are the types of instructional networks, whereby teacher and students interact? What are the network structures? What are the counts of interations between teachers-to-student/s and student-to-student/s? The types of networks and counts of network interactions can be used to parameterize your ABM if one is part of your research.

Teacher-to-whole class and how many interactions?
Whole class respond-to-teacher and how many interactions?
Teacher-to-one student, how many interactions, and to which students?
One student respond-to-teacher, how many interactions, and to which student/s?
Student-to-student/s, how many interactions, and which students?
Combination, how many of each interaction, and which students?

19. Are there networks of non-instructional interactions like student-to-student/s off task, if so how many interactions and to which students? This type of network and the counts of network interactions can be used to parameterize your ABM if one is part of your research.

20. If using a network analysis, what are the network measures and what more do they tell you about connections, strength of links, and strength of the network?

Nodes
Links/Edges
Centrality-in degree, out degree, thickness/weight of edge in relation to whole,
closeness, Eigenvector, actor betweenness, link/edge betweenness, levels of hierarchy, flow betweenness

21. What types and number of instructional, emotionally supportive, and behavioral management interactions are observed in the classroom. This can be done in half hour sessions by the teacher videotaping and then counting behavioral makers listed below. The range of data from category counts and specific interaction counts can be used to parameterize your ABM if one is part of your research.

Instructional interactions:
- Teacher-to-all student instructional
- All students respond to teacher respond
- Teacher–to-one-student instructional
- One student responds to teacher
- Network/s of teacher instructing one or more students
- Networks of students instructing one or more students

Emotional interactions:4
- Subsequent climate assessments
- Subsequent observation counts of interactions

Results from regression analysis
Network analysis results
Narrative qualitative results

28. How does each methodology add to understanding of the research phenomena and then how does integrating all the results add to understanding?

29. How can the results from each methodology help teachers improve the practice of teaching?

30. How can the results be used to emphasize the fact that in a classroom every interaction matters?

# An awareness based approach to sustainability: Agent-Based Modeling for decision making in energy policies

Giovanna Sissa,[A] Paola Girdinio,[A] Pietro Terna[B]

**The paper discusses the impact of social interaction on individual and collective behaviors and its effect on the consumption of energy. The underlying hypothesis is that ICT tools enable societal and psychological mechanisms leading to sustainable lifestyles. We envision tools supporting social norms, i.e. rules governing an individual's behavior by social sanctions that encourage sustainable behavior on the part of user and consumers. We present SAM4SN (Spread of Awareness Model for Social Norms), an Agent-Based Model (ABM) to explore the role of awareness in the consumption of a resource. Agents represent households that use a resource – e.g. energy or water – whose consumption has to be reduced. Agents influence each other and such influence improves their awareness that, in turn, influences resource consumption. Social influence and the role of smart metering functions as awareness's catalyst are described. SAM4SN is an exploratory model to play and explore different situations, leading or not to a sustainable consumption of energy. In particular, the sustainability tipping point and its role in decision-making will be introduced.**

**Keywords: social norms, awareness spread, energy efficiency, environmental sustainability, behavioral change, social influence, tipping point**

## Introduction

The report "Decoupling Natural Resource Use and Environmental Impacts from Economic Growth" (UNEP 2011) – a comprehensive document explaining on scientific grounds what needs to be done to make sustainable development possible – describes how the need to reduce energy consumption leads to maximize efficiency, but technology efficiency alone will not produce sustainability. There are risks that potential gains can be countered by rebound effects and only a combination of efficiency and sufficiency can be effective (Boulanger, Couder, Marenne, Nemoz, Vanhaverbeke, Verbruggen, & Wallenborn, 2013; Hilty, Lohmann, & Huang, 2011; Sissa, 2010; Sissa, 2013). We can observe that the cheapest, cleanest form of energy

[A] DITEN- Università degli Studi di Genova, Italy
[B] Retired professor, Università degli Studi di Torino, Italy

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is the energy we never use (Lopez-Lopez, Sissa, Natvig, 2011; Sissa, 2011).

Reduction programs are sometimes launched by local government or by utilities companies, like in Western Australia for water issues related to local climate changes (Anda, Le Grey Brereton, Breman, & Paskett, 2013). Such initiatives are traditionally coupled with regulatory interventions in terms of laws or economic incentives.

An innovative approach consists instead on focusing on behavioral changes, so a lot of attention is given to provide consumers with information and services to manage their energy use (Laskey & Kavazovic, 2010).

The paper starts from a basic tenet of social psychology: individuals are influenced by decisions, actions, and advice of other individuals, both consciously and unconsciously (Cialdini, 2009). Therefore, we mainly focus on social influence, taking into consideration the diversity of actors that may exert a different kind of influence. Such notion of social diversity leads to a network of neighbors, composed by different types of agents who are more or less influential based on their level of environmental awareness. Social norms - as opposed to prescriptive ones (Kinzing, 2013) – are pivotal in collective behavior and represent a turning point to reach the sustainability goals

The scientific contribution of this paper is to explore the potential of Agent-Based Modelling (ABM) to describe at micro level such influence and to observe at macro level its general effects on the resource consumption. In particular, we propose a model to represent awareness spread and to assess the importance of *smart metering functions* to turn awareness into sustainable behaviors. SAM4SN (Spread of Awareness Model for Social Norms) model aims to explore if and how environmental awareness can drive behavioral changes and how smart metering functions can support households in reducing or optimizing their resource consumption.

The paper is organized as follows. After an interdisciplinary overview on the issues linking environmental challenges, and in particular energy consumption, to individual awareness, behavioral changes and social norms we focus on environmental awareness as a social limiting factor to avoid overuse of a scarce or critical resource. Then we introduce the ABM paradigm to model the awareness spread mechanism and its effect on energy. Our model simulates social influence and its effects in achieving a given target of consumption reduction. Smart metering functions allows users to compare their consumption patterns with the ones of other consumers, as well as to dynamically re-define and share their personal reduction goals are seen as awareness catalyst. Thirdly, we introduce the concept of tipping point and its role in energy policy making. SAM4SN is a tool intended for decision makers to investigate situations as, for example, which initial configurations of different types of agent lead to sustainability and the required number of committed agents to enable a social norm. Such kind of investigation is important for planning campaigns or initiatives based on social norm effects. A decision maker can pivot for example on the idea of pilot programs to support selected groups of people to become proactive; he can discover that a nucleus of strong initial commitment against an environmental cause can counter any effort to promote it.

SAM4SN model has been certified at OpenABM.

The full code of the model is available at http://hdl.handle.net/2286.0/oabm.463 and the full description of

SAM4SN model is supplied according the ODD (Overview, Design concepts, Detail) protocol, the general protocol for communicating individual-based and agent-based models (Grimm, Berger, Bastiansen, Eliassen, Ginot, Giske… DeAngelis, 2006; Berger, DeAngelis, Polhill, Giske, & Railsback, 2010). In the ODD of the SAM4SN, the list of parameters with their values is supplied. A model interface description is also supplied at the above-mentioned permanent handle. See Sissa (2014) for further details.

## Environmental awareness, social norms, and behavioral changes

The European Union adopted the Energy Efficiency Directive (DIRECTIVE 2012/27/EU) on October 2012. The implementation of this directive, as well as other policies adopted in recent years[1] , requires a change in consumer behavior and energy consumption practices (EEA, 2013). In particular the Article 12 of the above mentioned Directive focuses on "consumer information and empowering programs" to promote behavioral changes.

While voluntary *behavioral changes* usually are driven by some kind of reward, economic rewards are often not strong enough to trigger a behavioral change (Ferraro & Price, 2013). Other reward mechanisms – like social recognition - may not be readily available at an individual level. Individuals are influenced by the decisions, actions, and advice of others when making a wide variety of decisions, both consciously and unconsciously. However, positive effects on the environment can only happen when an entire community adopts a responsible life style. Our purpose is to explore how environmental awareness can drive people's behavior. *Awareness* is defined in Oxford Dictionary as "a concern about and well-informed interest in a particular situation or development", so does not coincide with information: people may have plenty of information about something without being aware of it. Awareness is an individual aptitude that is developed and shaped inside a social context. How and when does this awareness arise? This central issue is considered in any theory of collective social behavior (Salerno, Yang, Nau, & Chai, 2011). Fischer (2010) in his research has argued that participatory processes are based on psychological mechanisms like social proof or social influence, and such mechanisms are amplified in a sociotechnical ecosystem, where technology enables from passive to aware and active role of users.

Understanding situations we are involved in is the first steps toward becoming able to act. Two essential factors have been recognized: providing people with feedback on their situation and assisting them in setting goals (Abrahamse, Steg, Vlek, & Rothengatter, 2007). ICT-based tools can enhance such factors (Costabile, Dittrich, & Fischer, 2011). These factors can be readily adapted to the encouragement of environmentally aware lifestyles. The first factor can be stated as providing individuals with real-time access to easily information about their personal resource consumption, while the second is providing them with a way to compare their lifestyles with some environmentally aware benchmark. For example, while an app for personal carbon accounting can enable citizens to understand and manage their individual carbon footprint, real time smart meters at home can reduce household energy consumption.

[1] 2030 Energy Strategy

Mechanisms of psychological ownership, social proof and social influence are basic concepts to approach behavioral changes in resource consumption.

*Psychological ownership* describes a state in which a person feels closely connected to an object or idea, to the degree that it becomes part of her "extended self" (Pierce, Kostova, & Dirks, 2002).

Instruments have to be appropriated by users, i.e. contextualized in their daily routine, to become effective (Klopfert & Wallenborn, 2011). A way to extend a social norm is to use rewards for "socially acceptable behavior" like incentives, although not necessarily monetary ones (Sissa, 2008).

As soon as people see something as "their own", its perceived value increases and they are more likely to invest time and effort in preserving it (Fischer, 2012; Dick et. al., 2011). *Social proof* describes how people act in a certain way because they see others acting that way (Cialdini, 2009; Fischer, 2010). In such situations, the fact that others make a choice acts as a proof that this choice is preferable. Individuals replace common background or geographic proximity with a sense of well-defined purpose and successful common pursuit of this purpose (EC 2011).

*Social influence* is an umbrella term for a loose congregation of social, psychological, and economic mechanisms, including:

- Identifying with (or distancing oneself) from certain social groups;
- Obeying authority and avoiding sanctions;
- Reducing the complexity of the decision making process;
- Inferring otherwise inaccessible information about the world;
- Gaining access to a particular network;
- Reaping the benefits of coordinated action.

The dynamics of collective decisions is driven by the influence network, i.e. the network of "who influences whom" that can determining, for example, the likelihood that "cascades" of influence can originate from small initial seeds, the ability of prominent individuals to trigger such cascades, and the importance of group structure in triggering and propagating large cascades (Watts & Duncan, 2002). Some models of social influence tend to assume, often implicitly, that all actors involved are of the same type. Whereas in reality, individuals may be influenced by a variety of actors - for example, peers, role models, media organizations, and high profile individuals – each of which may exert a different kind of influence, and may in turn be influenced differently. A growing research area inside social network analysis is now focusing on a special case of influence response - namely threshold rules, according to which individuals adopt a new state based on the perceived fraction of their peers who have already adopted the same state. While research on *threshold models* dates back to the late Seventies, the effectiveness of threshold rules for describing and forecasting collective decision-making processes is still an open research question (Grannovetter, 1978; Watts & Dodds, 2009).

Threshold models are well understood in certain special cases, like all-to-all approximation where all individuals are influenced equally by the states of all others. Some researches moved systematically up the complexity chain, reviewing the dynamics of cascades of influence on random networks. Other models (Watts, Dodds, & Newman, 2002; Watt & Dodds, 2009) of networks progressed with respect to the random network model by including some notion of topology; neighborhood relationships defined topologically or socially are giving rise to threshold models that are more and more popular in social network analysis. The classical Grannovetter's threshold model has evolved into a network setting where (as opposed to the conventional "all-on-all" influence assumption), individuals are influenced directly only by a small subset of their immediate "neighbors" according to some notion of distance (Grannovetter, 1978). In this context, we need a notion of *social diversity* to simulate a network of neighbors, who are more or less influential based on their level of environmental awareness (Ugander, Backstrom, Marlow, & Kleinberg, 2012).

The influence mechanisms in the field of domestic energy consumption are different from the influence mechanisms in other immaterial assets like opinions. Life styles are driven not only by opinions but also from a set of local conditions.

The energy consumption behavior is driven by not only individual aptitude and social influence but also from local physical constraints as the physical infrastructure of smart metering availability, the local price or local geographical situation as, for example, climatic conditions. The use and choice of electrical appliances, for example, are driven by a set of factors that make as very significant the comparison with neighbors that are in the same economic and social situation. For this reason our choice is of focusing on the influence of direct neighbors and to take into consideration the most extended area of influence of all neighbors - in a given area- as a global influence factor, i. e. in a quantitative way instead in terms of individual relationship.

The influence is modeled in term of local influence, global influence, and social reinforcement. We express such an influence by the awareness level of each agents.

We mentioned above that economic rewards alone are not strong enough to trigger a behavioral change and other kind of reward can be more effective. When a community adopts a responsible life style some positive environmental effects will happen in the end, and the adoption of a sustainable behavior is driven by awareness. Such awareness shifts from an individual dimension to a shared collective one; this generates the most effective reward: social appraisal. We claim that this mechanism is the trigger for a *social norm*. When environmentally friendly behavior becomes a social norm it will be carried on without any need for controls, fines or law enforcement because "Effective policies are ones that induce both short-term changes in behavior and longer-term changes in social norm" (Kinzig, Ehrlich, Alston, Arrow, Barrett, Buchman…Sahari, 2013). Social norms are persistent and, once adopted, are followed even after the state intervention ceases. Making collaborative behaviors convenient may strengthen both personal and social norms, making all behaviors visible shows people what others are doing. ICT-based systems, as smart metering advanced functions, can be pivotal.

## An ABM approach in energy consumption mechanism

Simulation is considered by Axelrod (2007) as a third way of undertaking scientific research, after induction - i.e. the discovery of patterns in empirical data - and deduction – that involves specifying a set of axioms and proving consequences that can be derived from them. Axelrod (2007) remarks as "starting with a set of explicit assumptions, simulation does not prove theorems but instead generates data that can be analyzed inductively, as a way of conducting thought experiments". Some questions can however be answered with simulation experiments (Bianchi, Cirillo, Gallegati, & Vagliasindi, 2007). According to Marks (2007) "... a simulation might attempt to explain a phenomenon; it might attempt to predict the outcome of a phenomenon; or it might be used to explore a phenomenon, to play, in order to understand the interactions of elements of the structure that produces the phenomenon". There are important classes of problems for which writing down equations is not a useful activity. In such circumstances, resort to agent-based computational models may be the only way available to explore such processes systematically, and constitute a third distinct usage of such models (Axtell, 2000).

We present an *exploratory model* that might be used to play and explore different situations, in order to understand the interactions of elements of the structure that produces the phenomenon.

## SAM4SN

We focus on an urban district or a geographically limited area of a "North Global" country, i.e. the economically developed societies of Europe, North America, and Australia where the prevailing is known not to be sustainable in terms of energy consumption, carbon dioxide emission, and depletion of scarce resources. The SAM4SN allows defining a set of scenarios, to study the emergence of collective phenomena that are impossible to foresee at individual level. Of course, there will be scenarios that lead to overuse of the resource, and scenarios where this does not happen because the social mechanism has a positive effect, i.e. sustainable behavior emerges.

The model can be applied to given real situation supplying the geographical position of all agents and under the hypothesis that all agents have the availability of the same set of smart metering functions.

Consistently with the last statement, the network definition used here is that of the real neighborhood at the district level.

The goal is to observe at a macro-level how awareness can spread in the community, how the dynamics of awareness affects individual reduction goals, and how the availability of different smart metering functions impact on such mechanisms. "Green" people, i.e. people with high environmental awareness, can decide to limit the privacy of their own consumption information and share with the community their own consumption data. Such voluntary mechanism of "privacy versus reputation" is an emerging trend in some Global North communities, where becoming a green opinion leader is perceived as a social recognition.

The agents of SAM4SN represent (groups of) people involved in the consumption of a limited or critical resource. Each agent models a household. Agent can be or not be supplied by smart functions of metering.

The space of agents is bidimentional. SAM4SN agents interact by proximity and change their awareness according to the number and the type of their neighbors. The initial position of each agent is chosen randomly, under the only condition of "one household per patch". Once an agent's awareness reaches a threshold, the agent joins a different type (Fig 1). The awareness diffusion mechanism is a core point of our model. It is driven by the assumption that

