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Edited by Mirsad Hadžikadić & Liz Johnson

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Editor's Letter

Welcome to the new issue of the Journal of Policy and Complex Systems. Included papers range from environmental policy to tax distributions. Asim Zia tackles the issue of environmental policy design through the question of conservation versus development valuation conflicts in Tanzanian, Vietnamese, and Peruvian ecological systems. Hector Hugo Caicedo offers a systems thinking approach for targeted population health management in the United States, with specific recommendations for caregivers, biotechnologists, and policymakers. Pete Barbrook-Johnson, Corey Schimpf, and Brian Castellani reflect on the use of complexity-appropriate computational modeling for public policy evaluation in the UK. Dante Suarez models evolving agency in a social context. Bernardo Alves Furtado models tax distribution in metropolitan regions. Finally, R. N. Knowles investigates the dynamical organizations theory in relation to openness, synthesis, and change.

While the papers themselves are very diverse in the topics they discuss, they all contribute to the main focus of the Journal of Policy and Complex Systems to use some aspect of computational or mathematical models to develop, implement, or evaluate polices aimed at addressing one or more phenomena in complex social systems. This field is in the development stage, and we are grateful that every day, new researchers are entering this exciting field. We hope that this trend will continue and that we will all consider contributing to the future issues of the Journal.

Best regards,

Mirsad Hadžikadić
Editor, *Journal of Policy and Complex Systems*

Le damos la bienvenida al nuevo número de Journal of Policy and Complex Systems. Incluimos documentos que van desde la política ambiental hasta la distribución de impuestos. Asim Zia aborda el tema del diseño de políticas ambientales a través de la cuestión de la conservación frente a los conflictos de valoración del desarrollo en los sistemas ecológicos de Tanzania, Vietnam y Perú. Hector Hugo Caicedo ofrece un enfoque de pensamiento sistémico para la gestión de la salud de la población en los EE. UU., con recomendaciones específicas para cuidadores, biotecnólogos y creadores de políticas. Pete Barbrook-Johnson, Corey Schimpf y Brian Castellani reflexionan sobre el uso del modelo computacional apropiado para la complejidad de la evaluación de políticas públicas en el Reino Unido. Shigeaki Ogibayashi y Kosei Takashima abordan la estructura del sistema de un modelo basado en agentes responsable de la reproducción de ciclos económicos y del efecto de la reducción de impuestos sobre el PIB. Dante

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Suárez crea un modelo para la agencia en evolución dentro de un contexto social. Finalmente, Barnardo Alves Furtado crea un modelo de distribución de impuestos en regiones metropolitanas. Finalmente, R. N. Knowles investiga la teoría de las organizaciones dinámicas en relación con la apertura, la síntesis y el cambio.

Aunque los documentos en si traten de temas muy diversos, todos contribuyen al enfoque principal de Journal of Policy and Complex Systems de utilizar algún aspecto de los modelos computacionales o matemáticos para desarrollar, implementar o evaluar políticas dirigidas a abordar uno o más fenómenos en sistemas sociales complejos. Este campo está en la etapa de desarrollo y estamos muy agradecidos de que todos los días haya nuevos investigadores que entran a este emocionante campo. Esperamos que esta tendencia continúe y que todos pensemos en contribuir a ediciones futuras de la revista.

Cordialmente,

Mirsad Hadzikadic
Editor, *Journal of Policy and Complex Systems*

欢迎阅读新一期《政策与复杂系统》期刊。本次收录的文章范围从环境政策到税收分配。作者Asim Zia通过针对坦桑尼亚、越南和秘鲁生态系统中的保护与发展价值冲突，研究了环境政策设计问题。作者Hector Hugo Caicedo为美国定向人群健康管理提出一项系统思考方法，为护理人员、生物技术人员和决策者提出了具体建议。作者Pete Barbrook-Johnson, Corey Schimpf 和Brian Castellani 对“运用适度复杂的计算建模评估英国公共政策”进行了反思。作者Dante Suarez在社会环境下对演化能动性进行了建模。最后，作者Bernardo Alves Furtado对大都市地区的税收分配进行了建模。

