In this manuscript the authors discuss why it is important to employ complexity science to study policy and governance systems. Citing the need to develop better understanding of how these systems are resilient, adaptive and self-organizing, they describe complex policy and governance systems within the context of innovation, change and collapse. The authors then discuss how complex social systems are being analyzed in terms of systems dynamics and network architectures. Five theoretical frameworks of policy and governance systems including the multiple policy streams, punctuated equilibrium, institutional analysis and development, advocacy coalition and governance network frameworks are presented as some of the “complexity friendly” frameworks that have been devised to incorporate whole systems properties. We assess whether and how these frameworks are accommodating to complex adaptive systems modeling and how they may be used to generate hypothesis that may be tested, within limits, using complex adaptive systems modeling. Further, we assess the potential utilization of some innovative complex systems modeling tools, such as agent based models, discrete event models, and complex systems dynamic modeling to inform a meta-theoretical research program for comparing and refining alternate theoretical frameworks with respect to their adequacy in accounting for non-linearity, lags, inertia, cross-scale interactions and complex feedback loops.

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Theory Testing Using Complex Systems Modeling
in Public Administration and Policy Studies:
Challenges and Opportunities for a Meta-Theoretical Research Program

Over the past fifteen years a discussion concerning the potential role that complexity theory and science can play in addressing some of public administration and policy’s most persistent areas of interest and concern has taken place (Kiel, 1994; Comfort, 1994; Haynes, 2003; Farazmand, 2003; Dennard, Richardson and Morcol, 2008; Teisman, van Buuren, and Gerrits, 2009). Those contributing to this growing body of literature have drawn on the now widespread recognition that “wicked problems” operating on many different levels of scale (Rittel and Webber, 1973) confront public administrators and policy analysts, and suggest that complexity theory and science has the potential to approach wicked problems with fresh eyes.

Wicked problems may surface as a region’s capacity to respond to catastrophic events or a stubborn bureaucracy’s failure to adapt and innovate to meet changing needs. Wicked problems may be seen on a societal level as persistent and entrenched public policy problems or at the interpersonal levels within the blurring of lines between politics and administration; individual belief systems and institutional rules and norms. In this manuscript, we argue that wicked problems persist because our failure to understand their complexity. We argue that we have, thus far, failed to integrate the role of non-linear feedback loops operating within complex policy and governance processes into our theories and empirical research. As a result we have failed to capture how self-organizing and emergent behaviors contribute to innovation and change, as well catastrophic or near catastrophic failure. We argue that the emergence (or conversely, the seeming lack of emergence) of new behaviors, actions and events from seemingly stable and predictable structures and functions may be viewed as one of the primary forces driving the wickedness of public policy and public administration problems.

Klijn and Snellen have observed how, “The history of the field of public administration could be viewed as an ongoing attempt to search for concepts to grasp the complexity of day-to-day practices in policy-making and decision-making” (Klijn and Snellen, 2009, p.17). To a certain extent, complexity has always been a part of every day public management and policy practices. Just as field of physics “has discovered complexity by complicating its own language of description,” (Tsoukas, 2005, p.236), we argue here that public administration and policy has come to complexity science in much the same way. The meta-theoretical underpinnings of complexity theory, coupled with the computational tools and modeling capacity being utilized in complexity science, provides the field of public administration and policy with tools to employ this language to study observable phenomena. In this manuscript we discuss how the language and science of complexity may be combined with some of our existing policy and governance “complexity friendly” frameworks to provide the basis for a next generation meta-theoretical program.
Policy and Governance Processes as Complex Adaptive Systems

In this section we explore the relationship between rationality, bounded rationality, and non-rational processes, and emergent, self-organizing and adaptive properties of policy and governance systems. We suggest that the tensions that are inherent within the social sciences more widely between the deterministic sciences found in positivism and the relativistic sciences found in interpretivism are present in most models of complex adaptive systems as well and argue that this tension may be harnessed under a regime of theory-testing. We conclude by laying out a rationale for why public administration should be interested in the kinds of analysis that are possible using complexity theory and science.

Rationality, bounded rationality, and non-rationality.

Klijn and Snellen argue that our theories of public management and policy are often predicated on a continued reliance on theories of rational action found in most market-oriented and performance-based reforms of the past thirty years (2009). Arguably, no discussion of policy and decision making in the field today can be had without ascertaining the extent to which purely rational behavior and action is possible given the bounded rationality or near irrationality of social actors.

Rationality has been contested at a fundamental level as a Newtonian enterprise that is typically based upon a host of ultimately unprovable assumptions, e.g. decision makers know all possible permutations and combinations of alternatives, anticipate the complex sequence of events that could follow those alternatives and predict with certainty the consequences of those alternatives after these events have taken place. It has been widely noted, beginning with Herbert Simon (1957) and Charles Lindblom (1959), but extending well into contemporary times, that human behaviors and the range of societal interactions that shape them are not easily explained through collective or rational choice theories. Bounded rationalists accept the “premise” of rationality; while others reject any notion of rationality itself, adhering to the notion that people just act spontaneously, emotionally and instinctually. Bounded rationalists and those that reject the premise of rationality all understand that social agents see the world through the veils of their own subjectivity. They affect one another, forming shared mental models (Senge, 1990), collective theories-in-use, and norms that guide virtually every facet of social interaction (Argyris and Schon, 1996). This is a view adhered to by social psychologists who approach social agency as a matter of collectively constructed belief networks, and a range of mental and cultural models that could not be tested against any norm of rationality. In public administration and policy, we see widespread recognition that the social construction of numbers, symbols, metaphors, and narratives shapes power and political dynamics operating between social agents (Stone, 2002). Applying complexity science to the study of socially constructed phenomena will not reconcile the tensions that persist between the

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1 This widespread recognition of the bounded rationality of social actors has not stopped us from It is also noteworthy that the application of game theory, now common in behavioral economics, social psychology, and political science is based on idealization of social behaviors. These predictions are based on simplifications of what often amount to be highly complex, non-rational drivers of social interaction.
base assumptions guiding most theories of rationality, bounded rationality and rationality-defying mental and cultural models.

We argue, however, that those looking to apply complexity science and theory to the study of policy and governance phenomena will be pressed to avoid the kinds of positivist and postpositivist legacies found in most computer simulation models of complex systems (Buijs et al., 2009). These legacies become real modeling challenges as attempts are made to “make sense” of socially constructed belief systems. Agents in simulation models are given “decision rules” devised to simulate naturally occurring phenomena (North and Macal, 2007). Rule making behaviors are assigned values or probabilities through the ascription of algorithms. Ascertaining the reliability of these algorithms necessarily draws upon positivistic assumptions found in quantitative analysis.

The ontological tensions that arise between the “naïve realist” or “empiricist epistemologies” found in the positivist traditions of science and the social constructionism common to more qualitative, interpretive sciences may be found in virtually any attempt to apply complexity science to the study of social phenomena (Buijs et al., 2009). We argue that although efforts to develop computer simulation models of complex policy and governance systems are essential for describing how parts of complex systems operate, we cannot rely on positivist, Newtonian approaches to science alone to describe the emergent, self-organizing and adaptive characteristics of nonlinear feedback loops and policy centric networks. These properties become, “The choices of agents in human systems are based on perceptions which lead to nonproportional over- and under-reaction; there are almost always many outcomes possible for any action; group behavior is more than simply the sum of individual behaviors...” (Stacey, 2006, p.80).

Although discrete events and processes may unfold in linear, somewhat predictable fashion and represent important facets of a policy or governance system’s functioning, rarely may a whole system be described in terms of such linearity. In the worst case, an ecological fallacy may result from confounding the analysis of isolated processes of, or events within, a system to the more broadly construed system as a whole. The simplifications that we are prepared to make to describe the linear relationships between two or more variables within discrete events or processes are often not enough to account for the complexity of the whole (Marion, 1999, p. 27-28). Indeed, our capacity and drive to describe how discrete events and processes are linked together into a wider whole system presses us to distinguish between merely complicated systems and complex systems that exhibit qualities of self-organization, adaptation and emergence.