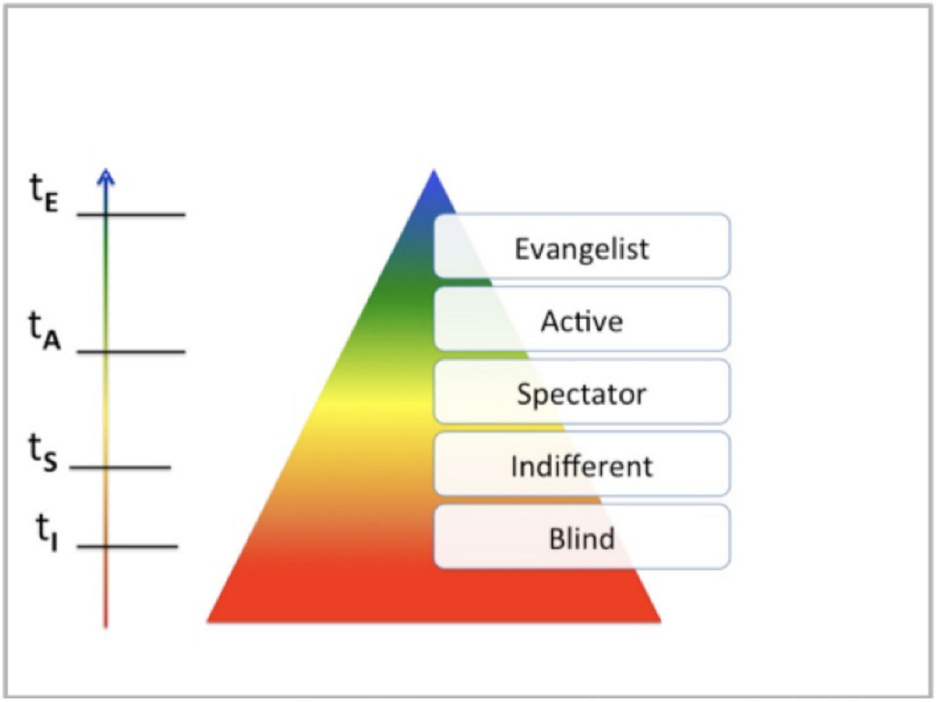


**Figure 1. Agent types and awareness thresholds**

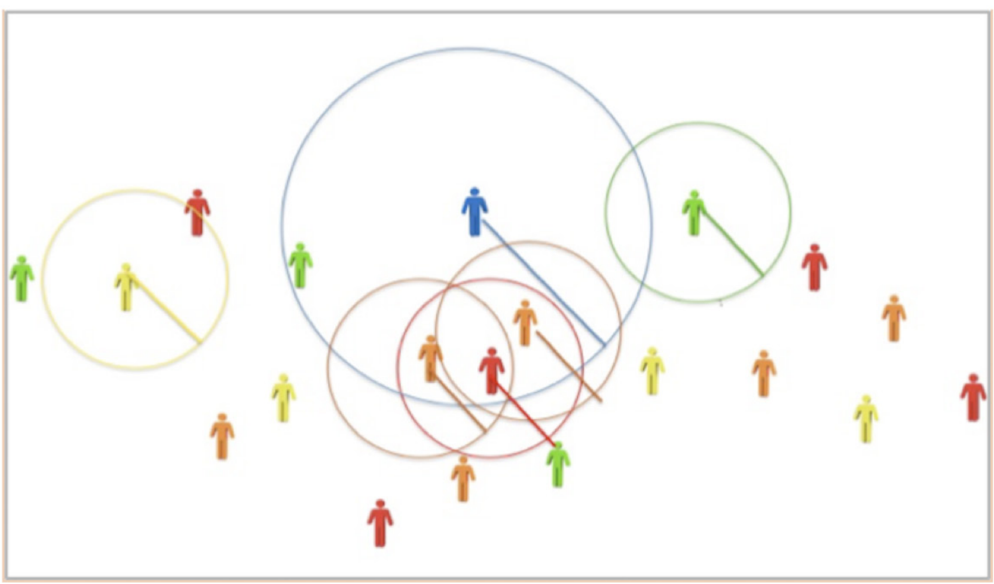

**Figure 2. Influence radius of agents**

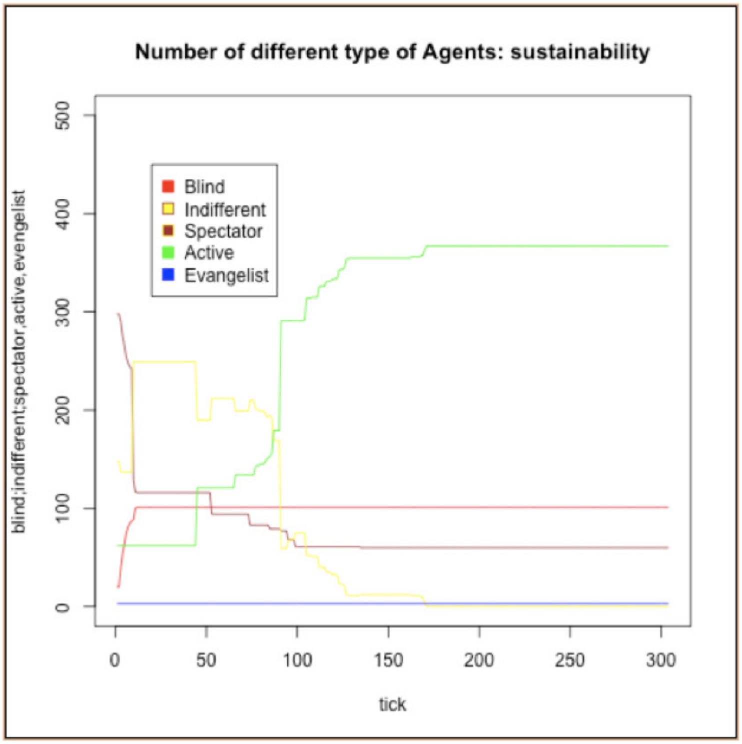


**Figure 3. Dynamics of agent types**

the most influential neighbors are those lying at the two extremes of the awareness scale: evangelist and active agents at the top and blind agents at the bottom (Fig. 2).

The awareness of the agents is updated at each process iteration (Fig. 3). A basic design principle of this mechanism is context-dependence: the influence of neighbors depends on their type. In addition, the rate of awareness change and thresholds are different for each type. Another important design principle is saturation: the "greener" the agents, the higher the threshold they have to reach for moving to a new type. A third principle is hysteresis: once agents become "green" (i.e. join the active or evangelist types), their awareness never decreases. Finally, transitivity of influence supports a kind of cascade effect, limited by the influence sphere of the agents.

Each agent has a *reduction goal* concerning the limited resource and progresses toward its goal at a given rate. At each run, the number of agents belonging to a type can change, while total number of agents is constant. Main global variables include the cardinality of each type of agents, the current resource consumption, and an overall reduction goal.

The model evolution stops when the global consumption reduction goal is achieved. With each iteration, agents look around to verify how many neighbors they have and what type. According to its neighborhood, each agent then changes its awareness level. The rules to update awareness are different for each agent type. This models general community-based social pressure. Blind agents can change their awareness only if they have completely green neighborhoods and even then, their awareness increases very slowly.

After the upgrade of awareness of each agent, if the agent's awareness rises beyond a given threshold the system updates the agent state, i.e. sets the membership of the agent to a new type.

Each type of agent has a different consumption and such consumption is updated according to an individual reduction goal. The overall consumption is evaluated based on the individual consumption and on resource production on the part of evangelists.

Each agent's own resource consumption depends on an overall reduction goal. For each agent type, the goal is computed as the difference between the previous tick resource consumption and the individual reduction goal that has to be reached with a given rate.

The only agent type able to produce resources (in addition to consuming them) is the evangelist. The overall resource production includes the sum of all resources produced by evangelists.

The individual reduction goal varies according to agent type. SAM4SN relates awareness change to the availability of specific functions of a smart metering system. The rationale is that availability of smart metering functions enables the agent to know its own consumption of the resource and to identify an individual reduction goal. For blind agents, it is independent from the availability of any facilitating conditions, because blind agents want to increase their consumption despite any evidence of the need to reduce it. When the function of comparison with neighbors is available, agents know the consumption of other agents and can set their own reduction goal based on the minimum consumption of other agents.

The reduction goal depends on the minimum known consumption and is given by the difference between the previous consumption of the agent and the reference consumption of another agent that has the minimal consumption. Such difference is multiplied by a green-competition index.
The minimal consumption of agents is computed as the consumption of the green agent whose consumption is minimal in the whole system. In a real situation, green agents accept to disclose their individual consumption in exchange for social reputation. The green-competition-index gives a weight of the aptitude of an agent to emulate the less consuming agents. The green competition index is small for low-aware agents and increases for high-aware agents until reaching the value of 1 for evangelists.

Agent's awareness is also modified by the mechanism of *social reinforcement*. Each run a comparison takes place between the individual agent's consumption trend and the global trend of resource use and when they are concordant, there is positive social reinforcement and such social reinforcement is added to the agent's awareness, increasing it. In other words, reinforcement relies on the comparison between the global trend of resource use and the individual trend of consumption.

Our model identifies both individual consumption trend types (i.e. reduction versus increment) and an overall consumption trend. It is important to remark that agents know the global trend of the resource consumption, but not the overall reduction goal nor the global resource use level. When their behavior trends are concordant with the general consumption trend, the agents can "reinforce" their beliefs and this social reinforcement, in turn, changes their awareness. Positive reinforcement happens when both individual both global consumption trends are of reductions; negative reinforcement happens when both individual both global consumption trends are of increasing.

The statistical robustness is quite implicit, due to the construction of the model, being the unique source of stochastic behavior is the space localization of the agents in laboratory use cases.

In configurations where the results are related to small changes in agents' attitude, the soundness has been verified repeating the simulation one hundred times. Two extreme cases are reported, where the system behaves in a completely different way, changing the aptitude of a unique agent among about three hundred. In the first of the two cases, we measured 0 different outcomes; for the other one we measured the 14% of different outcomes.

With large actual sample of agents with their real data and real geographical location, the outcome– after one year of simulated behavior– are pretty consistent with ex-post real data.

The notion of committed agent is implemented in SAM4SN, as well as the notion of quasi-committed agent.

In our model, evangelist agents are strictly committed agents, because they are very determined in their belief. Their awareness cannot decrease, so they cannot change their type. When an agent becomes evangelist, it will be forever.

Blind agents and active agents are "quasi committed" agents because their belonging to a type is very strong, if compared with other types of agent, like spectators and indifferent ones.

We introduced the notions of commitment and "quasi-commitment" as useful notions when linked to the concept of social reinforcement. Once a committed (evangelist) or quasi-committed agent (a blind or an active) is reinforced in his belief, this reinforcement is persistent and the agent remains reinforced as it was (positively or negatively) while not committed agents (spectators and indifferents) are responsive to positive or negative reinforcements.

We have to introduce the notion of *committed* and *quasi-committed agents*. In our model, committed agents coincide with evangelists, i.e. the most influential ones, while blind or active agents are "quasi-committed". The notions of "commitment" and "quasi-commitment" are linked to the concept of social reinforcement. Once a committed (evangelist) or quasi-committed (blind or active) agent is reinforced in its belief, this reinforcement becomes persistent and the agent remains forever reinforced, while non-committed agents (in our model, spectator and indifferent agents) remain responsive to positive or negative reinforcements. In our model, awareness is affected by social reinforcement, because the reinforcement value is added to the awareness level. When both global and individual trends are of reduction, and the first is higher than the second in absolute value is, awareness increases. When both global and individual trends are of increase, and the first is higher than the second in absolute value is, awareness decreases.

As soon as enough people with high social influence (Christakis & Fowler, 2009) adopt a social norm (Kinzig et al. 2013), a *tipping point* is reached (Gladwell, 2000; Levin, Barrett, Aniyar, Baumol, Bliss, Bolin,...Sheshinski, 1998). The idea of a tipping point for environmental sustainability is used by Kinzig and colleagues (2013) and derives from theoretical works (Xie, Sreenivasan, Korniss, Zhang, Lim, & Syzmanski, 2011) about the role that committed agents have in reaching consensus. In particular, Xie and colleagues (2011) have introduced the value of 10% of committed agents - as a critical value for opinion diffusion -.

The critical point in an evolving situation that leads to a new and irreversible development is called tipping point.

In our system the agents that are "consistent and inflexible" in their beliefs" are the active ones and the evangelists, i.e. the green agents, but also the blinds.

In SAM4SN this notion is specialized and the *sustainability tipping point* (STP) is defined as "a logical state variable that becomes true when the relative number of green agents with a negative variation of individual consumption is greater than the 10% of the total number of agents and the total number of green agents with a positive reinforcement is greater than the total number of unaware agents with a negative reinforce".

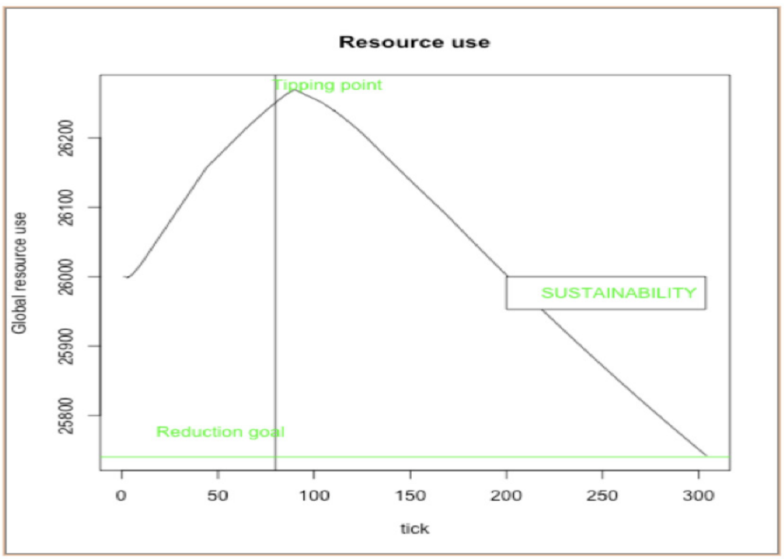


**Figure 4 – Sustainability Tipping Point**

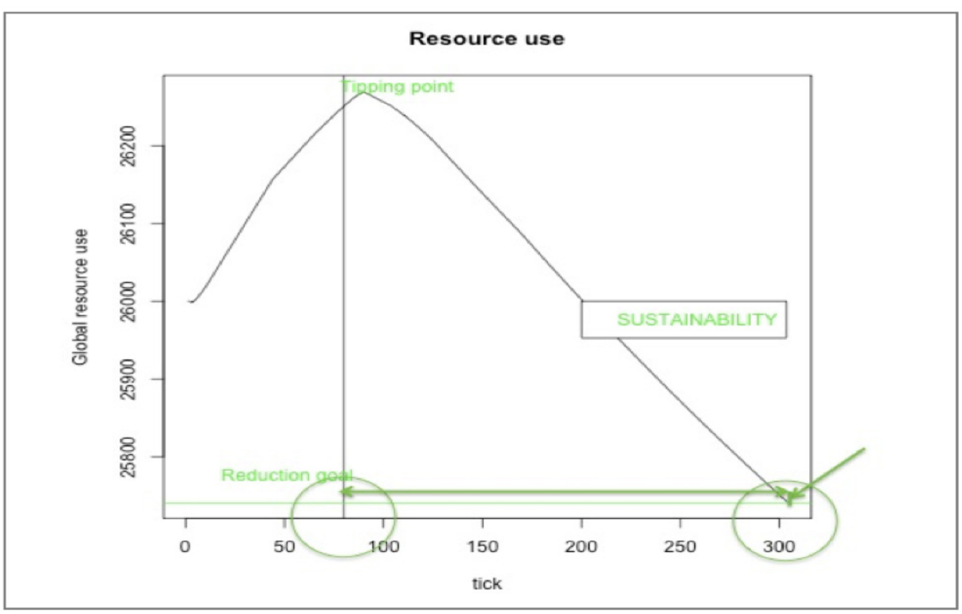


**Figure 5 - Sustainability Tipping Point and Reduction Roal**

Looking at situations evolving toward sustainability, we can observe, as the Sustainability Tipping Point (STP) is reached much earlier than the overall Reduction Goal (RG). In Fig. 5 for example we can observe as the RG is reached after 300 runs, while the STP is reached only after about 80 runs.

If we can consider the reaching of the RG as a long-term effect of a sustainability social norm, STP could be seen as an “early warning” signal, able to anticipate the reaching of sustainability. An interesting property of SAM4SN would rely on considering the STP as a sustainability real-time indicator.

Robustness of the model

The statistical robustness is quite implicit, due to the construction of the model, being the unique source of variability the space localization of the agents. In each case here the results are related to small changes in agents’ attitude, the soundness has been verified repeating the simulation one hundred times. Two extreme cases are reported, where the system behave in a completely different way changing the attitudes of a unique agent of about three hundreds. In the first of the two cases we measured 0 different results and for the other one 14% of different outcomes. With large actual sample of agents with their real data and geographical location, the outcome–after one year of simulated behavior–, are consistent with ex post real data.

**Sustainability Tipping Point as indicator**

An indicator is a measure that is used to demonstrate change in a situation, or the progress in, or results of, an activity, project, or program. STP could be considered as a qualitative monitoring indicator.

An indicator is a useful tool if it is reliable. To demonstrate if the STP is a reliable indicator we have to demonstrate four conditions.

- The STP becomes always true when the system leads to sustainability.
- The STP becomes true always before the reaching of the sustainable state.
- The STP stays always false when the resource consumption trend is unsustainable.
- The STP becomes true only once.

We performed three sets of experiments to demonstrate these conditions. Each set is composed by 81 experiments.

The configurations of each set of experiments depend on the initial number of different types of agent and on the configuration of the smart metering functions, that impact on consumption patterns: simple metering availability and neighbor comparison affect the individual reduction goal, while feedback and suggestion affect the rate to reach such a reduction. The availability of one or more smart metering functions facilitates the reaching of sustainability.

We performed such three sets of experiments using NetLogo BehaviorSpace utility. We set as “time limit” for the experiment that the simulation stops after 800 runs, if the reduction goal is not reached before. For more details, you can see Sissa (2014).

We observed the results of the three sets of experiments, in order to verify the four conditions required to consider the STP a reliable indicator.

We recorded the run when the STP becomes true and we call it STP.

If the STO becomes true and then false and again true, etc., it means that there are more STP, and it is against out theory that the STP is a reliable indicator of sustainability.

There are four possible situations.

I. The system reaches the reduction goal and the STP become true only once. In other words, there is sustainability and only one STP. The number of this kind of case is recorded in the second column.

II. The system never reaches the sustainability and the STP never becomes true. There is unsustainability and zero STP. The number of this kind of case is recorded in the third column of Table 1.

III. The system reaches sustainability and the STP becomes true several times. There is sustainability and more than one STP. The number of this kind of case is recorded in the fourth column of Table 1.

IV. The system never reaches the sustainability and the STO becomes true one or more times. There is unsustainability and one or more STP. The number of this kind of case is recorded in the fifth column.

When situations II or I happen (columns 2 and 3), the STP satisfies all the four conditions to be considered an indicator toward sustainability.

When the III or IV situations happen, the STP does not satisfy the four conditions to be considered an indicator toward sustainability. The III situation fails to satisfy Condition-4 (the STP becomes true only once). The IV situation fails to satisfy Condition-3 (STP stays always false when the resource consumption trend is unsustainable.).

We have to verify if (and to quantify how often) the STP fails to satisfy some of the four conditions required to be a reliable indicator.

Looking at the three sets of experiments as a whole, we can say that the STP behaves as a good indicator in 92.6% of the 243 experiments.

In 7.4% of the total 243 experiments, it leads to some errors: 0.8% of the results are fully wrong indications, while 6.6 % of the results are only partially wrong, because what it is wrong is the quantitative evaluation of the advance of STP toward RG, while the kind of foreseen trend is correct.

Looking at the single set of experiments, we observe that in the first set of experiments (SET-1) the STP was always able to anticipate the future state of the system. In the second set (SET-2), the behavior of STP failed in 20% of the experiments. While in the third case (SET-3), there are 2.5 % of errors.

Trying to conclude, we can say that the STP relative advance can be considered a quantitative indicator able to foresee in the all cases when the system will reach the reduction goal. On the total possible final scenarios, the STP error percentage is around 7% in average and in the worst case, it can reach the 20%.

The availability of such an indicator can have several useful applications in decision-making

To be a useful indicator the STP has to be able to supply some quantitative information about a future state of sustainability of the system. In our case, it corresponds to know “how early” the STP becomes true before the system reaches the sustainability (i.e. the reduction goal). This time interval is expressed in terms of run number of SAM4SN. We recorded the run when STP becomes true and, for the sake of simplicity, we call it STP.

We recorded the run when RG has been reached and we call it RG.

The difference between the RG and the STP represents the advance of the STP toward the reaching of the RG.

The *relative advance* of STP to RG is the ratio of the STP advance on RG. It gives a number between 0 and 1. We indicate it as STPRA (STP relative advance).

The Relative advance of STP on RG is an indicator, able to quantify how early the STP is on RG. We evaluated the STPRA values on a set of 81 experiments, to find if and how much this potential indicator is significant in its amount. For all experiments, we recorded the data described in table 2.

We observed as in all 81 experiments the system reached the sustainability (i.e. the system stopped before the time limit of 800, so the RG is smaller than 800).

STP can be considered as a new qualitative monitoring indicator of reduction goal reaching. We have seen that its behavior as indicator is reliable in most cases, with an average error percentage of 7 %.

We derived the STP Relative Advance (STPRA) toward the overall reduction goal and we found that such advance is significant, because its value is around the 60% in average.