尽管本期文章探讨的主题是多样化的，但都对《政策与复杂系统》期刊的主要研究范围有所助益，即使用计算模型或数学模型中的某些方法来开发、实施或评价针对复杂社会系统中一个或多个现象的政策。该领域现处于发展阶段，笔者对越来越多新研究者加入到这一领域表示感谢。笔者希望，这一趋势将继续下去，同时笔者也将考虑继续为本刊文章投稿。

祝好，

Mirsad Hadzikadic

编辑

《政策与复杂系统》期刊

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Meta-Decision Modeling of Wicked Environmental Policy Design Problems: Understanding Conservation Versus Development Valuation Conflicts in Tanzanian, Vietnamese, and Peruvian Social–Ecological Systems

Asim Zia

University of Vermont, Burlington, VT, USA

azia@uvm.edu

Abstract

The central hypothesis of the study is that policy design problems are "wicked" because they involve a host of meta-decision choices, such as (i) which values should be used by decision makers to measure the outcomes of alternate policy and planning alternatives? (ii) What is the logic of establishing space–time boundaries by which a policy or planning alternative is included in the set of alternatives? (iii) Given the multiplicity of decision rules, how should decision makers choose which descriptive or normative decision rule/algorithm to apply in a given context? (iv) How shall the weights be assigned to the pluralistic values and actions on the basis of which decision makers judge their decisions? While these meta-decision choices are contained in every decision confronted by planners and policy makers, it is hypothesized that there is no single "best" or "optimal" procedure (i.e. governance structure) to decide about meta-decision choices in complex social–ecological systems. The complexity and wickedness of these four meta-decision choices is elaborated in the specific context of tropical forest conservation versus economic development valuation conflicts in three tropical countries—Peru, Tanzania, and Vietnam. A decision theoretical framework on meta-decision models (MDMs) is presented that uses iterative multi-stakeholder participatory mechanisms to explicitly illuminate the system-wide trade-offs that emerge when alternate meta-decision choices are made in evaluating conservation versus development conflicts. Theoretical and methodological implications are drawn to inform the design and development of

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MDMs in resolving wicked landscape design problems in a broad range of public policy and planning contexts.

Keywords: tropical deforestation; biodiversity conservation; international development; group decisions and collective behaviors; ecological valuation; conflict resolution and cooperation; poverty; sustainability

Modelado de Meta Decisiones de Problemas de Diseño de Políticas Ambientales: Entendiendo la Conservación Frente a los Conflictos de Valoración de Desarrollo en los Sistemas Ecológicos Socioambientales, en Tanzania, Vietnam y Perú

Resumen

Este documento tiene la hipótesis central de que los problemas de diseño de políticas son "perversos" porque involucran una gran cantidad de decisiones de meta-decisión, como (i) ¿qué valores deben ser utilizados por las personas que toman decisiones para medir los resultados de alternativas de política y planificación? (ii) ¿Cuál es la lógica de establecer límites espacio-temporales mediante los cuales se incluye una política o alternativa de planificación en el conjunto de alternativas? (iii) Dada la multiplicidad de reglas de decisión, ¿cómo deben los tomadores de decisiones elegir qué regla / algoritmo de decisión descriptivo o normativo se aplica en un contexto dado? (iv) ¿Cómo deben asignarse las ponderaciones a los valores y acciones pluralistas sobre la base de qué tomadores de decisiones juzgan sus decisiones? Si bien estas decisiones de decisión sobre la meta-decisión están contenidas en cada decisión que enfrentan los planificadores y los responsables de la formulación de políticas, se plantea la hipótesis de que no existe un único procedimiento "mejor" u "óptimo" (es decir, una estructura de gobierno) para decidir sobre las opciones de decisión sobre los sistemas complejos en la ecología social. La complejidad y la perversidad de estas cuatro decisiones de toma de decisión se explican en el contexto específico de la conservación de los bosques tropicales frente a los conflictos de valoración del desarrollo económico en tres países tropicales: Perú, Tanzania y Vietnam. Se presenta un marco teórico de decisión sobre modelos de meta-decisión que utiliza mecanismos participativos iterativos de múltiples partes interesadas para iluminar explícitamente las compensaciones de todo el sistema que surgen cuando se toman decisiones alternativas de meta-decisión al evaluar los conflictos de conservación versus desarrollo. Se elaboran implicaciones teóricas y metodológicas para informar el diseño y desarrollo de modelos de meta decisión en la resolución de problemas perversos de diseño de paisajes en una amplia gama de políticas públicas y contextos de planificación.