Self-organization, adaptation and emergence

Complexity science can help us account for emergent behaviors through the discovery of simple rules that set in motion the chain of events leading to path dependent outcomes that are particularly difficult to rationally anticipate. Drawing from observations of the complex, coordinated behaviors of flocks of birds, fish and colonies of social insects, social scientists have discovered the simple rules that predict the flow of traffic on roadways and sidewalks, the behaviors of large crowds of humans, and the development of land use patterns (Batty, 2005). While the eloquence of these models and the shear fascination evoked from seeing patterns persist across species are stunning, they account for what may best be metaphorically deemed, the low hanging fruit of social complexity. Although we may arrive at a certain level of predictive authority to, say, anticipate how
changes to zoning laws will effect land use patterns, or the expansion of roadway capacity impacts traffic congestion, we will have a much harder time composing models that can account for more finer grained analysis of complex social systems in which outputs are not readily observable.

Studies of policy implementation have consistently reinforced the notion that predicting the coordinated actions of various combinations of policy actors is an undertaking wrought with uncertainties (Pressman and Wildavsky, 1973; Hill and Hupe, 2002). The successful implementation of a new program or regulation may hinge on the role of an individual champion, the unfolding of certain events, or the development of certain plans, laws or protocols that serve as particularly useful in guiding action. The combining, comingling and/or competition of dueling and complementary interests lead to the unpredictability of outcomes. When viewed through the lens of complexity science, such outcomes are “path dependent,” meaning that they are the result of certain combinations of activities that take place over the course of time (Pierson, 2004).

Path dependency fuels the capacity of complex systems to self organize, engraining them with the ability to make their own structures more complex (Meadows, 2008, p.79). Self-organization leads to the emergence of new structures and functions. Miller and Page, suggest that, “[E]mergence is a phenomenon whereby well-formulated aggregate behavior arises from localized, individual behavior. Moreover, such aggregate patterns should be immune to reasonable variations in the individual behavior” (2008, P.46). Thus, the emergence of new patterns of organization and behavior are formed “from the bottom up.” However, bottom up emergence arises from stable subsystems that may be driven by top down or reified rules and norms that provide for a system’s stability. “Complex systems can evolve from simple systems only if there are stable intermediate forms” (Meadow, 2008, P.83). These stable intermediate forms most likely exist at the meso levels of established organizations and institutions, and long standing, institutionalized communities of practice. These stable meso levels form the basis of subsystems that, “can largely take care of themselves, regulate themselves, maintain themselves, and yet serve the needs of the larger system, while the larger system coordinates and enhances the functioning of the subsystems, a stable, resilient, and efficient structure results” (Meadows, 2008, P.82). Instability in subsystems comes about through self-organization, resulting in the emergence of new behaviors, functions and structures.

In the agent-based models arising from the kind of matrix algebra found in Boolean statistics (Richardson, 2008a; 2008b) network agents construed as nodes in the network

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2 Theories of policy systems and networks can play an important role in determining which combinations of events and actions are important. Koopman and Klijn discussion of how decision making unfolds within complex governance networks is particularly useful here. Applying the Cohen, March and Olsen’s garbage can approach to decision making (1972), they lay out one way to articulate how network complexity can be modeled.

3 Paul Pierson notes that, “We largely lack a clear outline of why the intensive investigation of issues of temporality is critical to an understanding of social processes. The declaration that ‘history matters’ is often invoked, but rarely unpacked. Many of the key concepts needed to underpin analyses of temporal processes, such as path dependence, critical junctures, sequencing, events, duration, timing, and unintended consequences, have received only very fragmented and limited discussion” (Pierson, 2004, P.6). We have been effective at using time as a variable in studies relating to how the relationships between two or more variables change over time. Descriptions of how complex adaptive policy systems change over time have mostly been completed through case studies that have included timelines. Computer simulation models are also now being produced that try to capture the role that path dependency and nonlinear feedback plays in complex adaptive systems.
are guided by decision rules and scripted relationships (Stacey, 2006). These rules and scripts are oftentimes described in terms of the decision heuristics of agents (North and Macal, 2007). These heuristics may be guided by formalized institutional rules, laws and contracts, as well as through commonly held social norms and shared beliefs. Emergence results when agents change these rules and scripts, or change their reactions to these rules and scripts. The complex interaction between stable institutional rule structures and active and semi-autonomous social agents helps to determine the relative stability or instability of the system. In more relatively stable social systems, instances of instability have been recognized as moments of “punctuated equilibrium” (Baumgartener and Jones, 1993), during which social systems can experience sudden and profound changes.

Stability and instability of complex policy and governance systems

The extent to which a policy and governance system is stable or experiences instability should matter to those interested in public administration and policy. Unstable systems, or at least unstable subsystems of a larger system, are needed to foster innovation or change. We find the PA field interested in these phase transitions in the literature on adaptive environmental management (Norton, 2005) and the transition management of sustainable systems (Kemp and Loorbek, 2003). However, when instability strikes a system on such a scale as to trigger a cascading effect of increasingly strong, positively reinforcing feedback loops, a collapse of the entire system is one of the possibilities in which a system can stabilize. When such large scale instability ripples through a society, revolutions are spawned. Such large scale instabilities can also be triggered by natural disasters like tsunamis, hurricanes, tornados and other acts of nature; human error in critical systems such as the recent financial crisis, nuclear power plant meltdowns, oil rig blowouts, or widespread power blackouts; or intentionally triggered chaos, such as those found in acts of terrorism. Complexity science is deepening our capacity to ascertain the alternative stable states of complex systems or in the very least the stability of subsystems within larger systems. We may use this capacity to simulate system instability when innovation and change is called for, or maintain system stability during instances of shocks to the system.

Ascertaining the resilience of policy and governance systems becomes a critical feature in managing uncertainty and anticipating risk (Koopenjan and Klijn, 2004). "Large organizations of all kinds, from corporations to governments, lose their resilience simply because the feedback mechanisms by which they sense and respond to their environment have to travel through too many layers of delay and distortion" (Meadows, 2008, p.78), and the same may be said for systems on the whole. The resilience of complex policy and governance systems becomes important because systems can experience catastrophic failure (as in the recent cases of failed emergency management networks and financial regulation networks) or be so stable that they fail to adapt to changing conditions (as highlighted in the many instances of bureaucratic inertia).

According to Stacey, the application of complexity science to the study of social systems, "will have to focus on the meanings of the irregular patterns of behavior observed and on reasoning about the kind of system those patterns are being generated by. Instead of looking for causes and effects it [will be] necessary to look for patterns and their systemic implications" (Stacey, 2006, p.96). We argue that the PA and policy field has made extensive inroads into understanding how patterns persist in complex policy and
governance systems. The challenge lies in taking these theoretical and decidedly qualitative observations to test the efficacy of these models to provide some basis for explaining the emergence, adaptation and self-organization of system or sub-systems.

**Theory-testing policy and governance frameworks**

Theory testing allows scientists to prove the significance of certain casual patterns and draw inferences regarding the generalizability of claims derived from these evidence-based patterns. The emergent, self-organizing and non-linear qualities of complex adaptive systems places significant constraints around the capacity of social scientists to draw inferences from the kind of computer simulation modeling that is required of most studies of complex adaptive systems (Bankes, 2002).

Within PA and policy the application of computer simulation modeling to address the kinds of questions of most important concern to the field have begun to emerge. Agent based models have been constructed of collaborative governance groups, the combination of computer simulation models with game theory have yielded studies that examine some of the fundamental tenants guiding the establishment of voluntary ties (Axelrod and Cohen, 1999), with specific inferences drawn to administrative practice (Knott, Miller and Verkuilen, 2003; Jonston et al., 2008; Nan et al., 2008; Johnston et al., 2010). A body of complementary, yet incommensurate, theoretical frameworks have evolved to describe the relationship of coalition formation and policy development, the persistence of network ties established to achieve particular policy goals; the role of feedback and equilibrium in the formation and implementation of public policies; and the coupling of policy streams. We assess whether and how these theories are accommodating to complex adaptive systems modeling and how they may be used to generate hypothesis that may be tested, within limits, using complex adaptive systems modeling. Further, we assess the potential of some innovative complex systems modeling tools, such as agent based models, discrete event models, and complex systems dynamic modeling, to inform a meta-theoretical research program for comparing and refining alternate theoretical frameworks with respect to their adequacy in accounting for non-linearity, lags, inertia, cross-scale interactions and complex feedback loops.