Because the sustainability tipping point and the overall reduction goal are independent, this result is not trivial.

| Experiments | Situations | | | |
|---|---|---|---|---|
| | I (Sust, 1 STP) | II(Unsust,0 STP) | III(Sust, STP>1) | IV (Unsust, N.STP> 0) |
| SET-1 | 81 | 0 | 0 | 0 |
| SET-2 | 65 | 0 | 16 | 0 |
| SET-3 | 0 | 79 | 0 | 2 |

**Table 1- Results of 243 (3 sets of 81) experiments on Sustainability Tipping Point**

| CASE-NUMBER | STP (run number when STP become true) | Reduction Goal (run number when RG is reached) | STP Advance on RG | STP Relative Advance (STPRA) | Number of STPs |
|---|---|---|---|---|---|

**Table 2 – Data of experiments**

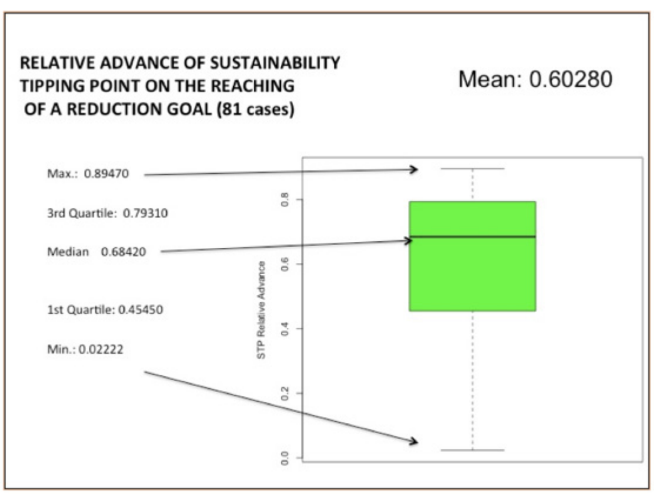


**Fig. 6 Amount of the STP Relative Advance**

*SAM4SN in decision-making*

From this consideration, we can estimate the potential interest of such an indicator. Considering the STP an indicator of an emergent social norm toward sustainability could help in estimating “if and how long after” a given target will be reached.

STP and STPRA can help decision makers to establish which initial configuration of different types of agent leads to sustainability and the required number of committed agents to enable a social norm. To consider the initial commitment of agents as a constraint to reach an overall objective is an approach for several kind of campaigns or initiative based on social norm effects.

A decision maker can pivot on that idea, for example, with pilot programs to support group of people to become more proactive and committed on a given cause. On the opposite, he can evaluate that a strong initial commitment against such cause will counter any effort toward it.

In policy-making, it can be useful to distribute effort and resources in environmental sustainability programs, while for a utility company the STP can be valuable to predict trends of decrease in resource consumption.

SAM4SN has been developed to study the sustainability issues in terms of need to reduce the consumption of a limited resource. Sustainability is reached when a given overall goal of reduction is reached and we applied SAM4SN to the broad and popular area of household energy consumptions.

A further immediate opportunity is to apply SAM4S again in the context of household energy consumption, but in real environmental ICT-based policy programs from the beginning, allowing building a real dataset to initialize the model. In such kind of policy-based programs, the STP can be a useful tool for policy makers to understand, for example, the areas of a political intervention where to allocate more resources or fewer resources. The sustainability tipping point can give decision makers a support to understand if a sustainability social norm is emerging in a given area.

Continuing to stay in a household consumption field, SAM4SN is a suitable ABM to study other limited resource, as for example water consumption in domestic field. For utilities companies SAM4SN could be a tool to explore how and when to invest on smart metering functions development.

SAM4SN is a tool to explore and better understand the classes of phenomenon related to sustainability issues in terms of reduction of consumption of a limited resource in a broad sense. The basic elements that are mandatory to apply the SAM4SN approach in sustainability issues in any contexts are:

- The limited resource to be reduced;
- The reference institution where the resource is used and where specific awareness can spread;
- The limiting factor on which to play

SAM4SN can be used as a virtual laboratory where to perform experiments on such mechanisms and concepts. Acknowledging consumers as truly actives entails that they can take part in the construction of the solution. A direct recommendation is then to allow consumers to have unrestricted access to their own consumption data. A further recommendation is to allow them, on a voluntary basis, to relax some privacy-based constraints toward a dimension of social reputation. More generally, a trend toward environmental sustainability entails that consumers should always have access to their own data, to make effective the notion of appropriation. We can refer to consumers as well as to users or citizens. In all cases, the main idea of our research is that the environmental awareness is an individual feature affecting the whole sustainability mechanism.

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# Complex System Behavior In Democratic Policy Theory

Michael Givel[A]

**The theoretical underpinning of modern U.S. policy theories commenced with Harold Lasswell's policy cycles theory in the 1950s. This analysis indicates while modern theories have become very nuanced, their primary orientation is a more sophisticated continuation of the policy cycle theories of Lasswell. This paper consolidates modern US theories into a comparative policy theory based on complexity and democratic policymaking. These represent two significant gaps in the conglomerated model of US policy theories. The paper concludes with an updated policy model incorporating complexity interactions and democratization to nudge policy theory forward.**

**Keywords: public policy, complexity, Lasswell, US policy theories**

## Introduction

Many scholars of US public policy studies view political scientist Harold Lasswell and his policy sciences delineation in the early 1950s as the starting point for modern US public policy theories (DeLeon & Martell, 2006; Lasswell, 1951a). The original policy science, which was multidisciplinary, utilized a variety of interdisciplinary methodological approaches, and was focused on applied government problem solving ( Birkland, 2011; DeLeon & Martell, 2006; Lasswell, 1948; Lasswell & Kaplan, 1971; Theodoulou, 2013). Government decision making according to the policy sciences theory included the following unilateral and linear staged policy cycle approach: intelligence, promotion, prescription, invocation, application, termination, and appraisal that lead back to intelligence (Lasswell, 1956).

An updated and another linear version of Lasswell's policy cycle approach emerged in the 1970s to the 1980s (DeLeon & Martell, 2006; Weible, 2014). This updated conception of the policy sciences policy cycle model included the following unilateral steps: a problem or issue reaching the public agenda, policy formulation, policy enactment, policy implementation, and feedback through policy evaluations ( Anderson, 1975; Jones, 1970; Lasswell, 1956; Lasswell & Kaplan, 1971; Weible, 2014). The stages heuristic theory remained dominant as a descriptive model as Jenkins-Smith and Sabatier argued until the 1980s.

Critics have also argued these modern policy theories continue to be based primarily on a linear model of policy making that is mechanistic and clock-like

[A] University of Oklahoma

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in orientation (Givel, 2015). This, in turn, does not reflect how complex human and policy interactions emerge and are adopted. Another criticism is that modern policy theories, due to nature of their attempts to be empiricist and technocratic, have become not only linear, but also hyper-specialized in areas such as housing or energy policy. They also no longer focus on democratic governance and ideals as advocated by Harold Lasswell (deLeon, 1997; Fischer, 2003; Hodgson & Irving, 2007).

A key issue in the modern age has been the impact and influence of powerful interest groups, elites, and social classes in influencing complex public policy decision making[1] related to bolstering corporate markets and profits. This happened while undermining the democratic influence by others who are perceived to have an agenda contrary to business interests (Jorgensen, 2011; Gilens & Page, 2014; Page et al., 2013; Ferguson et al., 2015). Additionally, given the fragmented and insular silo nature of current US public policy theories, we are at even a further disadvantage to now describe and predict with an overarching and definitive policy theory how this universal question of how economic wealth and political power is exercised in complex policy systems.

The U.S. policies utilized in this paper are from the authoritative book, Theories of the Policy Process, Third Edition published in 2014 and from Policy Studies Journal's August 2013 edition and compendium of articles labeled: "New Theories of the Policy Process" (Cairney & Heikkila, 2014). In this paper, I assess and analyze whether or how a consolidated policy model might be able to account for democratic policy based in complex system behavior.

## Literature Review

Preeminent political scientist, Harold D. Lasswell's theory of democracy first began in the late 1920s into the 1930s with several publications related to the role of propaganda in governing a democratic society (Lasswell, 1927a; Lasswell, 1927b; Lasswell, 1934a; Lasswell, 1935; Lasswell, 1939; Lasswell, 1950). The purpose of propaganda in governance in a democratic society is to increase and control mass emotional feelings toward positive governance and public policy outcomes (Lasswell, 1935). For example, in a military conflict a propagandist uses targeted appeals to the mass population to depict an enemy combatant as foreboding and treacherous. This is accomplished by employing public relations and advertising symbols designed to arouse the emotions of a mass public (Lasswell, 1934b).

The emergence of Lasswell's policy sciences of democracy in the 1950s was grounded in part in his earlier consulting work and analyses related to propaganda during WW I with the Office of War Information, Office of Strategic Services, Foreign Broadcast Information Service, Psychological Warfare Division, Office

[1] One prominent example of the insular and silo nature of modern US policy theory is embodied in the robust defense of punctuated equilibrium theory by Prindle (2012) in which he asserted that punctuation in national tobacco policy making occurred and was much longer than the 1980s to the present time period Givel indicated was the case in four separate scholarly publications for U.S. state tobacco policy making that did not include federal tobacco policy making. Moreover, in the review of mobilization by Givel (2006b) in U.S. states tobacco policy-making policy was based on careful scholarly historical analyses of historical trends for state tobacco policymaking that did not occur from 1964 to the 1980s.

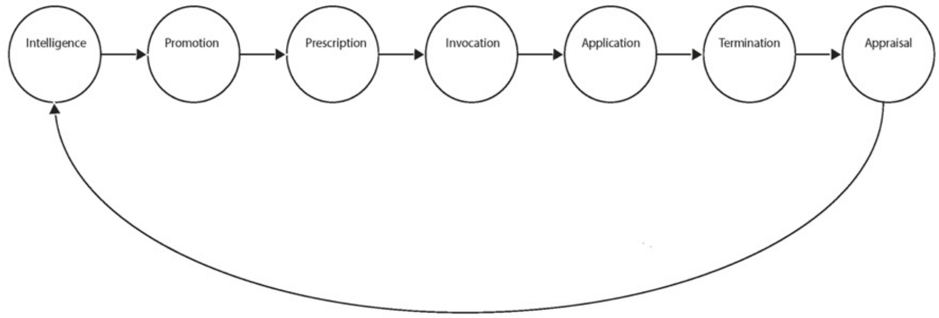



Figure 1.

Harold Lasswell's Policy Cycle Model

of Facts and Figures, and Psychological Warfare Division of the US Army (Farr et al., 2006). Like the elite promoter of democratic propaganda, the policy scientist for democracy of Harold Lasswell emerged as an elite promoter and defender of democracy in the name of human dignity (Farr et al., 2006). Critics of this argued that elite decision makers on behalf of democracy was contradictory as how can one be a proponent of technical policy expertise on behalf of democracy and yet not recognize the will of the majority may be a better or more appropriate arbitrator of policy decisions (Farr et al., 2006; Gewirth, 1949).

Embodied in Lasswell's democracy shaped by the elites was a non-complexity, linear, mechanistic, and unidirectional seven phase cyclical decision making process (Figure 1) (Lasswell, 1963). The intelligence phase consisted of information that was considered by public decision makers. The promoting phase included the use of propaganda and argument to shape the final policy outcome. The prescribing phase is where the policy is formulated and enacted as a law or constitutional provision. The invoking phase consists of violation and prosecutions for violating the law. The application phase includes the continuing and routine operations of public agencies in implementing the law. The appraisal phase is evaluations of how adequately the law has been upheld. The terminating phase is when public policies meet their original goals and become institutionalized in society (Lasswell, 1963). This policy cycle then can and often does repeat itself as new problems or politics related to a policy area like education policy arises.

## Second Wave in US Policy Making

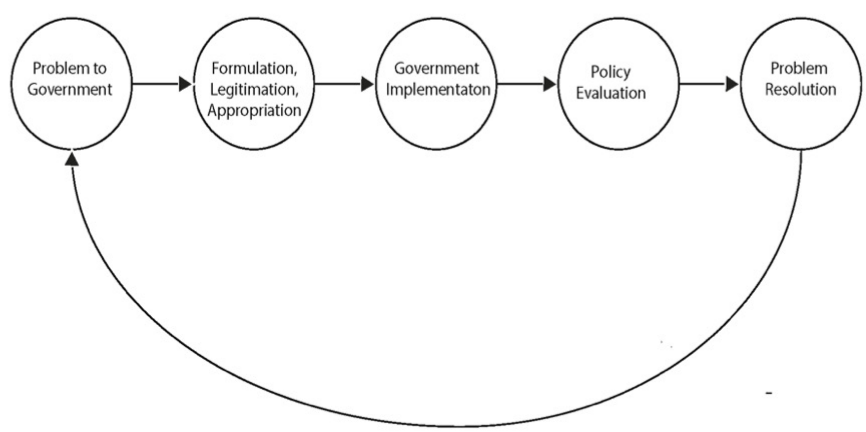
By the 1970s, several policy scholars adopted and refined Lasswell's linear and unidirectional policy cycle model (Anderson, 1975; Deleon, 1999; Jones, 1970; Jones, 1977; May & Wildavsky, 1978). The updated linear policy cycle (Figure 2) includes problems being recognized and understood, government formulation, and enactment, implementation of a policy by public agencies, policy evaluations, and problem resolution or change (Anderson, 1975; Deleon, 1999; Jones, 1977; May and Wildavsky, 1978). In the problem identification phase, policy issues are defined and perceived. In addition to legislation formulation and enactment, there is appropriation of funds for public programs. Public agency implementation can take a variety of forms such as law enforcement or development of rules that interpret a statute to implement a public program. Policy evaluation includes measurements of program performance in meeting the public policy goals of a program. Finally, similar to Lasswell's terminating phase, the final phase is the program meeting policy goals or creating policy change (Anderson, 1975; Deleon, 1999; Jones, 1970; Jones, 1977; May & Wildavsky, 1978).

While Lasswell's policy science for democracy focuses on the function and decision making process of elite policy analysts shaping policy toward democracy and dignity, the second wave of US policy theory downplayed this in lieu of a liberal interest group model of policy making and politics. In Lasswell's model, elite policy analysts promoting democracy, sometimes through propaganda, shaped democracy. The Second Wave model was based on specialized participation by public agencies, executive branch, legislative branch and particularly interest groups (Anderson, 1975; Jones, 1977).

In this model of interest group, pluralism groups compete regarding various public policies. Those groups with greater political access to public decision makers and have the organizational resources such as funding to employ lobbyists, scientific experts, and so on tend to be those that have a considerable bias in meeting their policy agendas in the policy process. E. E. Schattschneider (1960) referred to this policy advantage as a mobilization of bias. More specifically, the mobilization of bias, according to Schattschneider include a hegemony of policy values and institutional processes that benefit certain groups at the expense of other groups in the policy process (Schattschneider, 1960).

With that, the policy sciences for democracy linear policy cycle model of Lasswell shifted and changed. No longer was it an elite group of political scientists and policy analysts shaping democracy for the dignity of humans. The Second Wave was grounded in liberal interest group pluralism as the driving explanation of how power and influence occurs in the US policymaking process. A basic premise of interest group liberalism is that interest groups provide robust competition and policy compromise on the policy system and are a crucial link between government and the people the groups' represent. That is not to say that elements of Lasswell's policy elite driving public policy completely

Figure 2. States Heuristic Policy Cycle Model



disappeared. Instead of being involved in the political process in its entirety, the Second Wave emphasized policy analyzes and measurements in the program evaluation stage.

A second focus of the Second Wave related to the downplaying of democracy was an emphasis on linear and unilateral policy process in stages embodied in applied economics and policy impact assessment. The impetus for policy analysis and applied economics commenced in the Planning, Programming, and Budgeting System created in the US Department of Defense (Bardach, 2000; Bellinger, 2016). Primary goals of policy analysis was to bring a market-oriented economy and efficiency or the greatest wellbeing to society with the least amount of expenditures and costs (Bardach, 2000; Bellinger, 2016).

By the 1990s, critics of the Second Wave argued that the model lacked testable hypotheses. They claimed that it was biased toward an elite and insider model of how policy making occurs, did not incorporate intergovernmental levels, did not accurately describe how policy worked and occurred, and removed Lasswell's original call for policy analysis related to democracy in the entire policy making process, not just the program evaluation phase (Sabatier & Jenkins-Smith, 1993). Others such as Lowi had previously argued that interest group liberalism was a philosophy and condition in US policy making that undermined democracy due to the expansion of the administrative state since the New Deal (Lowi, 1979). This allowed the emergence of interest-group liberalism, which in turn reduced popular control as an elite constellation of interest groups, which increased their political influence over legislation and public agency activities (Lowi, 1979). This shifting of power has meant that the US government is ruled by interest groups and not always to the benefit of average citizens (Lowi, 1979). Other scholars have also indicated that there has been a dramatic increase in interest groups in recent years that primarily represent and are advancing the interests of the wealthy over those of less wealthy Americans (Ferguson et al., 2015; Fukuyama, 2011; Gilens and Page, 2014; Jorgensen, 2011). This has resulted in a linear policy system that is not substantially beholden to democratic accountability of individuals and citizens, but rather powerful interest groups.

## Third Wave of US Policy Theories and Democratic Theory

The extensive criticism of the policy cycle model by Sabatier and Jenkins-Smith and others (Sabatier and Jenkins-Smith referred to the policy cycle model as the stages heuristic model) in the 1990s resulted in a dramatic shift in U.S. public policy theory with significant fragmentation and balkanization as of 2016 into numerous other theories vying to become the predominant theory explaining U.S. policy making. As of 2015, this included: Multiple Stream Theory (MST), Punctuated Equilibrium Theory (PET), Social Construction Theory (SCT), Policy Feedback Theory (PFT), Advocacy Coalition Framework (ACF), Narrative Policy Framework (NPF), Institutional Analysis and Development Framework (IAD), Social-Ecological Systems (SES), and Policy Diffusion (PD) (Sabatier & Weible, 2014).

### *Analysis of Current US Public Policy Theories*

In order to consolidate the myriad of fragmented and balkanized US public policy theories, I utilize a conglomerated flow diagram of the interactions of institutions, networks, contexts, and events as depicted in all of the current U.S. policy theories. This is accomplished by using a political path analysis approach focused on key political decision making factors as described in peer reviewed figures of the most promising theories of the US policy process. Key political decision-making factors in this path analysis are those primary political institutions like a legislature and overarching and primary factors like socio-economic influences driving policy. Most theories have flow diagrams depicting the theory and this will be used. If a theory does not have a flow diagram, then the major themes of interactions will be used. This analysis does not cover methods of studying US policy theories that accompany these theories including rational choice, historical, sociological, and social constructivist but instead focuses on linkages between interactions in these theories. In this paper, I am not seeking to explain all that the current US policy theories explain. However, I am combining them through path analysis to shed light on questions typically ignored by the theories individually. From this conglomerate path analysis, I will then analyze overarching theoretical themes and elements of these consolidated US policy theories.