Palabras clave: deforestación tropical, conservación de la biodiversidad, desarrollo internacional, decisiones grupales y conductas colectivas, valoración ecológica, resolución de conflictos y cooperación, pobreza, sustentabilidad

棘手环境政策设计问题的元决策模型：解析坦桑尼亚、越南和秘鲁社会生态系统中的保护与发展价值冲突

摘要

本文提出了一个中心假设，即政策设计问题是“棘手的”，因为其中涉及到大量的元决策选择，例如(1)决策者应使用哪些价值来衡量政策和规划备选方案的结果？(2)在一套备选方案中纳入政策或规划备选方案的时空界限如何建立(3)鉴于决策规则的多样性，决策者应如何选择在特定情况下应用哪种描述性或规范性决策规则/算法？(4)应如何分配决策者据此判断所作决定的多元价值和行动的权重？虽然这些元决策选择包含在规划者和决策者面临的每一项决策中，但本文假设在复杂的社会生态系统中不存在决定元决策选择的单一“最佳”或“最优”程序(如治理程序)。本文透过秘鲁、坦桑尼亚和越南三大热带国家热带森林保护与经济发展价值冲突的具体背景阐述了这四种元决策选择的复杂性和邪恶性。笔者提出了一种基于元决策模型的决策理论框架，该框架运用迭代多方利益相关者参与机制来明确说明系统范围内的权衡。这一权衡在评价保护与开发冲突中实施元决策选择替代方案时出现。本文总结了设计开发元决策模型以解决公共政策规划广泛背景下邪恶环境设计问题在理论与方法层面的意义。

关键词：热带森林砍伐，生物多样性保护，国际发展，群体决策与集体行为，生态评价，冲突解决与合作，贫困，可持续性

(1) Introduction

Rittel and Webber (1973) mentioned problems of long-term planning and management as examples of wicked problems, and contrasted these with the "benign" or "tame" problems of mathematics and science. Benign problems have a unique, determinate solution. One knows when a benign problem is solved. Wicked problems, on the other hand, have no determinate solution; even the correct formulation of the problem is contested, and there is no "stopping rule."

Rittel and Webber hypothesize that wicked problems have no definitive solution—and no agreed-upon formulation—because disagreements involve multiple competing interests. For wicked problems, we cannot expect "optimal" and final solutions; rather, we can only expect a negotiated and balanced outcome, a resolution, that will be acceptable for a time, but always open to re-negotiation as the context and power relations change in society. The question remains: how should or can environmental planners understand and model wicked environmental policy design problems?

While Rittel and Webber laid out 10 defining characteristics of wicked planning problems, they left the methods of their resolution as open questions for future research. Most of the follow-up research in response to Rittel and Webber (1973) is seen in very diverse disciplines ranging from computer science (DeGrace & Stahl, 1990) to psychology (Conklin, 2005). In follow up to Rittel and Webber's seminal work, the theorists of adaptive management (Norton, 2005; Norton & Steinemann, 2001) and regional planning (Andrews, 2002; Innes & Booher, 1999, 2010; Sager, 1997) frameworks have proposed adaptive and participatory decision making and effective communication as the most salient ways for resolving the wicked planning problems. To continue to deepen adaptive management knowledge in light of insights generated by Rittel and Webber's work, a formal analysis that aims at modeling and understanding wicked planning problems by using meta-decision theory is pursued in this paper.