In the next section we argue that public administration and policy researchers have drawn on an extensive body of case study data to devise and refine a wide array of systems-based and network based theoretical frameworks. These theories and frameworks are “complexity friendly” because they can:

- Avoid simple reductionism, addressing the holistic properties of complex systems;
- Accommodate the existence of new structures and functions;
- Accommodate the existence of feedback, stocks & flows, inputs and outputs;
- Allow for the self organization of the system as a whole or parts of the subsystem;
- Allow for dynamic interactions that lack clear cause and effect relationships; and
- Accommodate time and path dependencies.

We discuss a range of theories and frameworks found within the public administration and policy studies literatures that have been devised to explain whole policy and governance systems. We are quick to note, however, that the five frameworks selected here do not represent all of the possible complexity friendly public administration and policy theories that exist. In the concluding section we argue that the epistemological foundations of
complexity science need not be viewed as mutually exclusive of the wide ranging, domain specific theories of public administration and policy studies.

**Complexity friendly public administration and policy theories**

In this section we describe how system dynamics and network architectures provide a meta-theoretical link between five PA and policy theories presented here. We describe systems dynamics and network architectures as the base of a meta-theoretical framework that may be employed to study policy and governance systems within simulated environments. We discuss how some of the selected frameworks devised to study policy and governance systems use many of the basic tenants of system and network theory as epistemological foundations.

We argue that these “whole system” frameworks serve as the bridge between the highly particular contexts and applications found within specifically observed phenomena, and the systems and networks foundations that persist across all natural and social systems. Although useful thought experiments and “toy models” may be constructed to aid in our understanding of complex policy and governance systems, developing models of these systems that are calibrated to patterns at multiple scales of observation is critical if complexity science is to have utility for the public administration and policy field.

Calibration of complex systems models with observed patterns has been used for theory testing in ecology (Grimm et al., 2005), sociology and anthropology (Epstein, 2006), business management (North and Macal, 2007), and land-use policy (Manson and Evans, 2007) among many other arenas.

**System dynamics and network architecture**

The evolution of general systems theory has been told many times, with its origins dating back to the 1920s (von Bertlanffy, 1968). Early on system dynamics frameworks were used to describe biological and a little later mechanical systems. These theories became more readily applied to social systems beginning in the 1960s (Boulding, 1956; Simon, 1966). The public administration field adopted system dynamics constructs in various iterations of public budgeting reforms (Schick, 1966) and policy analysis (Dror, 1967). A little later, system dynamic frameworks began to be applied to explain organizational dynamics. Organizational theorists like Simon (1966), Perrow (1967), Katz and Kahn (1978), Ackoff (1980), Minzberg (1983), Scott (1987), and Wieck (1976) began to explain organizational behavior in terms of stocks and flows, the transmission of authority and power, and the relationship between an organization and its external environment. “Systems thinking” became popularized in the late 1980s with Peter Senge’s work (1990). To this day the organizational sciences apply system dynamics frameworks to describe how organizations work and use these descriptions to undertake strategic planning (Richardson, 1991). The popularity of the “logic model,” predicated on charting the relationship between inputs, processes, outputs and outcomes is now widely used in program and performance evaluation contexts (Poister, 2003). This application of systems theory may be tracked back to the “soft systems” applications first envisioned by Checkland (1978) and others in the 1970s (Lockett and Spear, 1980). Although the kind of conceptual
models that are derived through the application of the logic model and other system thinking tools and techniques can be used to capture some of the emergent, self-organizing properties of complex systems, these models are ultimately only capable of capturing the temporal dimensions of social adaptation and change when applied within computer simulation modeling.

The building blocks of a dynamic system are the ebb and flow of resources, and more specifically, the translation of one form of resource into another. The most typical example of this can be found in the utilization of financial resources to undertake an action, which, in turn leads to results. In this sense, money is inputted into the system, and usually nonmonetary results (for example children educated, clients served, waterways cleaned, material goods provided) are outputted. The drivers that support these dynamics can be described in terms of feedback loops. These feedback loops are, themselves, driven by the structural and functional relationship that exists between two or more social actors in a network (Baumgartner and Jones, 1993).

Network analysis has been a staple of social science research for many decades. Anthropologist Alfred Radcliffe-Brown was the first to make the case that any observation of social phenomena needs to be anchored in, “the patterns of behavior to which individuals and groups conform in their dealings with one another” (1940, p.228). Network concepts have a long and rich history of being used to study organizational form and the diffusion of information across social structures. Social network analysis may be traced to the early Hawthorn experiments of 1924 to 1932, marking the first use of “network configurations to analyze social behavior...” (Berry et al., 2004, p.540). Social network analysis has been used to study the diffusion of knowledge, beginning with Coleman, Katz and Mentzel’s ground-breaking study of information diffusion in physician networks (1977). Stanley Milgram’s “small world” research is often cited as an important breakthrough in social network analysis, demonstrating the “six degrees of separation” that exist between any two people. Over the last few decades, the progress of social network analysis has benefited from advances in statistical methods and computer programs in much the same way as system dynamics modeling has (Wasserman & Faust, 1994).

We argue here that capturing the behavior of complex adaptive social systems ultimately requires the integration of both system dynamics and network architecture. Whole systems are comprised of networks of social agents that are bound together and influenced by agent characteristics, ties between agents, feedback loops unfolding between individual social agents and institutional rules, and a variety of exogenous factors that drive agent behavior. Classic social network analysis captures network structures at one point in time, but cannot easily account for the drivers that shape this structure, nor can it predict how the structure may change over time. Likewise, system dynamic models may provide some explanation for how components of a system relate and influence one another, but they generally do not capture the material practices that lead to collective action. The processes and activities found in system dynamics logic models require social agents to perform them.

Just how this performance is undertaken as a function of collective action may best be described in terms of network nodes and ties. Particular agents may be associated with

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4 There are, of course very important exceptions to this. Social networks may exhibit certain scale free qualities that are readily predictable [add footnote on scale free].
undertaking particular tasks or carrying out certain events. As tasks are collaboratively undertaken and events unfold through the agency of individuals and institutions, networks form. The deep integration of human and social capital, as Bourdieu clearly lays out, speaks to this point (1986). As tasks become collective practices, and events are shaped by the spaces within which common practices unfold “action arenas” form (Ostrom, 2005). Communities are built around common practices, often referred to as “communities of practice” in the organizational learning and knowledge management literature (Wenger, 1998; Koliba and Gajda, 2009). In this way, the characteristics of individual agents, including their mental models, decision heuristics, and their stock of existing resources, can have a significant influence on the structuring and functioning of the whole system. The nature of the ties between agents, the other major building block of networks, also can have a significant bearing on the whole system (Burt, 1997). However, the behavior and properties of whole systems must be considered as both the sum of all of the system’s parts (in this case, network nodes and ties), but also something significantly more that this sum.

Within the gap between the “sum of all parts” and “whole network behaviors and actions” lies a complex adaptive system’s capacity to undertake self-organization. The conclusion to be drawn from the differentiation of network structures and system dynamics is that our models of complex adaptive social systems ultimately need to incorporate both system dynamics and networks structures into them.

Theoretical frameworks of policy and governance systems

System dynamics and social network analysis are agnostic regarding ascribing deeper meaning or explanations for the kinds of linear causalities and nonlinear feedback loops found within complex adaptive social systems of particular structures and functions. To address these needs, we must turn to the broad array of social sciences mobilized to study human behavior (psychology and social psychology), social groups (sociology), organizational and institutional forms (organizational and management sciences), and the rise and fall of complex societies (anthropology and history).