*Conglomerated Model of U.S. Public Policy Theories*

As indicated in Figure 3, the conglomerated model of U.S. policy making is a much more nuanced version of the previous linear policy cycle models. Within this model are key policy issues, problems, or politics that capture the attention of public decision makers who occupy overlapping political institutions comprising judicial, executive, and legislative governmental structures and functions. This includes intergovernmental relations between a central national government and governmental sub-units like states, provinces, districts, local governments, and so on. The primary focus of political decision-making is based on insider politics and advocacy in the halls-of-power by interest groups who compete and compromise to make policy in a pluralistic manner. The result of this cooperation and competition in the political system results in government agencies implementing policy outputs or government actions by political institutions and between government institutions in the form of policy diffusion and institutional collective action (Berry & Berry, 2014; Felock, 2013). From the policy outputs come policy outcomes or impacts of the policy that are then converted into policy feedback. Policy feedback may occur with input into policy issues or with input for political institutions.

An added feature of the conglomerate model of U.S. policy making is that it has been become highly balkanized since the 1990s (Heikkila & Gerlak, 2013). Individual areas of the policy model have been focused on by groups of U.S. policy scholars (Heikkila & Gerlak, 2013). for analysis and pronouncement of the necessity of a particular theory to describe the policy process. Contributing to this balkanization is that certain groups of policy scholars who support a particular theory have alternative methodologies comprising rational choice, historical, sociological, and social constructionist that provide differing approaches to explain the modern policy cycle theory.

Also, at the core of this conglomerated model is an insider-oriented system of interest groups that vie in the policy system for political advancement (Heikkila & Gerlak, 2013). The basis of this policy system is a policy process that is implicitly and explicitly assumed to have some form of democratic structure and decision processes. But, what this does not address is how democratized or not is a given policy system like the U.S. policy system and others. The next section addresses this issue.

*Gaps in Conglomerated U.S. Policy Theory Model*

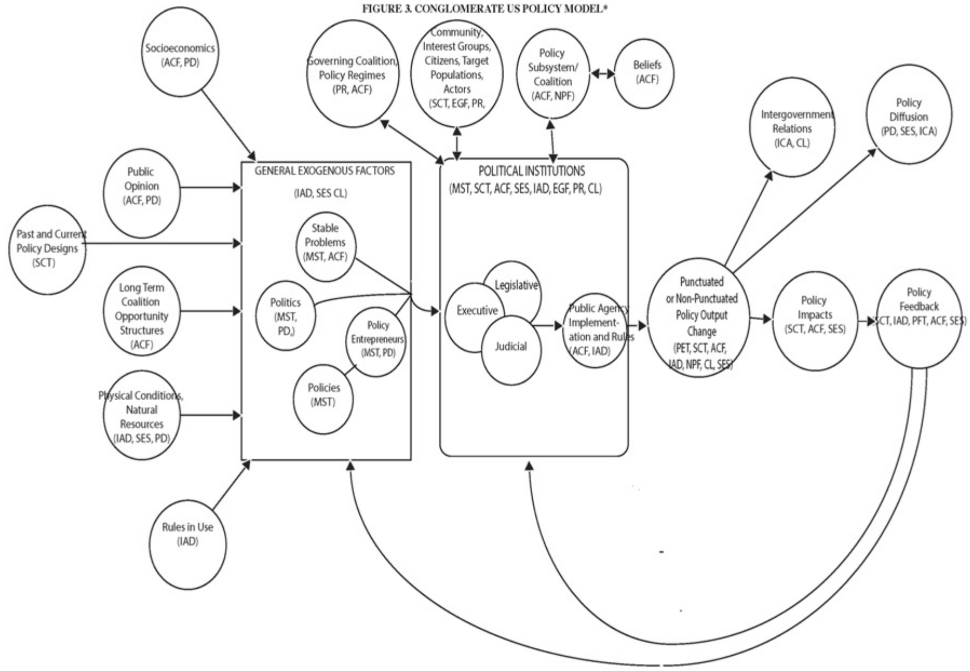
Significant areas of the conglomerated model of U.S. policy making that are not focused upon incorporate a theory of democracy in policy making including the role of political and economic inequality, the capacity of a state to steer toward more democratic outcomes, as well as complex system behavior in policy making processes.

*Democratic Policy*

Currently, markers that describe types of policy outputs in the conglomerate U.S. policy model has been described in the U.S. policy theories that emphasize policy feedback and evaluation particularly as described by policy feedback theory and social construction theory (Heikkila & Gerlak, 2013; Mettler & Sorelle, 2014; Schneider et al., 2014). For Mettler and Sorelle, public policy outputs result in the meaning of citizenship, form and patterns of governance, and group power and advocacy including political agendas (Heikkila & Gerlak, 2013; Mettler & Sorelle, 2014). In particular, citizenship means the rights and obligations of citizens including involvement in the political process allowed by a government system on its citizens.

The system of influence is one of group activity in the policy making process based on particular policy agendas of the groups (Mettler & Sorelle, 2014). For social construction theory, the end result of a policy output or outcome is different types of policy designs for various public policies (Schneider et al., 2014). Each of these theories are oriented toward the process of how policy is made and all of the

FIGURE 3. CONGLOMERATE US POLICY MODEL*




* ACF= Advocacy Coalition Framework; IAD= Institutional analysis and development framework; SES= Social Ecological Systems; PR= Policy Regimes; CL=Collective Learning; MST= Multiple Streams Theory; SCT= Social Construction Theory; PFT=Policy Feedback Theory; ICA= Institutional Collective Action; and PD= Policy Diffusion

theories argue that groups are at the center of how politics and policy change is made and happens (Cairney & Heikkila, 2014). None of the individual theories, however, comprising the modern conglomerated policy cycle model of U.S. policy theories addresses the issue of how democratic is the policy system (Cairney & Heikkila, 2014).

Democracy as a policy output and outcome requires a definition. In scholarly studies, democracy has had four prominent groupings of definitions including: constitutional, substantive, procedural, and process (Tilly, 2007). According to Tilly (2007), constitutional and legalistic definitions of democracy focus on the written and unwritten constitutional provisions, laws, agency rules, executive function orders, and court decisions constitute the foundations of democratic societies. Substantive definitions of democracy focus on how a society and government implements through the political process substantive public policies like peaceful conflict resolution that promote democracy (Tilly, 2007). On the other hand, proponents of procedural definitions of democracy focus on governmental practices and procedures such as promoting multi-party elections and fair elections (Freedom House, 2015). In contrast, process oriented democratic theories focus on a set of processes that must ideally continue to occur for a society to remain democratic (Dahl, 1998). These pluralistic requirements include universal suffrage, equal access to the political process, and public policy that is always open to change (Dahl, 1998).

While all of these definitional groupings provide elements of what democracy and democratization might look like, together they present a more nuanced view of democracy. From a public policy theoretical perspective, what ultimately is important is what government does or does not do in terms of promoting policy outputs and outcomes that represent greater democracy or not. Based on this public policy definition, these groupings can be categorized and viewed as being formal, informal, or action-oriented. Contained within formal elements of democracy are constitutional and legalistic definitions of democracy.

Informal elements of democracy are the manner and the way that political institutions including executive, legislative, judicial, and public agencies interpret how to implement formal legalistic provisions. This includes the appropriation of funds in implementing democratic policies. For instance, while the 14th Amendment to the US Constitution calls for equal protection under the law, has this provision been historically applied to some groups and not others such as gay and lesbian people? Incorporated within informal elements of democracy are constitutional and legalistic, substantive, procedural definitions. Finally actions represent non-written and informal practices that are implement or not formal or informal provisions of democracy that are ultimately policy outputs and outcomes. For instance, even if there are constitutional provisions that provide for peaceful resolutions of conflict do a given nation's military engage in military coup d'états? In this scenario, the lack of peaceful resolution of conflict is a move away from democracy.

*Features of Less Than Democratic Policy*

So, what features of a policy system are moving away from or are not democratic? Signs of a policy system that are less than democratic include formal and informal requirements and non-written actions in a given regime that result in a small segment of citizens provided civil and political rights, extreme inequality between economic groups, gender, race, ethnicity, religion, national origin, age, sexual identity and preference, and so on (Tilly, 2007). Another symptom of weak or no democracy is little or no state protections in practice and action against arbitrary and capricious state actions such as being jailed with no description of the charges (Tilly, 2007). Facilitating policy outputs and outcomes that could favor greater procedural democratic elements include competitive and fair multiparty elections with universal suffrage (Levitsky & Way, 2013). Other elements include little or no violation of civil liberties such as free speech, press, or the right to association or state institutions that limit an opposition party or candidate to compete fairly in elections (Levitsky & Way, 2013).

*Inequality and Democracy*

With respect to social and economic inequality in a policy system, characteristics of less democracy are governments whose policies favor powerful interests and the wealthy class of citizens with respect to economic issues related to manufacture, production, and distribution of goods and services that enrich and further enrich the wealthy. In the U.S., for instance, reflecting a trend of less democracy, income and wealth inequality has risen sharply with upper income households in 2014 receiving 49% of aggregate income up from 29% in 1970 (PewResearchCenter, 2015; Geewax, 2015). State policies, in essence, protect economic privilege through political means including formal and informal requirements and informal non-written actions. According to Tilly (2007), other features of how the rich and powerful in a less than optimal democratic fashioned are bolstered include state actions that opt out of democratic options, beneficial relations with the state that support unequal relations between classes, elites, and groups, and actions by the state that enhance economic largess for the wealthy at the expense of other groups.

Social forces that counter inequality include social movements and revolutionary movements (Tilly, 2007). These outside the halls-of-power advocacy movements ordinarily pressure insider political institutions to enact policy that create significant reform or in the case of political revolutionary movements to radically change and overhaul societal political institutions and public policies (Tilly, 2007). Social movements by their very definition are broad based mass and grassroots movements that seek significant reform of a political system such as the enactment of federal civil rights laws in the U.S. (Tilly, 2007). These movements may be on the political left, center, or right. Recently, contention theorists have argued that social movements are the result of specific periods of contradictory policy demands in which government is central to resolve the conflict (Buechler, 2011; McAdam et al., 2001). This approach is state-centered and has been criticized for ignoring or downplaying non-state oriented forms of social movement action such as protests that focus on changing public opinion or other non-state institutions and actions (Dyke et al., 2004; Buechler, 2011). Other criticisms of contention politics is that it centers on state resolution of conflicts when social movement research has focused on others such as social movement organizational development, non-state networks of organizing, and ideological considerations such as forms of feminism or economic and social class (Buechler, 2011). As a result, some social movement scholars have called for a multi-faceted approach to study social movements based on all these above factors including organizing in cyberspace (Buechler, 2011; Castells, 2012). Ultimately, what social movements seek is much greater access and control of political decision-making and governmental power. By contrast, political revolutionary movements seek a radical overhaul either through violent or non-violent means of an entire political and economic regime. One example of this was the Cuban revolution of 1959 that brought Fidel Castro to power and transformed Cuba into a Marxist-Leninist state.

*State Capacity*

State capacity in the context of democratic policy is the ability of governmental institutions to formulate, enact, implement, and steer public policies that enhance or not formal, informal, and action-oriented policies related to democratic procedure, process, legal, requirements, and substantive policies. This provides policy outputs and outcomes that are more or less democratic. Within the context of steering public policies toward democratic or not policy outputs and outcomes, public policymaking is often characterized by contrasting, nuanced and complex systemic factors.

In summary, key factors not covered currently by the conglomerated US policy model relate to democracy, including inequality and state capacity to steer a democratic course, as well as complex policy systems behaviour, means the current conglomerated U.S. policy model is incomplete. The next section will update the conglomerated US policy model to incorporate democratization and complex system behaviour resulting in a comparative policy model.

*Overview of Complex Policymaking*

Complexity theory provides a basis and overarching foundation to explain how democratic public policies are formulated and implemented including due to social movements or revolutionary movements. In relation to complexity theory, third wave theories such as multiple streams, advocacy coalition framework, and policy diffusion theories all describe or predict features of complex system behavior (Givel, 2015). On the other hand, other third wave theories such as punctuated equilibrium theory and institutional rational choice are primarily linear in orientation (Givel, 2015).

*Nature of Policymaking*

The general nature of complex public policymaking linked to varying democratic policy outputs and outcomes are predicated on self-organization by governmental policy institutions including executive, judicial, and legislative functions. Once policies are formulated and then enacted policies are often implemented by public agencies. Additionally, public policymaking occurs through complex and dynamic interactions of organized policy system parts. For example, in health policy it is normal to evaluate smaller policy parts such as health care access or affordability.

Policy processes and system self-organization also creates positive and negative feedback loops. When societal policies become less than optimal for a particular group, class, individuals or elites then a positive feedback loop can occur due to an effort to change the policy in a direction that is beneficial to a particular party. A negative feedback loop can occur because of one or more policy institutions or classes, elites, groups, or individuals are blocking policy change.

*Context of Policy Process*

Unlike what is postulated in linear and mechanical policy models that policymaking occurs through a one directional and governmental process occurring in stages, democratic public policy occurs through many complex and interrelated factors. Included in this are interactions between the physical universe, biological systems on earth, and policymaking.

*Initial Conditions and Nesting*

Emergent democratic public policy output and outcome trends stem from unique and complex initial conditions when a particular policy event occurs. Because each policy is emergent and unique, the probabilities are large that no two policies originate from the same original conditions. Increasing complexity in the policy making process happens when policies are based on actions like natural processes on earth where government policymaking usually does not take place. Initial conditions are not only horizontal across a policymaking system, but can be nested and vertical. (2015)

*Key Strange Attractors*

Even though democratic policy outputs and outcomes are not usually predictable over a long period of time due to their emergent nature based on complex interactions and implementation, there are universal characteristics in policymaking equivalent to fixed points or in chaos theory--strange attractors (Williams, 2003). One prominent key attractor or fixed point in any political system is whether policy outputs and outcomes result in more or less democracy predicated on "…human welfare, individual freedom, security, equity, social equality, public deliberation, and peaceful conflict resolution (Baumgartner & Jones, 2009; Givel, 2010; Tilly, 2007).

*Policy Change*

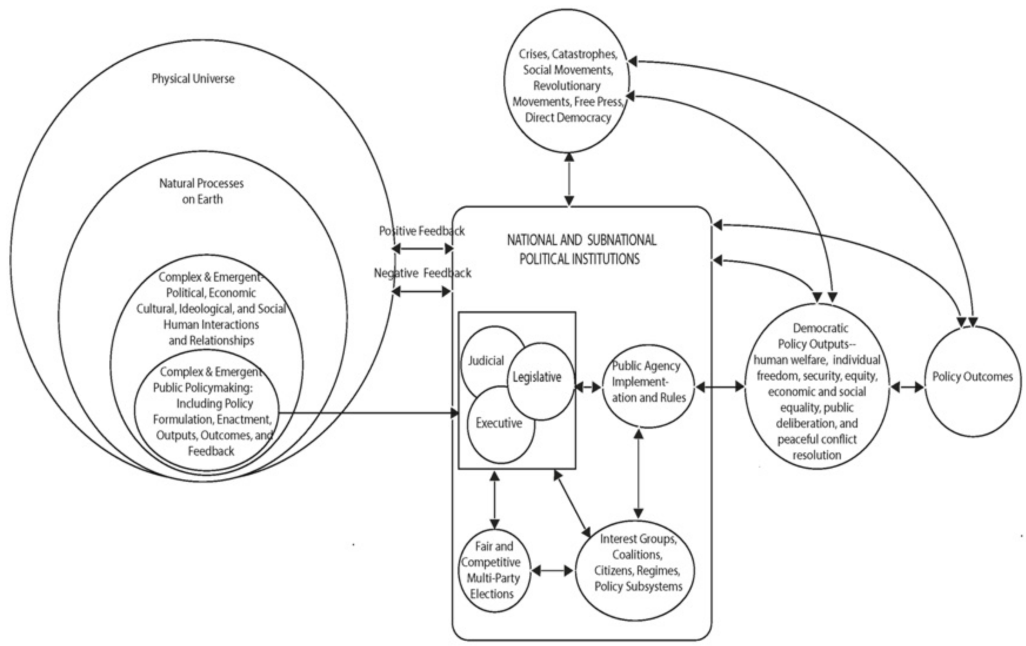
Ordinarily, complex democratic policy change or not happens within a stable political system. Regardless, policy crises or catastrophes may also radically alter a stable political system through a significant event such as a Great Depression or political revolution. Such crises can create a transitional period of time where unstable policy behavior occurs. For example, from September 5, 1793 to July 28, 1794 during the transitional "Reign of Terror" after the French Revolution, substantial policy instability occurred.

**The Road Forward: Democratic and Complexity Policy Theory**

Figure 4, provides an update to the current conglomerated U.S. policy theories that are predicated on pluralist theory and interest group interactions and assumes this is democratic in scope. The updated conglomerate model provides a comparative basis to describe and predict how democratic a given society's public policies might be based on complex system behavior. Policy decisions and causes can be bilateral or unilateral. For instance, a natural catastrophe can be the unilateral cause of emergency responses and public policy making. On the other hand, a policy that is implemented by a public agency may be returned to a legislative body due to a bilateral flow of decision-making, regulation, and political concerns. Incorporated into this model is how complex system behavior influences democratic policy-making.

Additionally, in line with the recent call for a multi-faceted approach in social movement theory building social movements are considered exogenous to insider political institutions, but also linked to political institutions. Ultimately, the aim of all

Figure 4. Democratic Policy Model




social movements or political revolutionary movements is to change government policies as well as in some cases political institutions. Thus, outsider social movements in all forms whether state centered or not or both is also tied to political institutions significantly enacting and implementing significantly different public policies. Figure 4 provides for this multifaceted approach by linking outside social movements and revolutionary movements with insider political institutions of state decision-making.

## Comparative and Complex Democratic Policymaking Process

The right side of Figure 4 provides an overview of how the nested complex policy process operates in terms of democratic policy outputs and outcomes. Emergent and complex factors from the policy environment including natural forces of the universe, natural processes on earth and complex and human interactions continually impact the nature and functioning of democratization in the policy process. Insider political institutions including executive, legislative, judicial, and public agency formal and informal policy decision making interact with outside forces of advocacy and change. These outsider forces include: crises, catastrophes, social movements, political revolution, direct democracy initiative, referendum, and recall votes, and a competitive and free press. Insider influences on the political institutions also include the impact of fair and competitive multiparty elections, interest groups, citizens, regimes, and policy subsystems. From this complex and interactive policy system come the enactment and implementation of policy outputs and outcomes that may be more or less democratic.

The nested policy system, itself, as well as within the policy system engages in positive and negative feedback loops. Negative policy feedback is defined as a democratic policy output or outcome that becomes less significant on the policy system. Positive feedback is when a policy output or outcome becomes amplified and has more of an impact on the democratic policy system. Both positive and negative policy feedback in the Democratic Policy Theory Model are interlinked with and impact on an ongoing basis the nested and complex policy system at all levels.

Discussion

US policy cycle theory has evolved from a more rudimentary form as put forth by Harold D. Lasswell beginning in the 1950 to the conglomerate model of today. Since the 1990s, the study of US policy theory has fragmented and balkanized into separate theories that often focus on various aspects of the original linear policy cycle model. This has created a current impasse in terms of moving and nudging US public policy theory forward with competing theories and leaders of theories not agreeing on a unified theory.