This paper re-frames Rittel and Webber's "wicked" planning problem hypothesis in a decision theoretical framework. In particular, it is hypothesized that the application of decision analysis techniques in resolving wicked environmental design problems requires determination of meta-decision choices in structuring a decision problem, such as the choice of the set of values pursued, the set of alternatives, the appropriate decision rule, and the choice of the weights to be assigned to the pluralistic values and alternative mixes in public decision-making arenas.[1] Explicit focus on structuring the decision problems could illuminate wicked value conflicts often observed in highly tense economic development versus biological and ecological conservation-related public decision-making arenas across the globe. This paper has

1 In the rest of this paper, public decision-making arenas are defined as containing at least two or

a central hypothesis that environmental policy design problems are "wicked" because they involve a host of meta-decision choices, such as:

> (i) Which values should be used by decision makers to measure the outcomes of alternate policy and planning alternatives (the value pluralism problem)?
>
> (ii) What is the logic of establishing space–time boundaries by which a policy or planning alternative is included in the set of policy and planning alternatives (the system boundary problem)?
>
> (iii) Given the multiplicity of decision rules, how should decision makers choose which descriptive or normative decision rule/algorithm to apply in a given context (the decision rule problem)?
>
> (iv) How shall the weights be assigned to the pluralistic values and actions on the basis of which decision makers judge their decisions (the weighting problem)?

While these meta-decision choices that concern value pluralism, system boundaries, decision rules, and weighting procedures are contained in every decision confronted by planners and policymakers, it is hypothesized that there is no single "best" or "optimal" procedure (i.e. governance structure) to decide about meta-decision choices in complex social–ecological systems. The complexity and wickedness of these four meta-decision choices is elaborated in this paper in the specific context of tropical forest conservation versus economic development valuation conflicts.

In Part 2, the formal decision theoretical concept of meta-decision choices is introduced. Next, in Part 3, a generalized methodology of *meta-decision models* (MDMs) is described. The methodology aims to model wicked environmental policy design problems through a participatory mechanism to address dynamically evolving meta-decision choice problems. In Part 4 of this paper, the methodology for applying the proposed MDM in the three sampled tropical countries is presented. In particular, participatory workshop data is presented to address the meta-decision choice questions in the context of conservation versus development valuation trade-offs in three tropical countries. In Peru, the study site focuses on Madre de Dios region where South American region-wide road building projects and the implementation of hydropower mega-scale projects threatens the conservation of Amazonian watershed system. In Tanzania, recent eviction of pastoralists and farmers to allow for the expansion of Ruaha National Park system boundaries is in focus. In Vietnam, the study focuses on Bai Tu Long National Park and its surrounding areas that are increasingly pressured from urbanization, tourism, and mining industries. A three-day multi-stakeholder participatory workshop was implemented in each of the three tropical countries to

more individual decision makers.

engage in deliberations and interactive exercises about the conservation versus development conflicts at the three study sites. Stakeholders were engaged in a variety of interactive exercises to brainstorm about meta-decision-making choices for their respective planning problems. Quantitative data on pluralistic values and their weights by different stakeholder groups was collected and analyzed to compare alternate planning options in these conflicting situations. In addition, qualitative data on stakeholder perceptions about system boundaries and different decision rules/algorithms to resolve these problems was also collected and analyzed.

MDMs provide a multiple stakeholder participatory methodological framework to model the wicked environmental policy design problems, and this paper is just an initial step in this direction. Part 5 of this paper concludes and provides a future research agenda for both possible theoretical developments of MDMs and their applications in understanding and modeling wicked environmental policy design problems.