Policy and governance systems organized around the framing of public problems, the deliberation of policy alternatives, and/or the implementation of public policies are complex social systems of a particular type. They are guided by dynamics that are governed by certain political and administrative practices undertaken by social agents representing a variety of public, private and nonprofit sector institutions and interests. There have been a number of conceptual frameworks that have been devised as comprehensive theories of complex governance and policy arrangements. The most widely known and respected framework is the institutional analysis and development (IAD) framework first developed by Nobel Laureate, Elinor Ostrom. The IAD framework draws on institutionalism and neo-institutionalism theories, game theory, transaction cost theory, and common resource pool theory to craft a description of multi-institutional systems that explain the crafting of public policy as ultimately an institutional design problem in complex “action arenas.” Ostrom (2005) emphasizes the roles that rules play in structuring governance arrangements. Drawing on her empirical analysis of natural resource management networks she makes a compelling argument in favor of more decentralized concentrations of power and authority to enhance performance in some institutional contexts and conditions. Other comprehensive frameworks may be found in John Kingdon’s multiple streams framework (1984), Baumgartner and Jones’ policy subsystem
and punctuated equilibrium framework (1993), and Paul Sabatier and associates’ advancement of the advocacy coalition framework (Sabatier and Jenkins-Smith, 1993).

Some of these frameworks impose homogenous assumptions about human decision making behaviors, such as expected utility maximizing behaviors in IAD, while others assume more unpredictable, chaotic decision making behavior, such as those found in the multiple streams framework. Another difference that arises across these frameworks concerns the balance between individual behavior and institutional norms and rules. ACF focuses attention on the role that common belief networks play in powerful advocacy coalitions. While IAD focuses more attention on the role that operational, collective choice and constitutional rules play in shaping multi-institutional arrangements.

A second grouping of theoretical frameworks common to PA and political science are built on the foundation of basic network architecture of nodes and ties. These theories and frameworks include policy network theory (Hedo 1978; Rhodes, 1997; Kickert et al., 1997), social network analysis (Waserman and Fuast, 199-; Comfort, 2007; Kapucu, 2006), public management networks (Milward and Provan, 1998; Agranoff and McGuire, 2003) and governance network frameworks (Sorensen and Torfing, 2005; 2008; Koliba et al., 2010). These frameworks account for the nature of the ties that are established between policy actors. Several of these frameworks account for the multi-scalar dimensions of social networks—meaning, they account for the fact that these networks are populated by individual people, groups, organizations and networks of organizations. The nature of the ties between these agents are premised on the types of resources that flow between them (Rhodes, 1997), the kinds of managerial strategies employed (Agranoff and McGuire, 2003) and the mixed structures of administrative authority (Koliba and Meek, 2009; Koliba et al., 2010) that persist within and across them.

In this manuscript we discuss how the system dynamics and network theories and frameworks that have evolved out of the public administration and policy fields can be drawn on to provide the theoretical foundations on which to model the complex adaptive systems that have emerged to create, coordinate and implement public policies. We argue that all of these theoretical frameworks are, to one degree or another, amendable to system dynamics and network modeling and therefore are “complexity friendly.” All of these theoretical frameworks are grounded in a system dynamics architecture. These frameworks operate through feedback loops, stocks and flows, and certain assumptions about input and output flows. All of these frameworks account for the roles that individual social agents, groups of agents and organizations play in the whole system. Some of these frameworks place a greater emphasis on either systems dynamics or network architecture. We will explore each of these below.
Table 1. Policy and governance frameworks relative to system and network theory

<table>
<thead>
<tr>
<th>POLICY AND GOVERNANCE FRAMEWORK</th>
<th>SYSTEM DYNAMICS</th>
<th>NETWORK ARCHITECTURE</th>
<th>LEAD AUTHORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple policy streams</td>
<td>Relationship between streams are characterized in terms of feedback loops</td>
<td>Streams are coupled through the joint actions of individual agents (organizations and/or policy entrepreneurs)</td>
<td>Kingdon, 2004</td>
</tr>
<tr>
<td>Policy subsystem/Punctuated equilibrium</td>
<td>System and subsystems undergo phase transitions...</td>
<td>Individual agents coalesce around certain policy domains</td>
<td>Baumgartner and Jones, 1993; 2003</td>
</tr>
<tr>
<td>Institutional Analysis and Development</td>
<td>Institutional rules inform the feedback loop and stocks and flows of resources</td>
<td>Role of individual agents in forming action arenas is important</td>
<td>Ostrom, 1990; 2005</td>
</tr>
<tr>
<td>Advocacy Coalition Framework</td>
<td>Advocacy coalitions influence one another through feedback</td>
<td>Belief systems of individual agents form into advocacy coalitions</td>
<td>Sabatier and Jenkins-Smith, 1993; Sabatier and Wieble, 2007</td>
</tr>
<tr>
<td>Governance and Policy Networks</td>
<td>Resource flows between agents in the network; policy tools and administrative actions provide feedback within the network</td>
<td>Relies on a basic node and tie configuration to explain agent interactions</td>
<td>Rhodes, 1997; Kickert et al., 1997; Sorensen and Torfing, 2005; Adam and Kriesi, 2007; Koliba et al., 2010</td>
</tr>
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</table>

Multiple policy streams

John Kingdon’s policy stream model, Figure 1, does not assume linearity, nor rational behavior on the part of policy actors. Problems, policies and politics streams may couple, and in fact, need to couple for agendas to be set and policy windows to open. Kingdon recognizes that policy streams are created and directed through social networks and indirectly asserted that social networks form within individual streams, and provide a basis for coupling of streams (1984). Kingdon recognizes that a number of policy actors, including interest groups, academia, media, and political parties coordinate actions within and across the policy stream. He grounds the policy stream model in the coordinated actions that arise during the pre-enactment phases of policy selection and design, although we may recognize the coupling of streams across all facets of the policy process.
Zahariadis observes that, "Much like systems theory, [policy streams] views choice as the collective output formulated by the push and pull of several factors... It shares common ground with chaos theories in being attentive to complexity, in assuming a considerable amount of residual randomness, and in viewing systems as constantly evolving and not necessarily settling into equilibrium (Kingdon 1984, p.219)" (2005, p.66). The extent to which problem, policy and politics streams are coupled is something that complexity science can shed light on, as coupling comes about through a generative process of interlocking feedback loops occurring across each stream. A wide range of actors are mobilized within each stream. Some of these actors span more than one stream—for example, a legislator may become convinced of the importance of a particular problem or policy solution and work to align the politics stream with a particular problem definition or policy tool. These dynamics can be modeled using systems dynamics tools.

**Punctuated equilibrium**

Baumgartner and Jones' punctuated equilibrium framework is predicated on the assumption that, “... policymaking both makes leaps and undergoes periods of near stasis as issues emerge on and recede from public agenda” (True, Jones and Baumgartner, 2007, P.157). Their view of policy subsystems draws extensively from the description of nonlinear systems dynamics discussed earlier in this manuscript. Their theory relies most directly on system dynamics models because of its reliance on feedback loops as a critical feature of subsystem dynamics.

The key factors of interest in punctuated equilibrium theory concerns the relationship between policy subsystems. This theory assumes that, “Political systems, like
humans, cannot simultaneously consider all the issues that face them, so policy subsystems can be viewed as mechanisms that allow the political system to engage in parallel processing (Jones, 1994). Thousands of issues may be considered simultaneously in parallel within their respective communities of experts. This equilibrium of interests does not completely lock out change. Issue processing within subsystems allows for a politics of adjustment, with incremental change resulting from bargaining among interests and marginal moves in response to changing circumstances” (True, Jones and Baumgartner, 2005, p.158-159).

Much like ACF, punctuated equilibrium theory recognizes the role that certain actors or combinations of actors play in establishing system wide equilibrium. These entanglements of subsystems are more than likely comprised of stable sets of institutional actors and rules. However, these same actors will likely produce “a plethora of small accommodations and a significant number of radical departures from the past” (True, Jones and Baumgartner, 2005, p.156). The ranges of small, short term accommodations and long term radical departures from the stable state must be placed within the context of the system as a whole. Those using punctuated equilibrium theory often rely on changes within the outputs or inputs of the whole systems over time to demonstrate phase transitions. Substantial deviations from the kind of variations attributable to small accommodations are noted. When radical changes to relatively stable patterns are noted, explanations are sought using system dynamics logic.