Analysis for this paper moves US policy theory forward by providing a path analysis oriented conglomerate model of US policy theories that results in a comparative policy theory that incorporates democratic and complexity theory. The result of this analysis of US policy conglomerate theory indicates that the policy cycle theory has currently evolved into a more sophisticated and nuanced policy cycle model. At the center of how politics and influence operates in the current U.S. conglomerated policy theory are interest groups and individuals vying for and advancing their agendas through political competition and cooperation in individual policy issues also known as the theory of pluralism and rational choice.

However, the conglomerated model of US policy has missing elements. These include the nature of democratization in a policy system and accounting for complex system behavior in policymaking. The enhanced model of policymaking presented in this paper includes key features of whether a society is democratic or not as it evolves based on complex system behavior. Rather than public policy outputs that primarily focus on the meaning of citizenship, form and patterns of governance, and group power and advocacy including political agendas, this enhanced policy model includes whether this political activity is also democratic or not (Heikkila & Gerlak, 2013; Mettler & Sorelle, 2014). Measurements of democratic policy outputs and outcomes are also commonplace amongst democracy scholars (Freedom House, 2015; Levitsky & Way, 2013; Munck and Verkuilen, 2002). Thus this enhanced policy model is not only descriptive, but predictive as well. Ultimately, this enhanced policy model moves policy theory forward by reunifying policy processes such as the interest group, social movement, and revolutionary movement participation in the policy making with complex democratic policy outputs and outcomes. This enables us to describe and assess what is the ultimate impact of a policy process on how democracy, political and economic power, privilege, and influence may occur in a society.

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# The Four Dimensions of Complexity: Using Framing in Resolving Wicked Problems (Poverty in the U.S.)

Ivan Udelll[A]

**The nature of complex problems requires policymakers to move from outdated twentieth century problem-solving methodologies that consume time, effort, and money without significant resolution. Complex social problems, such as U.S. poverty, call for policymakers to abandon failing policy and seek alternative fluid and adaptive approaches. Complexity science has led to better understanding of complex environments, but since its emergence in the 1980s has yet to deliver an explicit process that appropriately analyzes complex problems. Operationalizing such a process can be met with skepticism, but is essential in providing a focus or starting point for complex problem analysis. Dietrich Dörner laid the framework for a fluid and adaptive approach by identifying seven attributes of the four dimensions of complexity - chaos theory, complexity theory, paradox theory, and the concept of time. The poverty stricken rural north Florida town of White Springs is presented as a case study for "framing."**

**Keywords: poverty, complexity, wicked problems, Dörner**

## Introduction

I intend to investigate the nature of complex social problems that plague policymakers who seek to resolve them. With this article, I assess the family of complexity theories—chaos, complexity, and paradox along with the concept of time—the underlying cause of human failure in solving social problems. Scholar Dietrich Dörner laid out the attributes for this human failure in his 1996 work *The Logic of Failure.* In this article, I attempt to align these attributes with the family of complexity theories in order to construct a four-dimensional model of complexity. I propose "framing" as a tangible resolution method to abate problems that are characterized by the four dimensions of complexity. Lastly, I propose a study that measures effectiveness of this resolution method.

Over the last 25 years, much has been written about how organizations attempt to endure in the face of complex problems (Richardson, Cilliers, & Lissack, 2001). Complexity-theory studies have recommended how organizations should restructure as well as how they should be managed in order to withstand complex problems (Richardson, Cilliers, & Lissack, 2001). Further, complexity science has emerged as a means to address these needs (Richardson, Cilliers, & Lissack, 2001). However, Richardson, Cilliers, and Lissack (2001) assert that it (complexity science)

[A] University of Oklahoma

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has failed to deliver any tangible tools that may be used to analyze complex systems. Richardson, Cilliers, and Lissack (2001) cited that any attempt to operationalize such a complexity-based epistemology should be done so from a skeptical point of view. They also state, however, that from a pragmatic point of view, such frameworks are essential in providing at least a focus or starting point for analysis (Richardson, Cilliers, & Lissack, 2001). "Framing" is that starting point

U.S. poverty is a complex twenty-first century problem that exhibits four dimensions of complexity. This kind of problem requires abductive thought for policymakers to develop solutions that are in lock step with its changing nature. In policymaking, ultimately success or failure must be assessed primarily on whether the addressed problem exists after the policy is executed. Framing is a tangible, twenty-first century problem-solving construct that is complex and adaptive enough to bring resolution to twenty-first century problems. The following literature review describes and characterizes the wicked nature of the complex problems.

## Literature Review

Wicked problems are adaptive and inherently different from problems in the Newtonian sciences (Rittel & Webber, 1973). Problems in the natural sciences are definable, separable, and have solutions that are findable (Rittel & Webber, 1973). Problems of social- or policy- planning, such as poverty in the U.S., are ill defined and wicked. Often in solving wicked problems, not all factors are knowable at any one time. Solving a wicked problem requires ingenuity of viable solutions that may not be readily available. In other words, the solution may be known at a specific time but cannot be accessed at that time. Wicked problems can never be solved, only re-solved repeatedly, until the leader solving the problem runs out of time, patience, or money (Rittel & Webber, 1973).

Solutions to wicked problems, such as those related to poverty in the U.S., are never absolute. Better versus worse more accurately characterizes the nature of solutions to wicked problems. Each attempt by policymakers to solve poverty in the U.S. is a serious matter of concern for those that are poor. When dealing with affected or vulnerable populations, policymakers must not use the poverty issue as opportunity to learn problem solving through trial-and-error (Rittel & Webber, 1973). Policymakers must act in earnest when attempting to solve poverty in the U.S.

Pundits in the national media commentate that poverty exists because people do not have enough money, enough jobs, or enough motivation to work. This type of oscillation around a problematic issue is indicative of the nature of a wicked problem (Rittel & Webber, 1973). How policymakers choose to explain poverty exposes their understanding of the problem and determines the nature of how problem resolution is attempted. Some policymakers say poverty occurs because there are too few jobs or too many people living in poverty. Others cite inadequate assistance programs as the cause of poverty. Each explanation offers a different direction for policymakers to address poverty in the U.S.

Dörner (1996), in his seminal work, *The Logic of Failure*, reasons that policymakers who fail at solving wicked problems often employ logic that is as sound as the logic used by those who achieve success. Dörner (1996) maintained humans are highly deficient at solving complex problems. He described complex problems as traps having chaotic characteristics and attributes. For policymakers, poverty in the U.S. is one such trap. Dörner (1996) stated complex problems are situations that have seven defining attributes:

1. A large number of interdependent variables that affect each other, potentially leading to long chains of inter-related events.
2. Evolution over time, not a simple one-step-and-done situation.
3. Effects that act with time lags, so the results of action are not always immediately apparent.
4. Variables that act dynamically in response to external or internal stimuli, even if no action is taken by the policymaker
5. Unclear, conflicting, or tacit goals and objectives for what is to be achieved.
6. Intransparence where variables, their values, and how they relate to each other are not always known.
7. "Chaotic" behavior where slight changes in the initial state can have dramatic consequences downstream.

I discuss these seven attributes more in the next section using models of complexity. This complexity is first characterized by a three-dimensional model using chaos theory, complexity theory, paradox theory and then as a four-dimensional model by adding the concept of time.

**Table 1. The Four Dimensions of Complexity**

| Dörner's Attribute of Complexity | Theory or Concept | Dimension |
|---|---|---|
| 1) A large number of interdependent variables that affect each other, potentially leading to long chains of inter-related events | Chaos | First (1st) |
| 2) Intransparence where variables, their values, and how they related to each other are not always known | | |
| 3) "Chaotic" behavior, where slight changes in the initial state can have dramatic consequences downstream | | |
| 4) Variables that act dynamically in response to external or internal stimuli, even if no action is taken | Complexity | Second (2nd) |
| 5) Unclear, conflicting, or tacit goals and objectives for what is to be achieved | Paradox | Third (3rd) |
| 6) Evolution over time, not a simple one-step-and-done situation | Time | Fourth (4th) |
| 7) Effects that act with time lags, so the results of action are not always immediately apparent | | |

## The Four Dimensions of Complexity

Dörner (1996) laid out a case for a four-dimensional model of complexity with his attributes. Combined, the three theories of complexity (chaos, complexity, and paradox) and the concept of time make up the four dimensions of complexity (see Table 1).

The concept of time alters the three dimensional model of complexity to form a four-dimensional spherical model (see Figure 1). The sphere elucidates the concept of eternity, representing factors that have no beginning or ending. The sphere also represents the infinite iterations of complexity within a wicked problem.

### Complexity Theory

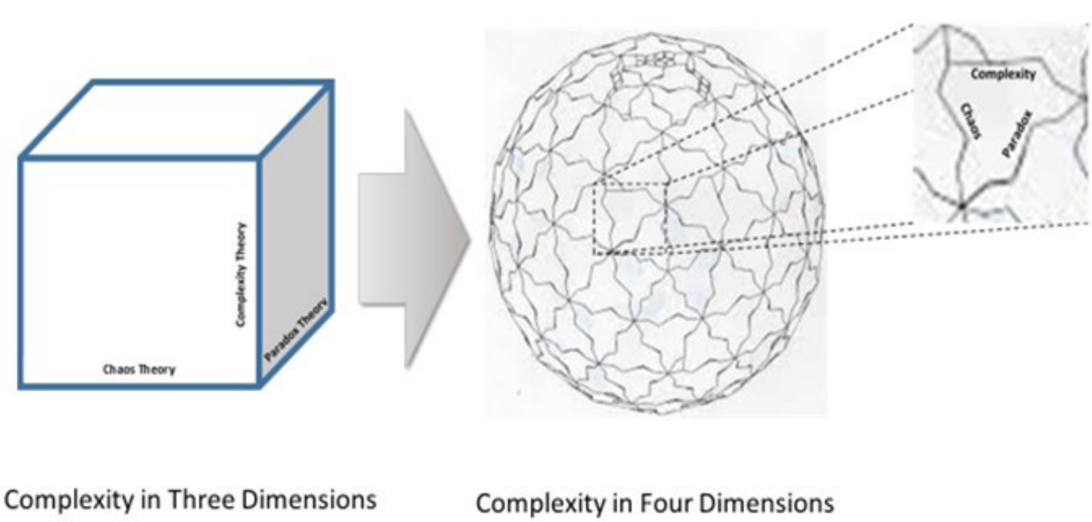
Derived from chaos theory, complexity theory is a body of science concerning systems that have uncertain behavior characteristics (Cohen & Gooch, 2006). The complexity theory describes systems where actors have dyadic relationships. However, interaction within those relationships exists in an illogical manner. The global action of a complex system cannot be predicted from an understanding of the behavior of a single actor. For example, knowing all there is to know about an individual bee will never reveal all there is to understand about how the hive will behave. In the Newtonian sciences, linear problem solving is attempted by breaking down subjects into smaller components until the sample can be understood through deductive reasoning. When policymakers apply this approach to complex problems, such as poverty, it fails. In the case of complexity theory, policymakers must use inductive reasoning.

***An Igbo man is asked, "If your wife and your mother are drowning, whom do you save?"***

### Paradox Theory

Paradox theory is a body of science concerning systems that denote contradictory interrelated elements within a situation that seem completely logical in isolation (Pasmore & Woodman,

**Figure 1. Models of complexity**



1997). However, these interrelated elements become illogical when applied simultaneously in the context of another problem. Plans and theories are dismantled easily by the influence of paradox (Pasmore & Woodman, 1997). Paradox exposes blind spots to linear thinking (Pasmore & Woodman, 1997). Paradox in complex adaptive environments tends to ignore neatly constructed linear theories (Pasmore & Woodman, 1997). Policymakers struggle with the paradox of the pros and cons of establishing anti-poverty policy. Increasing advances in technology, global competition, and social diversity will continue to intensify paradox found in the U.S. poverty problem. Policymakers must begin to examine how contradictions encourage organizational development (Pasmore & Woodman, 1997).

## Time

I propose that the construct of time has emerged as a dimension of complexity that confounds policymakers. Both the enormous amount of information and the time it takes that information to become available create an environment with emergent properties that is unforgiving to a policymaker who misjudges this fact. These emergent properties create another dimension of complexity, moving the three-dimensional model of complexity to a model that now has four dimensions. The application of time adds a metabolization[1] effect to complex problems. This means conditions of complex environments will always be moving in time, and at no point will they ever be the same as they were in any previous state. This emergence of time in complex environments is brought about by the twenty-first century information revolution. The effects of time in complex environments are described in three ways: as a linear construct, a social construct, and as simultaneity. Though all three descriptions are important, simultaneity is the most significant with regard to complexity.

### Linear construct.

Newtonian scientists consider time in a relatively simple matter: time occurs in a linear format from the beginning of an event until its end. These scientists measure time by comparing one standard motion against another. In this context, measuring time using a timing device is no more than comparing a motion of an event (one object) to the motion of the clock's hands (another object). Time in this sense has no independent existence (Zyga, 2011). This concept of time has given meaning to such phenomena as lags, timing, and age (Zyga, 2011).

### Social construct.

Time as a social construct yields concepts such as early or late (Levine &

[1] The understanding of metabolism includes two basic aspects. The first aspect is the continuous flow of energy and matter. All living systems need energy and food to sustain themselves; and all living systems produce waste. Life has evolved in such a way that organisms form communities. The second aspect of metabolism is the network of reactions. The emphasis here is on 'network.' One of the most important insights of the new scientific understanding of life is the recognition that networks are the basic pattern of organization of living systems. Wherever we see life, we see networks. It is important to realize that these living networks are not material structures, like a fishing net or a spider's web. They are functional networks, networks of relationships between various processes. Living networks are self-generating. They continually create or recreate themselves by transforming or replacing their components. In this way they undergo continual structural changes while preserving their weblike patterns of organization (Capra, 2005).

Wolff, 2007). Policymakers often use formal planning processes to formulate strategy in response to problematic situations. Timelines are the foundation of planning. Policymakers set start and finish points that are agreed upon by various stakeholders. To select start points, policymakers use some logic: the beginning of a fiscal or calendar year, an election, or a program's commencement. Conversely, policymakers often have more difficulty with selecting end dates: end dates become extended to accommodate yet unmet objectives or are hastened due to loss of funding, waned interest, or change in leadership.

**Simultaneity.**

Simultaneity is the third construct of time. This construct refers to two actors in the same frame observing the same activity, yet having two completely different experiences. These experiences are neither perception nor illusion. They are reality, genuinely different experiences occurring in the same space at the same time. This is exemplified by Einstein's Special Theory of Relativity (Lawson, 1920):

> *A spaceship moving from left to right at a constant speed. A ray of light from a high-powered green laser is aimed from the ceiling to the floor. The light appears to move down perpendicularly to the direction of motion. An observer "A" on the spaceship viewing this laser light will see this ray move straight down through the center of the ship in his reference frame. An observer "B" at rest, not on the spaceship, yet positioned to see the ship pass his view point would see this ray of light move down (diagonally) in his reference frame independent of the motion of the spaceship.*

To the observer A on the ship, the light is viewed exactly as it is behaving in his reference frame. To the observer B who is stationary, the light is viewed exactly as it is behaving in her reference frame. This concept of reference frames provides simultaneity within a time in space and makes real coexisting experiences. Reference frames add acuities to complex environments that may be unknowable by policymakers. Reference frames cause actors in the same environment to respond differently to stimulus caused by a change in policy. These reference frames are real and problematic in an age when so much information is available to so many people so quickly; this rate of information sharing outpaces policymakers' decision-making.

## Twenty-first Century Approach: Framing

Outdated, industrial-aged, twentieth century problem-solving methodologies have been ineffective in bringing resolution to today's complex problems (Donlon, 2001); these problems are resistant to such problem-solving approaches. A possible solution to a problem in one area may create a new problem in another area (Giblin, 2015). Twentieth century methods are devoid of sufficient adaptability and diverse cause and effect understanding to accommodate the wicked nature of today's complex problems. Twenty-first century methods must be as complex and adaptive as the problems they seek to resolve.

When attempting to resolve four-dimensional wicked problems such as poverty, policymakers must address all dimensions. The approach to resolution must be multi-faceted, flexible, and adaptive to accommodate factors attributed to chaos theory, uncertainty (brought on by human nature) related to complexity theory, contradictions introduced by paradox and emergent behavior over the time span of the strategy. Framing is this twenty-first century method.

Framing is an adaptive approach used to understand one's complex environment and interpret conflict. Ryan and Banach (2009) defined framing as the process through which a policymaker cognitively organizes knowledge about the world, interprets new experiences, and creates alternate worldviews. This process also allows for reframing once observations present new information about the problem. Simply, reframing is restarting a frame after discarding outdated hypotheses or theories that defined the original frame (Ryan & Banach, 2009). Reframing happens when legacy worldviews are no longer valid. The use of reframing makes sense of new information, events, or experiences.

Framing is a broad and supple approach to resolving wicked problems. It is a concept used to describe how individuals interpret particular reference frames within their environments (Schön & Rein, 1994). Policymakers use multiple perspectives through which amorphous, ill-defined problematic situations are assessed, made sensible and assigned action (White, 1987). A perspective is a subjective evaluation of relative information, data, and actors in a system (White, 1987). Policymakers who use the framing approach consider all stakeholders involved in a complex problem and work more deliberately to determine how policy implementation would affect them. Framing requires policymakers to first challenge their understanding of the problem, and this act of considering a problem from the perspective of all who are involved leads to a more comprehensive understanding of the problem.

Many twentieth century problem-solving approaches include heavy use of the narrative. The narrative in today's culture is manifested in several forms (White, 1987). The narrative is used as a tool to develop strategy, as a form of information delivery, and as a persuasion tactic (White, 1987). Currently, the narrative approach is a central component of the social construction theory. The narrative is a useful method in solving simplistic twentieth century problems. However, when used alone or by complacent policymakers, the narrative approach is apt to be too narrow in focus and too rigid to accommodate the adaptive nature of wicked problems (White, 1987). When used alone, the narrative tends to define the wicked problem and over time rigidly adheres to the original assumptions, clinging to worldviews too long.

## Framing Poverty

In the U.S., the poverty line is criticized for being estimated as both too high and too low. This dual criticism conveys the complexity and paradox in combating poverty in the U.S. and makes the current argument about poverty seem a bit hollow (Rector, 2011). In 2011, the Heritage Foundation claimed that the estimated poverty level was too high. According to the U.S. Census Bureau, 42 percent of those currently defined as being in poverty in the U.S. own their home (Rector, 2011). The average home belonging to those living under poverty has three bedrooms, one and a half baths, and a garage. To the contrary, Ellen Frank (2006) argues that the poverty level is estimated too low. She cites that families spend far less of their total budget on food than when the measure was established in the 1950s. In addition, the federal poverty statistics do not account for the regional differences of non-food costs such as housing, transportation, and utilities (Frank, 2006).