Institutional Analysis and Development (IAD)

Although there are many facets to Ostrom’s IAD framework, as shown in Figure 2, we highlight two of the major contributions it makes to the study of complex adaptive social systems here. These two facets concern the role that “rules-in-use” and rule making play in the structuring and functioning of these systems; and the “action arenas” through which these rules combine to structure action. Ostrom distinguishes between three types of rules: (a) operational rules that govern day-to-day activities of appropriators; (b) collective choice rules concerning overall policies for governing common pool resources and how those policies are made, and (c) constitutional choice rules that establish who is eligible to determine collective choice rules. The operational functions of any social system are governed by a complex array of operational rules, norms, habits and customs. Collective choice theory has long been viewed as a central feature of resource exchange frameworks. Collective choice is shaped by individual and collective interests all needing to be balanced in order to create an optimal level of autonomy and dependence.
Ostrom has focused much of her attention on how these rules shape social interaction and cautions that, “The capacity of humans to use complex cognitive systems to order their own behavior at a relatively subconscious level makes it difficult at times for empirical researchers to ascertain what the working rules for an ongoing action arena may actually be in practice” (Ostrom, 2005, P.19). The combining, comingling and competition of rules operating at various levels can be modeled using system dynamics modeling. These dynamics are represented as “rule-in-use” in her model shown in Figure 2.

The extent to which these rules guide the behaviors of those social agents in the IAD framework is predicated on how authoritative they are. As Etzioni has noted, compliance with rules can take coercive, renumerative and normative forms (1961), all of which contribute to the decision heuristics of social agents. We have noted how the self-organizing capacity of autonomous agents are shaped by decision rules and relational scripts. According to Ostrom’s approach, self-organized governance systems “need to match rules that impose costs in a rough proportion to the likely positive payoffs that appropriators are likely to obtain over time…” (2005, p.234). Ostrom’s emphasis on rational collective action is subject to the kind of critiques that have been raised regarding rational action more generally. Pierson argues that, “... we should generally exercise considerable skepticism about assertions that institutional arrangements will reflect the skilled design choices of rational actors. Instead, we should anticipate that there will often be sizable gaps between the ex ante goals of powerful political actors and the actual functioning of prominent institutions” (Pierson, 2004, P.15).

A second major dimension of the IAD model concerns the role of action arenas as spaces where social agents comingle with institutional rules of many forms to generate certain activities or events. Complex policy and governance systems will likely be comprised of many action arenas, each of which plays somewhere between a minor to major role in determining the outputs of a whole system. Variation in the structures of these action arenas becomes a critical consideration in the IAD framework. Ostrom (2005) has argued, quite effectively, how the composition of these action arenas has a considerable impact on a system’s performance.
Advocacy coalition framework

The Advocacy Coalition Framework (ACF), assumes, “(1) that belief systems are more important than institutional affiliation, (2) that actors may be pursuing a wide variety of objectives, which must be measured empirically, and (3) that one must add researchers and journalists to the set of potentially important policy actors (Sabatier and Jenkins-Smith, 1993)” (Sabatier, 2007, p.5). The ACF, shown in Figure 3, relies heavily on the existence of advocacy coalitions that are organized around common belief networks. Presumably these coalitions share common mental models of problem definition and policy solutions, and share a political will to influence the creation and implementation of public policies. The extent to which an advocacy coalition possesses power over other coalitions is shaped by parameters, external events, and constraints and resources available to a policy subsystem. The framework operates on the basic premise of system dynamics: inputs shaping outputs with potential feedback loops shaping the nonlinear, recursive nature of the system. Those who have worked to advance the ACF have tended to downplay the role that institutional rules play in shaping the actions of the policy subsystem. Emphasis is placed on the influence that the advocacy coalitions operating within a subsystem play. The dominant driver of coalition behavior are the “core beliefs” of coalition members.

The ACF exhibits some network qualities because it allows for the possibility to understand coalitions as collections of individual agents—each of whom contributions to the stability or instability of the coalition’s core beliefs. These agents have the capacity to influence one another. These influences are nonlinear. It is also possible to view individual advocacy coalitions as agents unto themselves. Coalitions are characterized by the emergence of bottom-up influences. According to Sabatier and his associates, these bottom up properties take precedence over top down and externally driven institutional rules and norms (Sabatier and Weibe, 2007).

Figure 3: Advocacy coalition framework (Sabatier and Weibe, 2007)
Governance (and policy) networks

The first application of network theory to policy arenas rested on institutional arrangements and the resources exchanged between them (Heclo, 1978; Rhodes, 1997). The subsequent “network turn” in public administration and policy studies has been marked by descriptions of policy networks (Rhodes, 1997; Kickert et al., 1997; Koopenjan and Klijn, 2004), policy implementations (Gage and Mandell, 1990; O'Toole, 1990; Hill and Hupe, 2006), and certain forms of intergovernmental relations (O'Toole, 2000; Wright, 2000). Inter-organizational networks have also been described as third party government (Salamon, 2002; Frederickson and Frederickson, 2006), public sector networks (Agranoff, 2005), governance networks (Sorensen and Torfing, 2005, 2008; Bogason and Musson, 2006; Koliba, et al., 2010), cross-sector collaborations (Bryson, Crosby and Stone, 2006), and public management networks (Milward and Provan, 2006; Frederickson and Frederickson, 2006; Agranoff, 2007). Figure 4 below shows an overview of the policy network approach that has been recently studied extensively by European scholars (Adam and Kriesi 2007).

Figure 4: Policy network approach (Adam and Kriesi, 2007)

Inter-organizational networks have also been described in terms of the functions that they perform, whether it be service contracts, supply chains, ad hoc, channel partnerships, information dissemination, civic switchboards (Goldsmith and Eggers, 2004), problem-solving, information sharing, capacity building, and service delivery (Milward and Provan, 2006), learning and knowledge transfer (McNabb, 2007), or civic engagement (Yang and Bergrud, 2008). Within this body of network literature we find the following similarities: networks facilitating the coordination of actions and/or exchange of resources between actors within the network; network membership being drawn from some combination of public, private and non-profit sector actors; networks carrying out one or more policy function; Networks exist across virtually all policy domains; networks are mostly defined at the inter-organizational level, they are also described in the context of the individuals, groups and organizations that comprise them; networks forming as the result of the selection of particular policy tools; and network structures allowing for

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5 With the obvious exception of inter-governmental networks, which may be described as networks of governments of different geographical scope.
government agencies to serve in roles other than lead organizations6 (Koliba, Meek and Zia, 2010, p.60).

Table 1: Governance network framework (Koliba et al., 2010)

<table>
<thead>
<tr>
<th>TYPE OF VAR.</th>
<th>VARIABLE</th>
<th>DESCRIPTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agents (Nodes)</td>
<td>Social scale</td>
<td>Individual; Group; Organizational/Institutional; Inter-organizational</td>
</tr>
<tr>
<td></td>
<td>Social sector (organizational level)</td>
<td>Public; Private; Nonprofit</td>
</tr>
<tr>
<td></td>
<td>Geographic scale</td>
<td>Local; Regional; State; National; International</td>
</tr>
<tr>
<td></td>
<td>Role centrality</td>
<td>Central – peripheral; Trajectory</td>
</tr>
<tr>
<td></td>
<td>Capital resources actor provides (as an input)</td>
<td>Financial; Physical; Natural; Human; Social; Cultural; Political; Knowledge</td>
</tr>
<tr>
<td></td>
<td>Providing accountabilities to…</td>
<td>Elected representatives; Citizens and interest groups; Courts; Owners/Shareholders; Consumers; Bureaucrats/Supervisors/Principals; Professional Associations; Collaborators/Partners/Peers</td>
</tr>
<tr>
<td></td>
<td>Receiving accountabilities from…</td>
<td>See above</td>
</tr>
<tr>
<td></td>
<td>Performance/Output and Outcomes Criteria</td>
<td>Tied to policy function and domain</td>
</tr>
<tr>
<td>Ties</td>
<td>Resources Exchanged/ Pooled</td>
<td>Financial; Physical; Natural; Human; Social; Cultural; Political; Knowledge</td>
</tr>
<tr>
<td></td>
<td>Strength of tie</td>
<td>Strong to weak</td>
</tr>
<tr>
<td></td>
<td>Formality of tie</td>
<td>Formal to informal</td>
</tr>
<tr>
<td></td>
<td>Administrative authority</td>
<td>Vertical (command and control); Diagonal (negotiation and bargaining); Horizontal (collaborative and cooperative); Competitive</td>
</tr>
<tr>
<td></td>
<td>Accountability relationship</td>
<td>See above</td>
</tr>
<tr>
<td>Whole Network</td>
<td>Policy tools</td>
<td>Regulations; Grants; Contracts; Vouchers; Taxes; Loans/loan guarantees, etc.</td>
</tr>
<tr>
<td></td>
<td>Operational functions</td>
<td>Resource exchange/pooling; Coordinated action; Information sharing; Capacity building; Learning and knowledge transfer</td>
</tr>
<tr>
<td></td>
<td>Policy functions</td>
<td>Define/frame problem; Design policy solution; Coordinate policy solution; Implement policy (regulation); Implement policy (service delivery); Evaluate &amp; monitor policy; Political alignment</td>
</tr>
<tr>
<td></td>
<td>Policy domain functions</td>
<td>Health, environment, education</td>
</tr>
<tr>
<td></td>
<td>Macro-level governance structures</td>
<td>Lead organization; Shared governance; Network administrative organization</td>
</tr>
<tr>
<td></td>
<td>Network configuration</td>
<td>Inter-governmental relations; Interest group coalitions; Regulatory subsystems; Grant and contract agreements; Public-private partnerships</td>
</tr>
<tr>
<td></td>
<td>Properties of network boundaries</td>
<td>Open – closed; Permeability</td>
</tr>
<tr>
<td></td>
<td>Systems dynamics</td>
<td>Systems-level inputs; processes; outputs and outcomes</td>
</tr>
</tbody>
</table>

We have settled on using the term “governance network” to describe what has thus far been an eclectic array of network labels. A governance network is “a relatively stable pattern of coordinated action and resource exchanges involving policy actors crossing different social scales, drawn from the public, private or nonprofit sectors and across geographic levels; who interact through a variety of competitive, command and control, cooperative, and negotiated arrangements; for purposes anchored in one or more facets of the policy stream” (Koliba et al., 2010, p.60). Governance network analysis is informed by resource exchange theory (Rhodes, 1997), vertical and horizontal conceptualization of administrative authority (Agranoff & McGuire, 2003), complex systems dynamics (Haynes, 2003), and social network theory (Wasserman & Faust, 1994). A.W. Rhodes (1997) was one of the first scholars to deeply consider the relationship between governance and inter-organizational networks, arguing that governance occurs as “self-organizing phenomena” shaped by the following characteristics: Interdependence between organizations. Governance is broader than government, covering non-state actors; Continuing

6 With the obvious exception of inter-governmental networks, which are relegated to networks of public sector organizations.
interactions between network members, caused by the need to exchange resources and negotiate shared purposes; and Game-like interactions, rooted in trust and regulated by rules of the game negotiated and agreed upon by network participants. Governance is, therefore, characterized by the interdependency of network actors, the resources they exchange, and the joint purposes, norms, and agreements that are negotiated between them. Considerations of network governance leads to an inevitable consideration of the bargaining and cooperative systems of more “horizontally arranged” ties, in addition to the traditional “vertically oriented” command and control systems of mono-centric government systems (Kettl, 2006, p.491). Mixed-form governance networks may incorporate all forms of administrative authority (Koliba and Meek, 2009) and rely on the basic architecture of networks: nodes, ties and whole network characteristics. Provan and Kenis distinguish between lead organization, shared governance and network administrative organizations structures (2007). These structures may be combined with the specific characteristics of network actors and the nature of their ties to determine how network structures lead to certain network outputs (Koliba et al., 2010).

**Toward a Meta-Theoretical Research Program**

Despite paradigmatic and theoretical incommensurability, theoretical advancement in policy and administrative sciences will require us to develop meta-theoretical procedures to test these theories in field settings. Schlager (2007) undertook a descriptive comparison of these theories on five criteria and frameworks on four criteria. For comparing theories, Schlager (2007) proposed to compare boundaries and scope of inquiry, a model of the individual, collective action, institutions and treatment of the policy change. For comparing frameworks, Schlager (2007) proposed to focus on type of actors, variable development, unit of analysis and levels of analysis. While these criteria provide important mechanisms to ascertain the commensurability of policy theoretical frameworks in terms of their boundaries and scope or models of individuals and institutions, these descriptive criteria do not provide adequate methodology to “test” whether one theory better explains public policy and administrative systems.

Sabatier (2007) recognizes this challenge and essentially proposes Karl Popper’s falsificationism as the “way forward.” In this context, Sabatier (2007) proposes seven heuristics for theoretical development: (1) Be clear enough to be proven wrong; (2) Make the concepts of the framework/theory as abstract as possible; (3) Think causal process; (4) Develop a coherent model of the individual; (5) Work on internal inconsistencies and interconnections; (6) Develop a long-term research program involving both theoretical elaboration and empirical testing among a network of scholars; and (7) Use multiple theories, if possible. Although Sabatier’s heuristics might be useful in ascertaining the fit of public policy theories in specific policy domains, the positivistic, Newtonian and falsificationist philosophy of science that underlies Sabatier’s meta-theoretical heuristics does not appear to do justice to the “complexity friendliness” of policy and governance systems. We argue that this misplaced emphasis on Newtonian and Popperian positivism as a method to refine public policy theories has undermined the nuanced complexity friendly theories that cannot clearly demonstrate “causal processes” (heuristic 3), or that
cannot develop a “coherent model of the individual” (heuristic 4). An abstract theory that simplifies observed phenomena in clearly differentiable causal processes will inevitably miss the inherent complexity of policy and governance systems.

We have argued in this manuscript that the challenges with the linear causality are accentuated by the social construction of belief systems and the active, emergent, adaptive behaviors of individuals. Some have argued that individuals in policy systems have such heterogeneous behaviors that we cannot, ever, develop “calibrated” and “valid” models of them. We may view this challenge from a meta-theoretical standpoint by juxtaposing a belief based model of individual (ACF) against a game theoretical model of the individual (IAD). These models of individual behavior may be coherent within the context of their specific theories, however, this “coherence” does not tell us whether belief based models are better than game theoretical models in describing and explaining the behaviors of actors in policy systems. We thus reject Sabatier’s meta-theoretical heuristic approach in its totality, and rather propose a long term meta-theoretical research program to public policy and governance that employs complex systems modeling tools to “test” the explanatory power of these theories in a large variety and contexts of policy domains.

The treatment of time plays a key role in the structuring of such meta-theoretical research program. Building our capacity to design computer simulation models that captures the temporal dimensions of complex systems and tests policy and governance frameworks will ultimately help us to address questions relating to policy and governance system stability, innovation and collapse. Recall our earlier discussion of the relationship between system stability and its capacity to innovate and change, and between system instability and its vulnerability for collapse. Developing our capacity to understand how complex adaptive social systems adapt is of tremendous importance.

The long term development of a meta-theoretical program for modeling the complexity of policy and governance systems will likely hinge on three critical questions:

1.) How incommensurable are policy and governance theoretical frameworks? To what extent are they compatible or comparable?

2.) What are the boundary conditions set for empirical studies of policy and governance systems? Where does the system begin and end? What get included and left out of the model?

3.) To what extent do assumptions concerning meta-patterning predetermine outcomes? How rational can/should actors be? When are discrete processes, discrete processes?