The official U.S. poverty rate has

dropped modestly from 19 percent in 1964 to 15 percent in 2012 (Lozano, 2015) (see Figure 2). These statistics indicate that anti-poverty policies have not significantly reduced poverty in the U.S. However, researchers from Columbia University, using the Supplemental Poverty Measure (SPM), calculated a supplemental measure back through time and adjusted for inflation (Jacob, 2012). These researchers calculated the poverty level as falling from 26 to 16 percent from 1967 to 2012 (Jacob, 2012). This presented a more significant drop in the poverty level. The SPM is cited to account for more success in the reduction of poverty. Conversely, some critics claim citing SPM does not meet the original objective of the war on poverty: reducing tax consumers and creating taxpayers because it includes aid as part of a person's income (Worstall, 2015).

Critics cite that means-tested welfare programs skew poverty level data, and they (means- tested welfare programs) remove incentives for recipients to get off welfare (Roy, 2013). The Cato Institute cited in some states, means-tested welfare income exceeds that of working wages (Tanner, 2013). In 39 U.S. States, welfare pays more than an $8 per hour job (Roy, 2013). In six U.S. States, welfare pays more than a $12 per hour job (Roy, 2013). In eight U.S. States, welfare pays more than the average salary of a U.S. teacher (Roy, 2013).[2]

In this section, I narrow the focus by framing the poverty problem of a sample group of the general U.S. population. The sample for this study is 776 people in the small north Florida town of White Springs. In 2014, the town of White Springs, through the Florida Department of Economic Opportunity (DEO) Competitive Florida Partnership program, decided to embark on long-term strategic planning using the framing approach. White Springs currently has 36 percent of households living below the poverty level compared to just 16 percent of the U.S. population living under the poverty level in 2012. The town meets the state of Florida's statutory definition of a rural area of critical economic concern. Further, White Springs has a low per capita income, low per capita taxable values, high unemployment, and low weekly-earned wages. A high percentage of the population receives public assistance through means-tested welfare. The town suffers from a lack of year-round stable employment opportunities (see Table 2) (Miller, 2014).

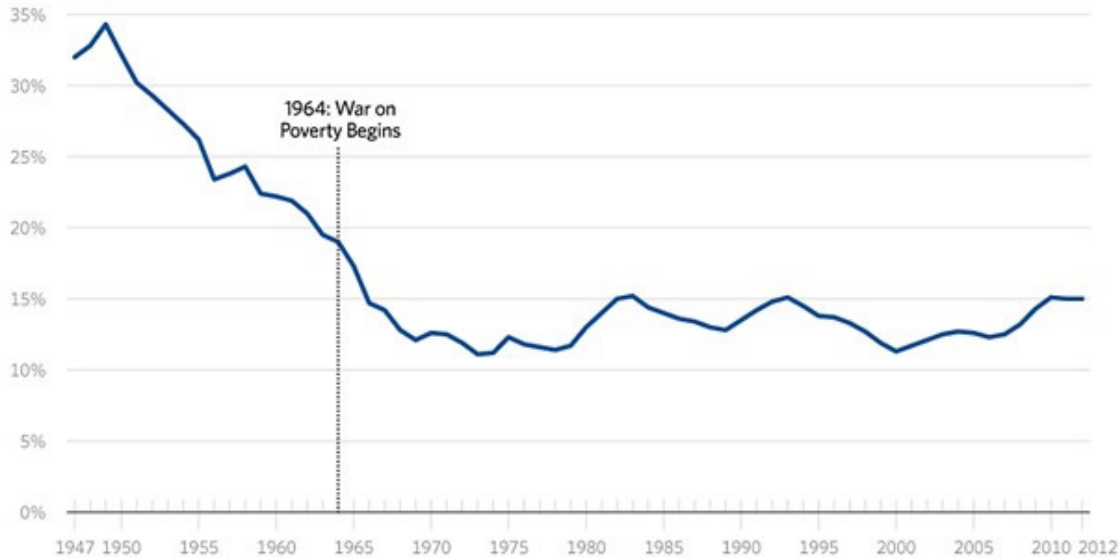
In March 2014, a group of scholars, planners, and policymakers began a framing exercise to create anti-poverty policy for the town of White Springs. This group used framing to identify key artifacts and issues in the systems that required resolution. It (the group) created the strategy for the White Springs case study during eight sessions. Two of the sessions in particular were with diverse community stakeholders: one session convened business owners and the other session a group of citizens. Diverse perspectives are critical in the process of framing not merely for the appearance of fairness, although the appearance of fairness is an important aesthetic, but to gain an

[2] The state of Hawaii offers $60,590 in annual welfare benefits, and welfare benefits are tax-free to the recipient as compared to work-related wages. This equates to $29.13 per hour, based on a 40-hour work week. The five states with the highest welfare benefits are: Washington, DC ($50,820 per year at $24.43 per hour), Massachusetts ($50,540 per year at $24.30 per hour), Connecticut ($44,370 per year at $21.33 per hour), and New York ($43,700 per year at $21.01 per hour). The five states with the lowest welfare benefits are Idaho ($11,150 per year at $5.36 per hour), Mississippi ($11,830 per year at $5.69 per hour), Tennessee ($12.120 per year at $5.83 per hour), Arkansas ($12,230 per year at $5.88 per hour), and Texas ($12,550 per year at $6.03 per hour) (Roy, 2013).

CHART 1

**Poverty Rate, 1947–2012**

PERCENTAGE OF INDIVIDUALS WHO WERE POOR BY THE OFFICIAL POVERTY STANDARD




**Sources:** Figures for 1947–1958: Gordon Fisher, "Estimates of the Poverty Population Under the Current Official Definition for Years Before 1959," U.S. Department of Health and Human Services, Office of the Assistant Secretary for Planning and Evaluation, 1986. Figures for 1959–2012: U.S. Census Bureau, Current Population Survey, Annual Social and Economic Supplements, "Historical Poverty Tables—People," Table 2, https://www.census.gov/hhes/www/poverty/data/historical/people.html (accessed September 10, 2014).

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| **Table 2. White Springs, Florida** | |
|---|---|
| Population (2012) | 776 |
| Municipal budget (2012-13) | $1.37 M<br>Or $1,765 expenditure per capita |
| Per capita income (2012) | $14,507 |
| Median household income (2014) | $29,106 |
| Poverty rate (2012) | 36% |
| **For population 25 years and over in White Springs:** | |
| High school or higher: | 83.0% |
| Bachelor's degree or higher: | 12.3% |
| Graduate or professional degree | 7.4% |
| Unemployed: | 16.9% |

expansive understanding of the complex problem and to inform resolution strategy. During the framing sessions, business owners and citizens offered subjective perspectives from their reference frames about poverty in White Springs. Via these frames, key themes to be addressed in the resolution approach emerged. The final frame was subjective and this subjectivity was captured. The planning group used the captured perspectives to write a rich, subjective eight-paragraph description of the environment of White Springs (Miller, 2014).

The group in its description depicted how approximately 50 years ago the town's population transitioned from primarily rural agriculture to industry (phosphate mining). While the culture remained steeped in traditional agriculture, for decades its residents enjoyed the benefits of a middle-class, blue-collar income. The town's population was served by an education system that was singularly focused on producing a workforce for the mining industry. This lack of educational diversity serves today as an obstacle to White Spring's economic growth. The planning group, in its description of the environment, noted how an antiquated and complex infrastructure also challenges the town's economic development. It also noted how White Spring's geographical location adds to the complexity of the town's economic problems.

Once the initial framing was complete, the planning group noted key observations and themes—areas of focus for policymakers. The group determined these areas of focus by identifying ends, ways, and means (see Figure 3). When using framing to solve wicked problems, policymakers must determine what desired plausible futures exist for the system in question. The planning group extracted factors from the frame and defined a desired endstate guided by the multiple subjective perspectives, rather than one based on a definition of poverty (absolute or relative). An endstate must be broad and strategic in nature and frame a desired environment that will exist at the end of a given period. This broad endstate must be able to withstand changes in directions of planning as well as changes in resourcing.

A key component in resolving wicked problems using framing is the resolution approach (see Figure 4). Phrases and terms that are derived in the frame should appear in the resolution approach's endstate. The frame is the driver and the focus for the resolution approach. There are

**Figure 3. Using the Ends, Ways, and Means to Identify the Key Elements**

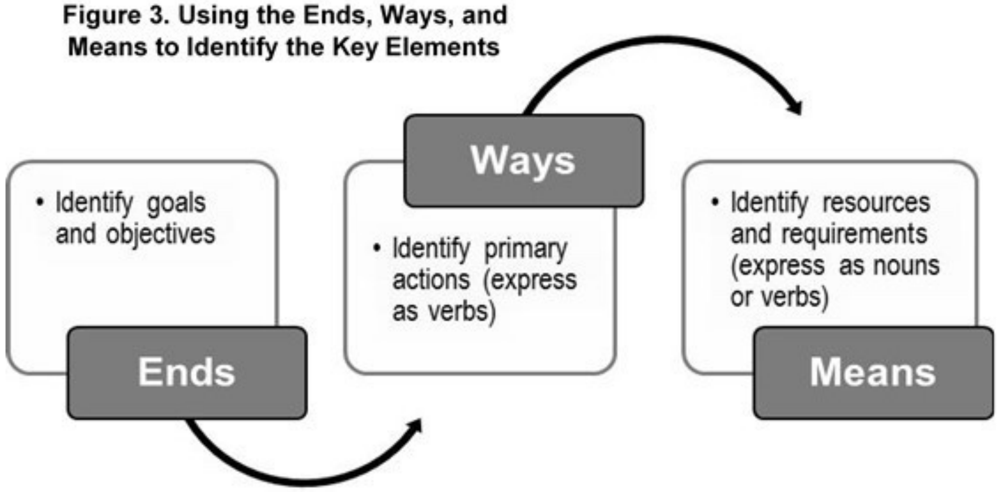
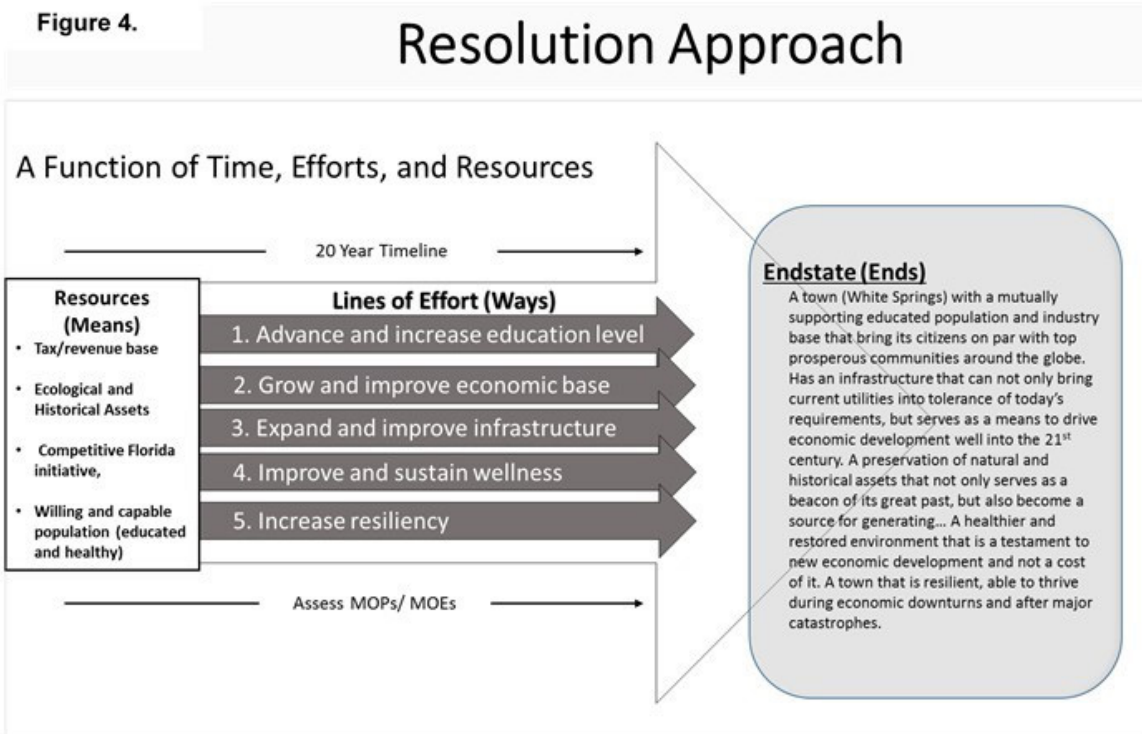


Figure 4.




five components to the resolution approach: endstate (ends), resources (means), lines of effort (ways), time, and assessments.

Steven Covey (1997) in his work, *7 Habits of Highly Effective People*, states that one should begin with the end in mind. That is exactly the case with framing and using the resolution approach. Constructing the resolution approach begins determining the desired endstate. Framing provides a rich understanding of the current state of the system of which the policymakers are concerned. Next, an understanding of the desired state should be derived. This desired state is the outcome or ends. Endstates in the resolution model allow policymakers to frame iterative plans well into the future of problem-solving efforts. As progress is made and strategies change, the endstate become the beacon that keeps planners focused on the appropriate ends. The endstate is the first component of the resolution approach to be completed. The following paragraph is the endstate determined by the framing process in the town of White Springs:

*A town with a mutually-supportive educated population and industry base that brings its citizens on par with top "human developed" communities around the planet. A town with an infrastructure that brings current utilities into tolerance with today's requirements and serves as a means to drive economic development well into the twenty-first century. To preserve natural and historical assets that serve as a beacon of White Spring's great past and also becomes a source for generating economic growth. To become a community with a restored and healthier environment (eco system) that is a testament to the new economic development and not the cost of it. To become a town that is resilient and thrives during economic downturns and post major catastrophes.*

As a part of the resolution approach, resources are the means to the endstate. Even before the ways are determined, the resources (means) must be delineated through inventory. This important step allows plausibility and feasibility to be assessed. White Springs and the DEO conducted an inventory of all resources available to policymakers. After conducting a resource inventory, White Springs determined the following assets or resources:

- Willing and capable underdeveloped population
  - Education
  - Health
- Underutilized tax/revenue base
- Competitive Florida initiative
- Ecological assets
- Historical assets.

The lines of effort in the resolution approach are broad and holistic treatments to wicked problems. Lines of effort are the ways to resolution, providing flexibility and adaptability. White Springs identified five ways, broad and acceptable, that it could achieve the prescribed endstate. These ways allow for change of plans (if needed) without changing strategy, objectives, and more importantly ends. Fundamental to lines of effort is that they occur simultaneously and are rank ordered. This order is a resource prioritization mechanism rather than order of execution. Should budgets be reduced and factor in decision-making, policymakers will be guided by this resource prioritization regarding what decisions they "should" make. After determining the endstate and inventorying the means, the policymakers decided on five ways (lines of effort) to resolve the wicked poverty problem in White Springs:

1. Advance and increase level of education
2. Grow and improve economic base of the town
3. Expand and improve infrastructure of the town and other areas of opportunities
4. Improve and sustain the overall health and wellness of citizens over their lifetime
5. Increase resiliency through building reserves for downturns beyond the control of the town.

A critical component of the resolution approach is the timeline. A wicked problem does not develop at once but over an extended period. Therefore, its resolution takes time. Time affects complex problems, instituting a period of waiting for resolution to come to fruition. Appropriate solutions to wicked problems may not yield results right away. Conversely, inappropriate solutions may yield immediate and short-term relief. More dangerously, some short-term solutions bring about more harm over the life of the problem than if no actions were taken. Even when positive results are noticed, waiting for full resolution of a wicked problem is difficult to accept for some actors. The timeline assures discipline over the life of the strategy.

Another critical component to the resolution approach and framing in general is assessment. Assessment in framing provides feedback in two distinct ways: through measures of performance (MOPs) and measures of effectiveness (MOEs). In order to measure MOPs and MOEs, clear intermediate and terminal objectives must be identified.

## Methods

I propose conducting a statistical analysis of this sample (the town of White Springs). To assess the effectiveness of framing, a 20-year longitudinal study will be conducted of the sample. The null hypothesis of this study is that the twenty-first century problem-solving approach framing is not more effective at resolving U.S. poverty than twentieth century problem-solving approaches. The alternative hypothesis of this study is that framing, a twenty-first century problem-solving approach, is significantly more effective in resolving poverty than twentieth century approaches. The research questions associated with this study are the following: Is the nature of complex problems addressable by a tangible process or method? If yes, can this method or process be standardized and used in such a way that can be replicated in policymaking? Proper assessment is done by developing objectives associated with lines of effort. To conduct proper analysis, this study proposes a series of measurements. The first two measurements are oriented toward proper analysis of the framing effort. These are measures of performance of the strategy derived from the frame and the measures of effectiveness of the strategy on the environment. The third measurement is oriented toward proper analysis of this proposed study.

Proper measurement of performance can be gained by gauging the rate of success in achieving intermediate objectives. Policymakers determine the intermediate objectives; these objectives are planned and executed in a specified amount of time. These intermediate objectives are vital for determining initial criteria for evaluating measures of performance. In the case of the town of White Springs, the following objectives were identified for each LOE (see Table 3).

Measurement of effectiveness of strategy is a bit more complicated than that of measurement of performance. In order to gauge strategy effectiveness, terminal objectives must be determined. Terminal objectives relate to effects within an environment policymakers seek to achieve. Terminal objectives are correlations of actions to effects that occur over a period. This renders MOE assessment more complicated than MOP assessment. Intermediate objectives in MOPs are direct cause and effect with planning and actions. Terminal objectives are vital for determining criteria for evaluating MOEs; terminal objectives must be aligned with the endstate. In the case of the town of White Springs, the following terminal objectives were identified (see Table 4).

To measure the actions and results of this study using MOPs and MOEs, intermediate and terminal objectives are gauged as progress is made until either attainment or complete failure of the related objective. Data will be collected of the general U.S. population annually. This includes capturing the median, means, and standard deviation for each of the terminal objectives listed in Table 4. The same data must be captured for the sample studied (White Springs, Florida). Once these measures are captured, the significance of any growth shown by the sample statistics must be statistically analyzed; this leads to the third measurement. The third measurement is statistical analysis of data generated from the sample. This measurement serves to test the hypothesis of this study. The null hypothesis is that the twenty-first century problem-solving approach framing is not more effective at resolving U.S. poverty than twentieth century problem-solving approaches. The alternative hypothesis is that framing, a twenty-first century problem-solving approach, is significantly more effective in resolving poverty than twentieth century approaches. Analysis of variance will be conducted to either accept or reject the null hypothesis.