It has long been noted that policy and governance systems exist within (and sometimes across) virtually all policy domains (Baumgartner and Jones, 1993). The relative resiliency of any complex policy or governance system needs to be gauged against certain outputs that are produced by these whole systems. The table below lays out how the various major theoretical constructs found in the five frameworks reviewed above that are being operationalized in two different types of policy and governance systems: transportation planning and watershed management.
Table 2. Application of major theoretical constructs by policy domain

<table>
<thead>
<tr>
<th>Theoretical Constructs</th>
<th>Policy Domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple Streams: Problems / Policies</td>
<td>Transportation Planning Networks</td>
</tr>
<tr>
<td></td>
<td>Transportation infrastructure maintenance or</td>
</tr>
<tr>
<td></td>
<td>growth / Project funding (grants; state &amp; local</td>
</tr>
<tr>
<td></td>
<td>budget allocations)</td>
</tr>
<tr>
<td>Punctuated Equilibrium: Radical Departures</td>
<td>Changes in funding criteria; Changes in</td>
</tr>
<tr>
<td>from the Norm</td>
<td>project evaluation criteria</td>
</tr>
<tr>
<td>Advocacy Coalition Framework:</td>
<td>State transportation planners; State</td>
</tr>
<tr>
<td>Dominant Advocacy Coalitions</td>
<td>transportation engineers; Regional</td>
</tr>
<tr>
<td></td>
<td>planners; Town planners; State and local</td>
</tr>
<tr>
<td>Institutional Analysis</td>
<td>Federal and state laws and regulations;</td>
</tr>
<tr>
<td>and Development: Institutional Rules /</td>
<td>Rational project evaluation processes /</td>
</tr>
<tr>
<td>Action Arenas</td>
<td>State agencies offices; Regional planning</td>
</tr>
<tr>
<td></td>
<td>boards and committees; State legislative</td>
</tr>
<tr>
<td></td>
<td>committees; Regional planning offices</td>
</tr>
<tr>
<td>Governance Networks: Governance</td>
<td>Intergovernmental arrangements; Lead</td>
</tr>
<tr>
<td>Structures / Resource Flows</td>
<td>state agencies / Funding; technical</td>
</tr>
<tr>
<td></td>
<td>information; political capital</td>
</tr>
<tr>
<td>System Outputs</td>
<td>Transportation projects implemented</td>
</tr>
<tr>
<td>System Outcomes</td>
<td>High performing transportation</td>
</tr>
<tr>
<td></td>
<td>infrastructure</td>
</tr>
</tbody>
</table>

Space precludes a deeper description of how we are operationalizing the meta-theoretical framework across these two examples. Descriptions of these projects have been presented and/or published elsewhere (Zia et al., 2010; Koliba et al., 2011; Zia et al., 2011 forthcoming). We briefly introduce this table to highlight how the theoretical frameworks introduced in the section above may be operationalized for a given empirically observable phenomena—in these cases, regional transportation planning and watershed governance networks.

In the next section we discuss how several different kinds of modeling platforms may be used to test the efficacy of each of these policy and governance frameworks. We will discuss how a meta-theoretical research program can use computer simulations predicated on system dynamics and network architecture we believe that major advancements in public administration/policy theory, research and practice are possible.

Common Computer Simulation Modeling Platforms

Most computer simulation tools currently employed to study and model complex governance and policy systems use one or more combinations of linear modeling (discrete event), system dynamics (complex system dynamics, agent-based models), and network architecture (agent-based models, discrete event). They provide a basis on which to capture the range of complex, adaptive characteristics found in policy and governance systems.
Models are built on representations of observable phenomena. Miller and Page (2007) describe the process of modeling as an, “attempt to reduce the world to a fundamental set of elements (equivalent classes) and laws (transition functions), and on this basis ... understand and predict key aspects of the world... Modeling proceeds by deciding what simplifications to impose on the underlying entities and then, based on those abstractions, uncovering their implications” (Miller & Page, 2007, p.40, 65). The effort to translate a conceptual model drawn up in abstract into an adequate simulation of real world phenomenon requires that model development be anchored in and calibrated to empirically observed phenomena.

Three of the more prominent modeling approaches being applied to study social dynamics are discrete-event modeling (DEM), agent-based modeling (ABM), and complex systems dynamics (CSD) modeling. Each modeling tool relies on a certain level of abstraction that may be characterized in terms of macro-meso-micro level scales; strategic, tactical, and operational levels; and degrees of detail used as parameters and variables for the models. Figure 2 below provides a visual overview of where each of these modeling types fits along a continuum of abstraction.

![Figure 2. Methods in Simulation Modeling](Source: Rivera, 2009)

Discrete-event models are usually structured as a rational sequencing of events, like a supply chain, assembly line or some queuing functions. DEMs can be constructed using a high resolution of details to guide the design of operating functions of a social system. DEMs rely on linear logic to sequence events. Events may happen simultaneously, significant lags may be evident, and emergent properties of network dynamics will likely evolve. DEMs are quite useful in certain kinds of industrial engineering and industrial ecology design efforts. Their applications in models of complex policy and governance systems may be used to capture the rationalized processes that follow a logical sequence of discrete events. DEMs can be used to model the routinized exchanges of resources and execution of public policies. This brings to mind Herbert Simon’s distinction between
programmable and unprogrammable policy problems. Problems that could be (or have been) programmed are amenable to DEMs, e.g. organizational routines; while unprogrammable problems defy modeling through DEMs (Simon, 1980).

The logic of complex system dynamics models (CSDs) may be traced to the long history of systems theory that is predicated on the flow of inputs, processes, outputs, and outcomes, stocks and flows, and feedback loops (Meadows, 2008). Systems dynamics is often employed using high levels of abstraction at the macro level. The articulation of feedback loops can aid in strategic planning when a deeper understanding of the relationship between variables is important. CSDs follow a non-linear logic and can be used to anticipate the emergence of new patterns of governing authority, resource exchanges, and policy actor interactions. CSDs are also critical because they can be used to track feedback loops, the shifting nature of resource flows, and assumed relationship between inputs, outputs and outcomes. While CSDs are extremely useful in understanding the inter-connections among different elements of a system, their high level of abstraction could diminish their utility in public management systems that are sensitive to disaggregate bottom-up as well as top-down processes and other boundary conditions.

Agent-based modeling (ABMs) provides the most useful modeling framework to capture the interplay between the micro, meso, and macro levels (North and Macal, 2007) and can accommodate the varying degrees of detail that are possible and desirable within a model of a governance network. In discussing the value of ABMs to the study of policy and governance dynamics, Squazzoni and Boero observe that, “Standard policy making models consider agents as atomized entities possessing rational expectations which individually react to a set of incentives, do not consider interactions or the mutual influence between agents and seem to take place ‘off-line’ and outside the particular system involved” (Squazzoni & Boero, 2010, p.5). They go on to add that ABM is currently, “the only technique available today to formalize models based on micro-foundations, such as agents’ beliefs and behavior and social interactions, all aspects that we know are of a certain importance [in order] to understand macro outcomes...” (Squazzoni, & Boero, 2010, p.6). In discussing the potential application of ABM to the study of policy processes, they suggest that in ABMs, “… agents are not usually viewed as fully rational utility maximizers who behave independently of each other, but rather as adaptive agents who are context dependent and follow heterogeneous threshold preferences...” (p.2). These threshold preferences may be described as the “decision heuristics” of network agents (North & Macal, 2007). ABMs appear to be the most effective means of modeling the types of emergent behaviors, structures, functions and actions that occur as a result of “bottom-up” dynamics.

Those who have considered the promise of ABMs and CSDs to the study of policy processes recognize that the field is still in the early stages of development (OECD, 2009). The capacity of ABMs and CSDs of complex policy and governance systems to lead to accurate forecasting and predicting particular policy outcomes is predicated on a “deep uncertainty” that characterizes our current state of understanding of complex social systems. Bankes (2002) characterizes this deep uncertainty arising as, “the result of pragmatic limitations in our ability to use the presentational formalisms of statistical decision theory to express all that we know about complex adaptive systems and their associated policy problems” (p.7263). Rendering the kind of validity needed to confirm or
disprove empirical hypotheses requires the development of large samples and a set of empirically-normed instruments and measures.

The extent to which simulations can be used to undertake theory testing in these contexts remains to be seen. We need to ask, just what kind of inferential reasoning is possible given the inherent nonlinearity and uncertainty characteristics of complex social systems? The deep uncertainty that characterizes simulated experimentation needs to be accounted for. The level of systemic error that is possible in computer simulation models can potentially be quite large. Modelers refer to this as “noise” in the model. Although efforts can be made to reduce the noise of a model, the propensity for large systemic error virtually assures us that the error rates of simulation models of social systems far exceed levels of statistical significance found in more linear regression models. We are mindful of why these error rates may be higher in social systems, than they are in the more predictable (but still uncertain) areas of natural and biological systems. We have noted already how social agents maintain a certain level of autonomy in most social systems. The capacity of individual social agents to exert their own free will inevitably leads to a certain level of unpredictability. Agent based modelers account for this unpredictability in ascribing probability functions to agent behavior that are, ideally, calibrated to empirical observations. Modelers must still make a wide range of choices in building their models, as they are boundedly rational as well. They make choices around what elements to incorporate into the model and should be prepared to defend those choices (Batty, 2005).

We will argue that those looking to apply complexity science and theory to the study of policy and governance phenomena will be pressed to avoid the kinds of positivist and postpositivist legacies found in most computer simulation models of complex systems (Buijs, Eshuis and Byrne, 2009). The ontological tensions that arise between the “naïve realist” or “empiricist epistemologies” found in the positivist traditions of science and the social constructionism common to more qualitative, interpretive sciences may be found in virtually all attempts to apply complexity science to the study of social phenomena. We argue that rather than call for the purging these models of rationalist assumptions, we need to recognize how these tensions play out within computer simulation models of policy and governance systems (Richardson, 2008a).

Those familiar with the current discourse around complexity science and public administration and policy will likely be familiar with Christopher Pollitt’s skepticism relative to this subject (2009). He bases his observations on the apparent dichotomy that persists between conceptual abstractions and the incapacity to empirically prove the validity of these constructs using complexity science.

Although space precludes a deeper discussion here, we recognize that the development of models that are calibrated to observed patterns hinges on our capacity to render a “thick description” of these phenomena. To adequately develop models that may be able to test the validity of certain theoretical constructs requires finer and finer grain analysis of social phenomena extending across all levels of social scale (individual, group, or organizations). In order to study and test the efficacy of theories relating to the social construction of policy streams, the path dependency of stable and destabilized systems, the decision making structures within action arenas, the belief networks of advocacy coalitions, or the emergent features of network composition, we will need to develop mixed method studies that combine elements of quantitative and qualitative social science approaches. As our capacity to undertake data mining of textual and narrative data expands, the
opportunities to understand the phenomenological traces of nuanced social interactions intensifies. The further development of methodologies that blur the lines between qualitative and quantitative approaches, like those found in Ragin’s qualitative comparative method, (2008) are called for. These advancements will deepen our capacity to develop finer and finer grained analysis of social systems and, in the long run, allow for the integration of theories and frameworks drawn from not only the kinds of policy and governance theories highlighted in this manuscript, but also extending into our theories of management as well.

Are these assertions based on wishful thinking? To what extent do we need to recount Christopher Pollitt’s view that, “complexity theorists should stand on their own two feet, epistemologically speaking, and should not need to invent or magnify paper tigers in order to enhance the value of their own perspective,” (2008, p.223)? In this manuscript we assert that this epistemological foundation may be found in the integration of systems and network theories with some of the major theoretical frameworks influencing the public administration and policy fields. Pollitt argues rightly that, “there are many theories and approaches which are non-hierarchical, dynamic, acknowledge the significance of endogenous as well as exogenous change, and so on” (2008, p. 223). We counter argue that the range of theories that he had in mind may be combined with many other “complexity friendly” theories to develop computer simulation models of policy and governance systems. In other words, we should not construe complexity theory as mutually exclusive of existing theories and framework. In this sense, the kind of theory that is derived through complexity science will, likely, not displace existing theories and frameworks, but rather deepen the explanatory authority many existing theories and frameworks, a point that Pollitt fails to recognize.

Conclusions

Those who have written about the promise and limitations of developing computer simulations of policy and governance systems note that the purpose for undertaking this may not lie in predicting, “the future state of a given system, but to understand the system’s properties and dissect its generative mechanisms and processes, so that policy decisions can be better informed and embedded within the system’s behavior, thus becoming part of it” (Squazzoni and Boero, 2010, p.3). Under the rubric of computer generated decision support systems, the very process of providing feedback about a systems’ dynamics and network structure back to critical agents in the system itself becomes an important component of decision making and action (Gammock et al., 2007). These models can be used “when policy makers need to learn from science about the complexity of systems where their decision is needed,” as well as “when policy makers need to find and negotiate certain concrete ad hoc solutions, so that policy becomes part of a complex process of management that is internal to the system itself” (Squazzoni and Boero, 2010, p.6). There is, indeed, a long history of employing computer simulation modeling to stimulate systems thinking (Mitroff et al., 1974).

Could it be that the main utility of complexity science to the study of policy and governance systems lies in its capacity to free the mind to think about alternative possibilities or develop deeper situational awareness (Endsley, 1995). We believe that the
kinds of visualizations, scenario generation and theory testing that are possible through computer simulation may be harnessed to design or redesign policy and governance systems. Although we believe that using computer simulation to provide “decision support” to policy designers and network managers is extremely important, we need to recognize that tailoring models to meet the needs of stakeholders possess significant challenges for those looking to create simulations to test theories (Koliba et al., 2011). Applied scientists will be more amenable to modify their models to meet the needs of stakeholders, and in the end if these models are used to promote better performing, more accountable policy and governance systems, then are not purposes of science as an engine of social progress fulfilled?7 The type of theories and frameworks that we have surveyed in this paper may then be viewed as important tools to be employed as a means to other, highly desirable ends (eg. better performance, knowledge transfer, learning, etc.).

Does the inherent uncertainty of these models mean that there is no room to undertake simulation experiments for the sake of theory testing and knowledge discovery? We would certainly hope not. In order to evolve our theory testing capacities, we will need to develop more models that rely on empirical data drawn from a variety of quantitative and qualitative sources. Although our early attempts to develop this kind of patterned oriented modeling will generate crude approximations of reality with limited predictive power, we believe that these early attempts of course grain models will evolve as our computational power and theoretical understanding of how complex adaptive systems work evolves. Early attempts at theory testing in these models will need to be evaluated with a less restrictive margin of error than what has traditionally been acceptable in hypothesis testing.

We do not believe that we have to sacrifice the pragmatic utility of developing these models in collaboration with stakeholders in order to advance scientific understanding. Partnering with stakeholders in the development of research questions (Koliba and Lathrop, 2007) and model parameters can improve not only the relevance of the model (Van den Belt, 2004), but the rigor of the model as well. This is particularly true when the authenticity of the data is predicated on the rapport that is established between research subjects and modelers. The complexity of most policy and governance systems will not easily reveal itself to modelers. In many instances the complexity of a system may remain a mystery to those who are most intimately involved in its daily operations. We believe that by partnering with the actors who contribute to the management of a policy or governance system a thicker description of the system may be rendered. These thick descriptions may, in turn, be used to design calibrated models of operating policy and governance systems.

We have asserted here that Newtonian assumptions regarding rational action and the linearity of causes and effects are not sufficient enough to describe, evaluate and design effective policy and governance systems. The persistence of wicked problems, from funding for health care, to managing the stability of our financial system or climate, to the preservation of our ecosystems and social welfare, suggests that we may cling exclusively to the Newtonian approach to science at our peril. A complex systems approach, on the other hand, may open up new vistas to confront these wicked public problems.

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7 In other papers we discuss the role that “governance informatics” can play in informing decision making of policy makers and public administrators (Koliba, et al., 2011a; Zia, et al., 2011)
References


Theory Testing Using Complex Systems Modeling

New York: Palgrave Macmillan.