The current poverty rate in the U.S. (the population) is 16 percent. The current poverty rate for the town of White Springs (the sample) is 36 percent. The first step in gauging the success of the strategy to resolve poverty in White Springs is to determine if there is significant difference between the poverty rate of the population (U.S.) and that of the sample (White Springs) at the end of treatment in 20 years. That is,

| Table 3. Measures of Performance (MOPs) | | | |
|---|---|---|---|
| Lines of Effort (LOE) | Intermediate Objectives | Achieved? Yes | Achieved? No |
| 1. Advance and increase level of education | a. Re-establish and make long term, funding for after school programs (H.O.P.E). | | |
| | b. Align education for youngest of students with long term projected industry requirements. | | |
| | c. Plan for and develop economic base to drive improvement of education levels. | | |
| 2. Grow and improve economic base of the town. | d. Leverage local ecological, historical, and natural assets to grow economic base. | | |
| | e. Exploit 21st century innovations to gain advantages in economic development. | | |
| | f. Grow economic base over entire time period to benefit every generation, to include current population suffering from recent economic downturns. | | |
| 3. Expand and improve infrastructure of the town and in other areas of opportunities. | g. Expand infrastructure in innovative ways to ignite new economic opportunities that do not currently exist (improve Interstate 75 and State Road 136 interchange). | | |
| | h. Improve infrastructure to maximize efficiency and reduce cost to the current population (taxes and utilities) and future economic. Partners. | | |
| 4. Improve and sustain the overall health and wellness for the lifetime of citizens. | i. Encourage development of healthcare systems (facilities) to capitalize on key demographics for positive population growth. | | |
| | j. Entice private investment that leads to the development of healthcare and healthcare related facilities. | | |
| 5. Increase resiliency through building reserves for downturns beyond the control of the town. | k. Upgrade utilities to modern standards that resist the effects of adverse weather conditions. | | |
| | l. Develop a diverse economic base that is resistant to any one or two types of effects. | | |
| | m. Construct facility or facilities that provide maximum safety in the most extreme conditions. | | |

| Table 4. Measures of Effect (MOEs) | | | |
|---|---|---|---|
| Outcome | Terminal Objectives (20 Years) | Progressing /Achieved? | |
| | | Yes | No |
| 1. Percent of subjects ages 25 years or older in White Springs, FL at the mean or one standard deviation above mean of U.S. | a. with high school diploma | | |
| | b. with two year college | | |
| | c. with four year college degree | | |
| 2. For all subject households in White Springs, FL | d. at the mean or one standard deviation below mean poverty rate for U.S. | | |
| | e. at the mean or one standard deviation above mean median household income for U.S. | | |
| 3. Percent of subjects in White Springs, FL | f. at the mean or higher of per capita income for U.S. | | |
| 4. Percent of subjects in White Springs, FL below the mean of U.S. population that | g. receive means tested welfare | | |
| | h. has school age children that receive free or reduced lunch | | |
| 5. Number of jobs created per 100 subjects compared to U.S. that is | i. at the mean per capita income for U.S. | | |
| | j. \$10,000–19,999 above mean per capita income for U.S. | | |
| | k. \$20,000 and above the mean per capita income for U.S. | | |

will there be a significant reduction of the poverty rate of 36 percent in the sample group? The next step is to determine if that reduction can be attributed to the twenty-first century problem-solving approach of framing. This will be gauged by analyzing the variance in the change of the sample's poverty rate each year. Conducting analysis of variance also will be done for each of the sample's terminal objectives listed in Table 4. As data is obtained, this study will seek to determine if change is due to routine variance or because of activities driven by the framing process. If the overall poverty rate of the sample is reduced and that reduction is assessed to be significant, a correlation can be drawn between framing and resolving poverty.

## Conclusion

Policymakers in the U.S. have attempted to solve or alleviate the effects of wicked problems for decades. Results of these efforts have been met with skepticism. U.S. antipoverty efforts (beginning in 1964) and their results serve as an archetypal example of decades of policymakers' attempts to solve a wicked problem with antipoverty policy not significantly reducing poverty in the U.S.

Having coined the term "wicked problem," Rittel and Webber (1973) deemed that the nature of complex adaptive problems renders them incapable of being solved only resolved. Further, wicked problems require inventive thought and strategies that match their adaptive nature in order to be resolved. Expounding on the characterization of wicked problems, Dörner (1996) observed and delineated seven attributes that contribute to the complexity of wicked problems.

This study asserts that these seven attributes lead to four dimensions of complexity: chaos theory, complexity theory, paradox theory, and the concept of time. Time is considered the fourth and foremost dimension. Time is a central aspect of policymaking and problem solving. It is senseless to think rigid strategies conceived at the beginning of resolving wicked problems can endure the entire span of time of the resolution process. It is equally senseless to think haphazard patchwork policy solutions work. The effect of time is an emergent dimension of poverty in the U.S. Twentieth century problems required deductive reasoning and analysis, where the formal logic was to break problems into parts in order to find a solution. Wicked problems require twenty-first century strategies, abductive reasoning, diagnostics, and synthesis (Dörner, 1996). Framing as a resolution approach to wicked problems provides these essential elements.

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# A systematic literature review of studies applying complex systems theory to public policies

Felipe de Oliveira Simoyama,[A] Flávia Mori Sarti

**A typical public policy environment is composed of self-organizing agents, nonlinear interactions and a high level of unpredictability. These features are sufficient to define public policies as complex systems, a field of study that is unfamiliar to most of policy makers and politicians. The purpose of this study is to verify whether complexity tools provide a more robust method for policy formulation and the current state of practical approaches for policymaking. This paper presents a systematic literature review of 35 studies on the use of complexity methods and tools in public policy in a range of issues, which can provide useful insights to guide policy formulation. This study reveals, among other results, that (a) there is a strong consensus supporting the use of complex system for modeling public policies; (b) agent-based modeling is preferred over other tools; (c) complex systems have not yet reached policymakers to be put into practice.**

**Keywords: complex systems, public policy, systematic literature review**

[A] University of São Paulo, São Paulo

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## Introduction

Frequently, public policies do not generate the expected results. In fact, despite the best intentions of a policymaker and the consensual nature of interactions between agents, public policies can beget totally opposite outcomes from the initial plans (Fischer, Miller, Sidney; 2007). In some cases, policy analysts detect the errors too late to reverse them. This sort of unintended consequences is notorious in various areas of public policy, such as: employment, healthcare, education and others. In some cases, these consequences could be predicted before policy implementation. In other cases, however, a policy designed for Region A can cause an unforeseen disaster in Region B. Chouvy (2013) distinguishes unintended consequences between direct and collateral. The first type occurs when the unintended consequence is a direct effect of an action, while a collateral consequence emerges when it is a result of an intended consequence of an action.

In fact, Chouvy (2013) argues that all public policies generate both direct and collateral unintended consequences, and these consequences, in almost all cases, are unmeasured (Reuter, 2009). Such level of unpredictability led to a consensus among researchers and specialists that the public policy process is a complex system (Kay, 2006), and traditional methods are no longer sufficient for estimating its effects, whether they are direct or collateral, beneficial or harmful.

The common properties of a complex system comprise complex collective behavior, signaling and information processing and adaptation (Mitchell, 2009), as detailed in table 1. The combination of these properties gives rise to a dynamic, hard-to-predict and often chaotic behavior, thus consequences cannot be properly foreseen.

Increasing complexity created the necessity for new tools, since traditional analyses no longer provided social sciences researchers with reasonable results. In fact, complex systems theory can be seen as a new way of observing the world around us and the social phenomena, and not merely a bunch of tools to improve processes and decision making.

In economics, there has been a long debate. Although economists from the Austrian school argued that statistics and mathematical methods could not provide reliable predictions in the area of social sciences (Mises, 1998), the use of complex systems tools can help detect unforeseen and unintended consequences, allowing policymakers for mitigating or avoiding harmful and perverse consequences of public policies, but it can also help detect unforeseen beneficial consequences in order to enhance its effects. Even Hayek (1945), a renowned Austrian economist, argued in favor of the use of complex systems in economics.

The scenario of the policy context is not much different. Despite the large number of studies reviewed for this paper, the use of complexity tools in public policies is limited and disperse. The so-called evidence-based policy movement, for example, does not consider complexity tools (e.g. computer simulations) as a type of evidence for policymaking, not even as a low-rank evidence (DFID, 2014; Nutley, Powelll & Davies, 2012). However, at the minimum, these tools provide insights that could serve as a good and distinct sort of evidence, offering policymakers a different view, which could anticipate multiple possible scenarios beforehand.

Even though complex systems science is far from being a primary tool

**Table 1: Common properties of a complex system**

| | |
|---|---|
| Complex collective behavior | The agents that are potentially affected by a policy take their individual and particular decisions by following simple rules and no central control. One could argue that the government or the state acts as a central control, however, as it will be presented, agents do not always behave as expected by policymakers. In fact, it is the case that agents adapt and create unexpected outcomes in both the short and long terms. For example, when government raises taxes it expects to increase its revenues. However, the number of unintended direct and collateral consequences that could arise therefrom is high. Agents could avoid taxes in legal and illegal ways. Firms could dismiss employees to reduce costs, they could leave the market, or they could even go bankrupt. Despite the fact that the State is a ruler, it cannot force, or even predict, how the agents will behave precisely. |
| Signaling and information processing | Agents in a society are constantly being provided with a huge amount of information, and they use it to take and update their decisions all the time. The fact that agents can use the same information in a completely different manner brings even more complexity to the system. New information allows agents to think, learn and evolve. |
| Adaptation | Adaptation is a concept very well established in biology. By receiving new information, agents will change their behavior in order to reach the best possible outcomes. Environmental changes constantly place new challenges to agents. As they will react in many different ways, chances are some will adapt better than others will. In biology, when a specie does not adapt to the environment, it can cause extinction. However, in a public policy system, unadapted agents often remain in the system, i.e. they do not die or extinguish. This could imply that public policies hold a very high level of complexity. |

for policymakers, we have gathered some sophisticated practical applications of complexity tools in different areas of public policy, such as: public transport, education, healthcare, water and energy resources, employment, immigration, discrimination, climate change and economics, and various others. In this paper, we have carried out this systematic literature review of studies on complex systems for public policies in both theoretical and experimental approaches. Our primary objective is to verify whether complex systems theory is beneficial in the field of public policies, and our secondary objectives include the analysis of what contexts of public policy has complex system theory been empirically tested, what tools have been used and what are the main results obtained so far.

## Methods

In this study, we carried out a systematic literature review instead of a narrative text. Such method allows for a more replicable and transparent process, since traditional literature reviews lack criteria for study selection, and thus transparency and replication are not possible. Here, we used a method adapted from Parris and Peachey (2013).

### Eligibility

Our primary objectives are to answer how useful complex system tools are useful to the public policy process, and to detect practical work in this field, identifying the main areas that are benefiting from such approach. We did not intend to compare the results of policies formulated with traditional and complex system approaches, because there is not a significant number of studies describing the results of real-world policies formulated with the support of such tools. As secondary objectives, we include the formal comparison of traditional and complex system approaches and the reason why policymakers are not receptive to engaging in complex systems.

We searched studies within a 10-year period (2005-2015) on complex systems and public policies, with two different approaches:

1. those that describe the use of complex system theory in the public policy area.
2. those with the aim of solving a public policy issue with the use of complex system methods and tools.

In addition, we used the following inclusion and exclusion criteria:

(a) Include only studies with full text available

(b) Include only studies in English language

(c) Include only studies with one of these components addressed in the abstract, results, or discussion: (c.1) the implications of the intersection of public policies and complex systems, or (c.2) an application of complexity theory to the policy context (empirical evidence or simulation).

**Table 2: The search strings used for this review**

| | Search strategy (1 primary term + 1 secondary term) | |
|---|---|---|
| **String** | Primary terms | "Policy" OR "policies" OR "public policy" OR "public policies" |
| **AND** | Secondary terms - complexity tools | "Complex systems" OR "complexity theory" OR "agent-based modeling" OR "ABM" OR "system dynamics" OR "computer simulation" OR "cellular automata" OR "chaos" OR "fractals" OR "nonlinear systems" OR "genetic algorithms" |
| **AND** | Secondary terms - public policy topics | "Public transport" OR "traffic" OR "land use" OR "education" OR "healthcare" OR "water resources" OR "energy" OR "employment" OR "labor market" OR "immigration" OR "discrimination" OR "crime" OR "violence" OR "climate change" OR "economics" |

## Search strategy

We have conducted this study based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (Moher, Liberati, Tetzlaff, Altman, & PRISMA Group. 2010) following all steps and guidelines. In order to identify papers on complex systems for public policies, we used the following search strategy:

1. Select the primary terms that fit the objectives of this study;
2. Select the secondary terms based divided in two categories: complexity tools and public policy topics;
3. Run iterated searches by doing minor changes in the terms, such as spelling and plurals;
4. Link one of the primary terms with one of the secondary terms using fundamental operators (and, or).

We used the library system of the University of Sao Paulo (http://buscaintegrada.usp.br) and the Federal University of Sao Paulo (http://unifesp.summon.serialssolutions.com) to search for articles published in peer-reviewed journals within the period of 2005-2015. These systems include results arising from the following databases: Art Full Text; EBSCOhost; ECCO - Eighteenth Century Collections Online; Faculty of 1.000 Biology; Hein Online; LSN - Legal Scholarship Network; Modern Language Association (MLA); International Bibliography; MOMW - The Making of the Modern World; Portal de Periódicos CAPES (Brazil); Scopus; Web of Science and USP internal database (theses, dissertations etc.). We also searched in the Journal on Policy and Complex Systems, which specializes in the applications of complex systems for public policies.

## Search Results

This search strategy resulted in 182 studies. The number of duplicates was low (n=7), due to the fact that we used only 2 different databases (USP and UNIFESP). Next, we read the title, abstract and discussions of all these 175 papers, and then

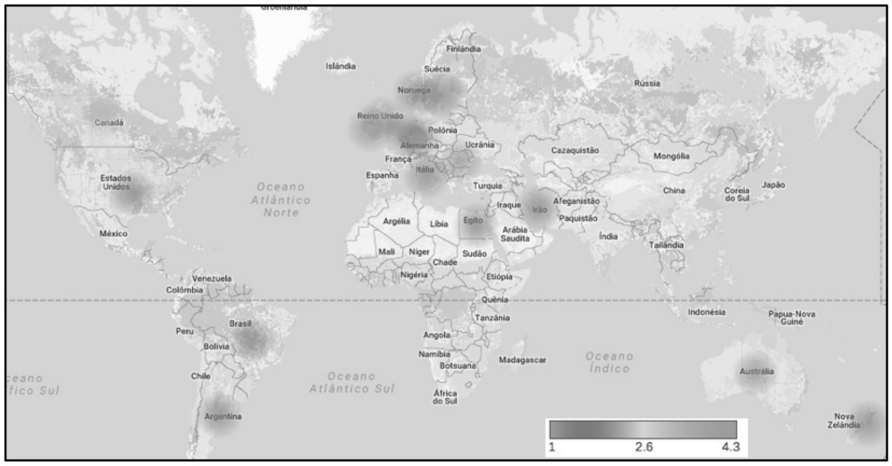


Figure 1: Country of origin of the 35 studies

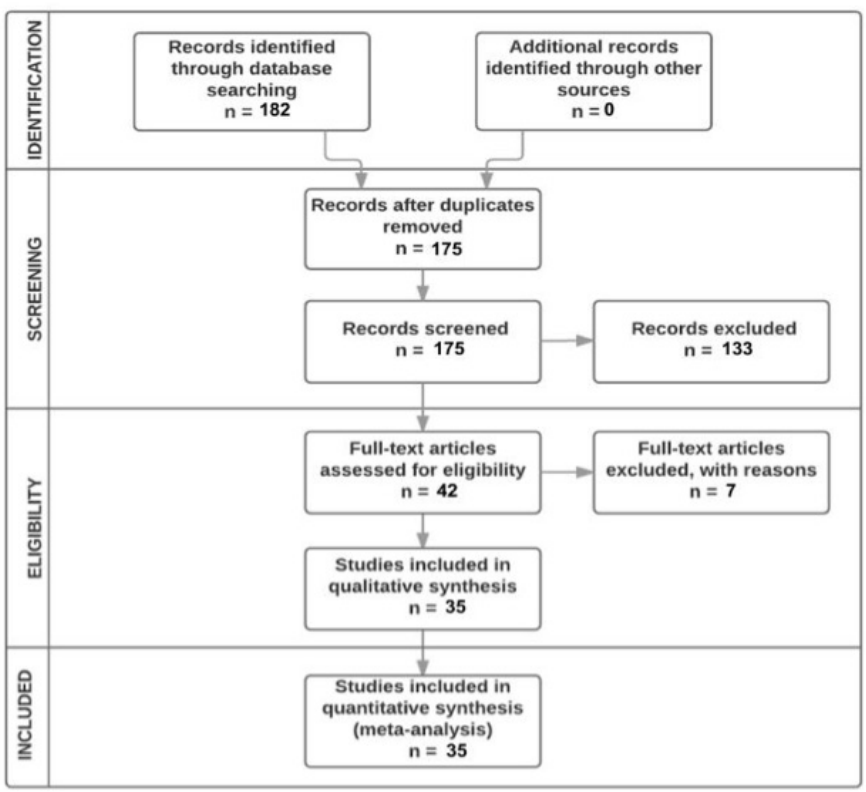


Figure 2: The PRISMA flow diagram

**Table 3: Journals included in the SLR**

| Journal | Number of studies |
|---|---|
| American Journal of Public Health | 5 |
| BEPAM | 1 |
| Ciência e Saúde Coletiva | 1 |
| Comput Econ | 1 |
| E-CO | 4 |
| Ecol Modell | 1 |
| Emergence: Complexity and Organization | 3 |
| Environmental Management | 1 |
| Health Care Manage Sci | 1 |
| International Journal of Health Geographics | 1 |
| International Public Management Journal | 1 |
| Journal of Coastal Research | 1 |
| Journal of Simulation | 1 |
| Policy and Complex Systems | 7 |
| Policy Sci | 1 |
| Public Administration Quarterly | 2 |
| Science | 1 |
| Water Resource Manage | 2 |
| **Total geral** | **35** |

selected those that fit our research questions and the inclusion/exclusion criteria. Then, 133 studies were removed from the final step. Finally, we did a careful reading of the final sample (n=42), of which 7 were excluded due to inadequacy to our research purposes, and thus reaching the final number of 35 studies, which came from a variety of journals (table 3) and countries, as shown in figure 1. Figure 2 represents the PRISMA flow diagram of such results.

## Data Synthesis

We used a spreadsheet to synthesize the information from all the selected papers. Since there are two major objectives in this study, first we separated descriptive (conceptual) studies from applied studies. Here, we considered as "applied" the studies containing models, simulations or even empirical evidence from real-world policies. In both cases, we performed individual critical appraisals of each study, based on an assessment adapted from Mays and Pope (2000), and then we rated the studies as high (A) or low (B) quality, as shown in table 4. The assessment of each study is presented in table 5. Finally, we structured the studies in concept-centric matrixes (Webster, Watson, 2002) and we decomposed the 2 original broad research questions into a topic-specific approach. This method enabled a more intelligible classification of the studies and allowed the researchers to focus on analyzing and discussing the data. In addition, this spreadsheet was used to summarize and combine the results of the studies, and thus provided an overall picture of the current state of complex systems for public policies.

## Findings

In general, the select studies show how positive can be the connection between public policies and complexity theory. After reading the 35 studies, we did not find

## Table 5: Results from the critical appraisal

| Reference | Type of study | Relevance | Clarity | Appropriateness of method | Context description | Sampling | Data collection and analysis | Reflexivity by the author | Total |
|---|---|---|---|---|---|---|---|---|---|
| Maroulies et al (2010) | Descriptive | | • | • | • | | | • | •••• |
| Dombkins (2014) | Descriptive | • | • | • | • | | | | •••• |
| Ghorbani et al (2014) | Descriptive | • | • | • | • | | | • | ••••• |
| Inguaggiato & Occelli (2014) | Applied | • | • | • | • | • | • | • | ••••••• |
| Kaplan & Galea (2014) | Applied | • | • | • | | | | • | •••• |
| McPhee-Knowles (2014) | Applied | • | • | • | • | • | • | • | ••••••• |
| Badham (2014) | Descriptive | • | • | | • | | | • | •••• |
| Chernicoff et al (2014) | Applied | • | • | • | • | • | • | • | ••••••• |
| Pinheiro, Filho, & Sarti (2012) | Descriptive | • | • | • | • | | | • | ••••• |
| Morçol (2010) | Descriptive | • | • | | • | | | • | •••• |
| Bankes (2005) | Descriptive | | • | | • | | | | •• |
| Dearing, Dawson, & Puppy (2012) | Descriptive | | | • | • | • | • | | •••• |
| Scott Jr. (2010) | Descriptive | • | • | • | • | • | • | • | ••••••• |
| Morçol (2012) | Descriptive | • | • | • | • | | | • | ••••• |
| McClure et al (2015) | Applied | • | • | • | • | • | • | • | ••••••• |
| Ferrante et al (2007) | Applied | • | • | • | • | • | • | • | ••••••• |
| Young, Borland, & Coghill (2010) | Applied | • | • | • | • | • | • | • | ••••••• |
| Thieler et al (2000) | Applied | • | • | • | • | • | • | • | ••••••• |
| Badland et al (2013) | Applied | • | • | • | • | | | • | ••••• |
| Chen et al (2012) | Applied | • | • | • | • | • | • | • | ••••••• |
| Zivkovic (2015) | Descriptive | | • | • | • | | | | ••• |
| Johnston, Matteson, & Finegood (2014) | Descriptive | • | • | • | • | • | | • | •••••• |
| Winz, Brierley, & Trowsdale (2009) | Applied | • | • | • | • | | • | • | •••••• |
| Akhbari & Grigg (2013) | Applied | • | • | • | • | | | • | ••••• |
| Lyons & Duggan (2015) | Applied | • | • | • | • | • | • | • | ••••••• |
| Cockerill, Daniel, Malczynski, & Tidwell (2009) | Descriptive | • | • | • | • | • | • | • | ••••••• |
| Osman & Nikbakht (2014) | Applied | • | • | • | • | • | • | • | ••••••• |
| Meek, De Ladurantey, & Newell (2007) | Descriptive | • | • | • | • | | | • | ••••• |
| Anderson, Chaturvedi, & Cibulskis (2007) | Applied | • | • | • | • | • | • | • | ••••••• |
| Mischen & Jackson (2008) | Descriptive | • | • | • | • | • | • | | •••••• |
| Mischen & Jackson (2008) | Descriptive | • | • | • | • | | | • | ••••• |
| MacGillivray & Gallagher (2012) | Descriptive | • | • | • | • | | | • | ••••• |
| Martin & Neugart (2009) | Applied | • | • | • | • | • | • | • | ••••••• |
| Rhodes & Murray (2007) | Descriptive | • | • | • | • | • | • | • | ••••••• |

significant criticism of the use of complex systems applied to the public policy area. In fact, we found only one study (2.86%) in which the author argues, "models are an oversimplification of reality" (Thieler, Pilkey Jr., Young, Bush, & Chai, 2000), in a criticism of the models used to predict beach behavior in the United States. In all the other 34 studies (97.14%), the authors argue explicitly in favor complexity theory for public policies. Other than Thieler et al. (2000), four studies present issues in the application of complexity theory to the public policy arena, as shown in table 6. However, these four studies are mostly focused on the benefits of complex systems tools.

**Table 6: Main issues in the application of complexity theory to public policies**

| Reference | Main issues |
|---|---|
| Ghorbani et al (2014) | Agent-based modeling (ABM) requires enhancement. |
| Morçol (2010) | Complexity theorists need to incorporate what is already known in public policy. In addition, there is not a distinct alternative, as complex adaptive systems (CAS) overlaps with some theories that already exist. |
| Thieler et al (2000) | Some models are an oversimplification of complex systems that are poorly understood. |
| Zivkovic (2015) | Complex system approach is difficult to public administrators. |
| Winz, Brierley, & Trowsdale (2009) | It does not provide exact solutions. In addition, the likelihood that two individuals will develop the same system dynamics model is small. |

**Table 7: The benefits of complexity theory to public policies**

| Topic | Statement | Evidence | Reference |
|---|---|---|---|
| Data aggregation | Do complex systems help to demonstrate how individual decisions relate to group level results? | Strong evidence in favor of statement (1) | Maroulies et al (2010) (A); Ghorbani et al (2014) (A); McPhee-Knowles (2014) (A); McClure et al (2015) (A); Anderson, Chaturvedi, & Cibulskis (2007) (A). |
| Identification of problems | Do complex systems help to identify problems of public policies in advance? | Strong evidence in favor of statement (1) | Badham (2014) (A); Chen et al (2012) (A); Cockerill, Daniel, Malczynski, & Tidwell (2009) (A). |
| New insights | Do complex systems help to gain new insights of public policies? | Strong evidence in favor of statement (1) | Kaplan & Galea (2014) (A); Chernicoff et al (2014) (A); Dearing, Dawson, & Puppy (2012) (A); Scott Jr. (2010) (A); Chen et al (2012) (A). |
| Government relationships | Do complex systems help to realign government relationships? | Weak evidence in favor of statement (1) | Inguaggiato & Occelli (2014) (A). |
| Nonlinear systems | Do complex systems help to analyze nonlinear systems of public policies? | Strong evidence in favor of statement (1) | Pinheiro, Filho, & Sarti (2012) (A); Morçol (2010) (A); Morçol (2012) (A); Lyons & Duggan (2015) (A); Cockerill, Daniel, Malczynski, & Tidwell (2009) (A); Rhodes & Murray (2007) (A). |
| Testing of policies | Do complex systems help to test policies "a priori"? | Strong evidence in favor of statement (1) | Ferrante et al (2007) (A); Badland et al (2013) (A); Akhbari & Grigg (2013) (A); Anderson, Chaturvedi, & Cibulskis (2007) (A). |
| Complex problems require complex systems | Do complex problems, such as public policies, require complex systems? | Strong evidence in favor of statement (1) | Dombkins (2014) (A); Zivkovic (2015) (B); Johnston, Matteson, & Finegood (2014) (A); Winz, Brierley, & Trowsdale (2009) (A); Lyons & Duggan (2015) (A); Osman & Nikbakht (2014) (A); Meek, De Ladurantey, & Newell (2007) (A); Mischen & Jackson (2008) (A); Mischen & Jackson (2008) (A); MacGillivray & Gallagher (2012) (A); Martin & Neugart (2009) (A) |

To answer our primary research objective ("Is complexity theory beneficial to public policies?"); we divided our answer 7 different topics, since the authors of the 34 "positive" studies provided different rationale to argue in favor of complex systems. Then, we sum the number of authors in favor of each topic and classified such conclusions as a strong (1) or weak (0) evidence. If three or more studies of high quality, as classified in table 5, supported a given topic, then we assigned 1. In contrast, we assigned 0 to the remaining topics. The results of each topic are presented in table 7.

**How do public policies benefit from complexity?**

There is a strong evidence in favor of the application of complexity theory to public policies. However, the reasons vary. Since complex collective behavior and interactions among heterogeneous agents are in the core of public policy implementation, policymakers are unable to foresee all the consequences of their actions, and thus some tools used by complexity researchers comes handy. In some sense, some of the topics presented in table 7 could be assembled, but it is important to note how the authors approach the coming of such theories and tools. For example, 6 different authors argue that complex system tools, specially agent-based modeling (ABM), can help to aggregate data from the individual level (agents) and then relate such data to the outcomes from the group level (Anderson, Chaturvedi, & Cibulskis, 2007; Ghorbani, Dechesne, Dignum, & Jonker, 2014; Maroulies et al, 2010; McClure et al, 2015; McPhee-Knowles, 2014). In their turn, Badham (2014); Chen et al (2012); and Cockerill, Daniel, Malczynski, and Tidwell (2009), argue that complex systems can help to identify problems of public policies in advance.

In a slightly different perspective, there are those authors that recommend the use of some tools to gain insights (Chen et al, 2012; Chernicoff, Naumov, Shahryar, & Holzer, 2014; Dearing, Dawson, & Puppy, 2012; Kaplan & Galea, 2014; Scott Jr., 2010). There are also those that recommend such tools to simulate and test policies "a priori" (Akhbari & Grigg, 2013; Anderson, Chaturvedi, & Cibulskis, 2007; Badland et al, 2013; Ferrante, Levy, Peruga, Compton, & Romano, 2007), mainly comprised of ABM, system dynamics and simulations. Cockerill, Daniel, Malczynski and Tidwell (2009), Lyons and Duggan (2015), Morçol (2010 & 2012), Pinheiro, Filho, and Sarti (2012), and Rhodes & Murray (2007) argue that complexity theory can help in the analysis of nonlinear systems, which is the case of public policies.

**What are the issues in approaching public policies with complexity lenses?**

Modeling is an important aspect of complex systems. In this way, criticism of modeling and simulation techniques are also applied to complexity theory. Thieler et al. (2000) argues against models that are merely an oversimplification of reality, and then recommends different approaches that, in his view, are better than usual modeling.

In addition, Morçol (2010) reasons that complex system researchers need to incorporate what is known in public policy. Ghorbani et al. (2014) and Zivkovic (2015) make other criticisms; however, the strongest evidence comes from Winz, Brierley, & Trowsdale (2009), who say that models do not provide exact solutions, and that it would be almost impossible for two researchers to build similar models. However, they argue

**Table 8: Covered topics in the included studies**

| Covered topics | Number of studies |
|---|---|
| Economy | 1 |
| Economy; Healthcare | 1 |
| Education | 1 |
| Employment | 1 |
| General | 13 |
| Healthcare | 8 |
| Hydrology | 3 |
| Land use | 1 |
| Land use; Healthcare | 1 |
| Models | 1 |
| Urban issues | 4 |
| **Total Geral** | **35** |

that the use of system dynamics can help in the comparison of different policies "a priori".

**In what contexts was complexity theory explored in public policies?**

Even though complexity theory can be applied in a variety of policy areas, we have found the predominance of studies on healthcare policies (table 8), considering only those applied in a specific area. There are 13 studies (28.89%) that are not topic-specific, i.e., they rather focus on the use of complexity applied to public policies generically, or on the use of specific tools of complex systems.

It should be noted that there are two studies that focus on two topics each: Pinheiro Filho, and Sarti (2012) (economy; healthcare) and McClure et al (2015) (land use; healthcare).

It should be noted that some applications of complexity theory in sub-sectors of public policies were not covered by our search strategy. For example, this is the case of science policy and innovation studies (SPIS), as defined by Martin (2012). Because typical innovation systems are more than the sum of its parts (Muller, Héraud, & Zenker, 2016), there is a growing interest in using complex systems to inform policies in this area, mainly related to the improvement of current indicators used by governments (Katz, 2006 & 2016).

**What are the main complex system tools recommended for policymakers?**

To answer this question, we used two different approaches. First, we analyzed only the tools used in the 17 applied studies, i.e., those that present an empirical evidence, a model, or a simulation (table 9). Second, we read the 18 conceptual studies and analyzed whether there was a recommendation of a complex system tool (table 10). In this sense, we can see a predominance of agent-based modeling (ABM) in both tables 9 and 10. Considering only the applied studies, ABM represents 47.06% of the total. System dynamics were used in 23.53% of the studies. When it comes to the conceptual studies, 11 out of 18 recommended one or more tools for the use in public policies. Of these 11, ABM was cited in eight (72.7%) studies.

**Table 9 - List of applied studies and tools used**

| Reference | Covered topics | Tools used |
|---|---|---|
| Inguaggiato & Occelli (2014) | General | Social network analysis |
| Kaplan & Galea (2014) | Healthcare | ABM |
| McPhee-Knowles (2014) | Healthcare | ABM |
| Chernicoff et al (2014) | Economy | System dynamics |
| McClure et al (2015) | Land use; Healthcare | System dynamics |
| Ferrante et al (2007) | Healthcare | Simulation |
| Young, Borland, & Coghill (2010) | Healthcare | Actor network |
| Thieler et al (2000) | Land use | Mathematical modeling |
| Badland et al (2013) | Urban issues | ABM |
| Chen et al (2012) | General | ABM |
| Winz, Brierley, & Trowsdale (2009) | Hydrology | System Dynamics |
| Akhbari & Grigg (2013) | Hydrology | ABM |
| Lyons & Duggan (2015) | Healthcare | System Dynamics |
| Osman & Nikbakht (2014) | Urban issues | Game theory |
| Anderson, Chaturvedi, & Cibulskis (2007) | Healthcare | ABM |
| Martin & Neugart (2009) | Employment | ABM |

**Table 10 - List of conceptual studies and recommended tools.**

| Reference | Recommendation of tool |
|---|---|
| Maroulies et al (2010) | ABM |
| Dombkins (2014) | Systems thinking; Multiple views; Technical Enterprise Readiness Index; ABM; WAVE Modeling |
| Ghorbani et al (2014) | ABM |
| Badham (2014) | Concept mapping, soft systems, flowcharts, causal loop diagrams, social network analysis, games, state transition, microsimulation, system dynamics, discrete event simulation, ABM |
| Pinheiro, Filho, & Sarti (2012) | ABM, Cellular automata |
| Morçol (2010) | ABM |
| Bankes (2005) | No |
| Dearing, Dawson, & Puppy (2012) | ABM, Cellular automata |
| Scott Jr. (2010) | No |
| Morçol (2012) | ABM |
| Zivkovic (2015) | New tool |
| Johnston, Matteson, & Finegood (2014) | Systems science |
| Cockerill, Daniel, Malczynski, & Tidwell (2009) | System dynamics. Collaborative modeling |
| Meek, De Ladurantey, & Newell (2007) | No |
| Mischen & Jackson (2008) | No |
| Mischen & Jackson (2008) | No |
| MacGillivray & Gallagher (2012) | No |
| Rhodes & Murray (2007) | No |

There can be many reasons that make ABM so predominant. For instance, Kaplan & Galea (2014) cite one of the advantages of ABM over other techniques: that the modeler needs to specify anticipated relations, leading to a higher level of transparency and documentation. In addition, Badland et al (2013), say that ABM helps to examine systems of autonomous individual agents that, programmed with simple rules, enable the researchers to analyze the system as a whole, in a bottom-up approach.

## Limitations

In this study, we tried to compile studies relating complex systems to public policies in the most systematic manner possible. However, the available studies vary significantly, which certainly makes assessments and classifications more difficult. In order to reach our objectives, we needed to combine different assessment tools for systematic literature review, coming close to the creation of a new method of SLR.

Another important issue is that some studies from the grey literature, or not published in peer-reviewed journals, were excluded, amounting to 20 studies. Other 13 studies were excluded due to date of publication (before 2005). In this manner, some important aspects of the relation between complex systems and public policies could have been lost due to these reasons.

In addition, our search strategy was limited to published materials written in English language. For example, a search in the library system of the University of Sao Paulo (buscaintegrada.usp.br) for the terms "*des systèmes complexes*" AND "*politiques*" (French) resulted in 6 more articles, while a search for "sistemas complejos" AND "políticas" (Spanish) resulted in 21 articles in the same library system. Moreover, this strategy could not cover the intersection of complex systems sciences and sub-sectors of public policies, since our main objective was to investigate public policies in the broader sense.

Finally, it is important to note that the quality assessment of individual studies, as presented in table 4, was carried out by the researcher, but some aspects of the methods were subjective, i.e., a different researcher could come to a different conclusion using the same methods.

## Conclusion

This SLR is the first synthesis of studies exploring the use of complex systems in public policies. Also, this study enabled the use of a hybrid method for assessing studies in a SLR, specially for social sciences, where studies on the same topic can be very distinct. This SLR shows that there is a strong evidence in favor of the application of complexity theory to the public policy area. For instance, all of the descriptive studies (100%) argued in favor of such use, whereas only 1 of the applied studies presented an explicit criticism, but not directly related to the purpose of this study, but rather related to the use of models in general. Also, it seems that researchers from different parts of the world are concerned with the current methods in public policies, since the studies included in this review are from 13 different countries on 5 continents.

However, there seems to be a distance separating research from practice, i.e., even though we have found some applied research in the area, none of them presented a case-report of an application where complexity theory helped policy formulation and/or implementation. Even though Zivkovic (2015) argued that complexity theory is difficult to public administrators, this bridge needs to be given priority, because, as we have seen, there is a very strong consensus that there are many benefits in such application. Such adversity, however, is not unique to complex systems. Many authors have already researched and provided recommendations on how to communicate research to policy makers and, fortunately, such solutions are feasible to meet the needs of complex systems science. These recommendations often include proposals to enhance the network and develop relationships with policy makers; to involve policy makers in the research; to hold meetings, conferences and workshops with policy makers; and to carry out systematic reviews aimed at policy practice. The proposals aforementioned arose from authors in the areas of healthcare (Lavis et al., 2010; Feldman, Nadash, & Gursen, 2001), natural resources management (Gibbons et al., 2008), drug abuse (Gregrich, 2003) and economics (Pannel, 2004).

In our analysis of the applied studies, we found a major concern in the areas of healthcare and even more to discuss the policy process itself. Another manner of "building the bridge" between researchers and policymakers is to help solving real-world problems and thus arouse in them more interest in complex systems. A policymaker might not be interested in how to formulate a policy (the process), but rather on how to solve the problem he needs to solve. In this sense, more applied studies on the areas of education, employment and urban issues are needed. Also, from the applied studies, we can observe that ABM is certainly the preferred tool used by researchers. Public policies are an area where decentralization is important, and this may lead to the success of ABM.

The excitement around complexity theory also brings concerns. Complex systems are a relatively new area in science. Despite the increasing number of researchers in many areas, such as public policies, economics and physics, complex system researchers, who may be biased towards their own field of research, called “Myside Bias”; conduct the applied systems (Stanovich, West, & Toplak, 2013; Baron, 1995). Other types of bias that can be directly related to complex systems are the "Optimism Bias" (Weinstein, 1980), the "pro-innovation bias" (Rogers, Shoemaker, 1971), "system justification" (Jost & Banaji, 2004) and "self-serving bias" (Miller, Ross, 1975), since most of the studies included in this review were carried out by complex system researchers, and not policymakers, that could have a more critical view of this approach.

At the outcome level, the complex systems approach for public policies is in its early stages and there is no debate between conventional and complex systems. Unlike medicine and related sciences, the number of SLRs in social sciences is low, as well as the number of randomized controlled trials (Parris & Peachey, 2012), what led us to include a high number of descriptive studies combined with the applied ones.

There are many opportunities for future studies. For instance, we did not find studies to measure the level of complexity of public policies' environment, which could be done through the quantity of information of a given situation or by the entropy increase of a system. Also, as already mentioned, there are few real-world applications of complex systems to public policies. In this manner, good models and simulations are as important as the ability to pass on the information until it reaches policymakers, who in fact have the power to implement them and make them useful.

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