(2) Formal Decision Theoretical Concept of Meta-Decision Choices

Decision theory could be mostly classified into four categories: descriptive, normative, pre-

Table 1. Descriptive and Normative Decision Algorithms and the Specific Situations in Those Algorithms Requiring Meta-Decision Choices

τ_D	***Descriptive Decision Algorithm***	***Specific Situations Requiring Meta-Decision Choices***
1.	Trend analysis/ forecasting (Armstrong, 2001; Porter et al., 1991)	Choice of variable, for which the trend/forecast is being estimated; separating stochastic from structural trends
2.	Descriptive scenario analysis (Ringland, 1998)	Choice of variables for generating scenarios; missing variables; uncertainties; ignorance
3.	Expected utility (Becker, 1976)	Incomplete information, nontransferable utilities, nonmonetary values, future discount rates
4.	Prospect theory (Kahneman & Tversky, 1979)	Incomplete information, future discount rates, extreme event likelihoods
5.	Revealed preference (Herriges & Kling, 1999; Wong, 1978)	Incomplete markets, nonmarket valuation
6.	Weighted utility (Chew, 1983)	Choice of weights
7.	Implicit expected utility (Dekel, 1986)	Choice of implicit utility function
8.	Lottery-dependent utility (Becker & Sarin, 1987)	Assumptions about risk-taking behaviors
9.	Rank-dependent utility (Quiggin, 1982)	Intransitive preferences

scriptive, and meta-decision-making (Cleveland, 1973; Corner, Buchanan, & Henig, 2001; Gal, Stewart, & Hanne, 1999; Hwang & Yoon, 1981; Kahneman & Tversky, 1979; Raiffa, 1968; Weiss & Bucuvalas, 1980; Winterfeldt & Edwards, 1986; Zeleny, 1982). These classifications are based on Hume's thesis that descriptive facts are separate from normative values (Hume, 1955). Most decision theorists share the ontological commitment that they can potentially discover an optimizing decision algorithm that can either describe how people *make* decisions (Armstrong, 2001; Becker, 1976; Becker & Sarin, 1987; Chew, 1983; Dekel, 1986; Herriges & Kling, 1999; Kahneman & Tversky, 1979; Porter, Roper, Mason, Rossini, & Banks, 1991; Quiggin, 1982; Ringland, 1998; Wong, 1978), or prescribe how people *should make* decisions (Beres & Targ, 1977; Farmer, 1987; Fishburn, 1976; Gregory & Keeney, 1994; Hwang & Yoon, 1981; Luce, 1956; Mulder & Biesiot, 1998; Saaty, 1980; Tversky, 1972; Yoon, 1989; Yoon & Hwang, 1985; Zeleny, 1982). Due to this ontological commitment, decision scientists have created many descriptive and normative decision algorithms, as shown in Table 1. Table 1 also shows specific situations in these descriptive and normative algorithms that require meta-deci-

Table 1. cont'd.

τ_N	***Normative Decision Algorithm***	***Specific Situations Requiring Meta-Decision Choices***
1.	Backcasting (Mulder & Biesiot, 1998)	Choice of values desirable at the end of decision horizon
2.	Normative scenario analysis (Beres & Targ, 1977)	Choice of preferable scenarios over nonpreferable scenarios; incomplete information; uncertainty
3.	Dominance (Gregory & Keeney, 1994; Yoon & Hwang, 1985)	No solution with multiple nondominant alternatives
4.	Elimination by aspect (Tversky, 1972)	Exogenous rank ordering from most important to the least important values required
5.	Lexicographic (Luce, 1956)	Exogenous rank ordering from most important to the least important values required
6.	Simple Additive Weighting (SAW) (Farmer, 1987; Fishburn, 1976)	Decision maker exogenously assigns the weights, which ought to be additive for multiple values
7.	Weighted product (Yoon, 1989)	Decision maker exogenously assigns the weights, which ought to be multiplicative for multiple values
8.	Analytical hierarchy process (Saaty, 1980)	One over-arching objective should be selected prior to determining weights through binary comparisons
9.	TOPSIS (Hwang & Yoon, 1981; Zeleny, 1982)	Positive and negative ideal solutions shall be exogenously determined

Note: It can be formally shown that benefit–cost analysis (BCA) is a special case of SAW.

sion choices.

It can be contended, however, that description and prescription are two facets of the same decision *process* (Norton, 2005) and that (1) each descriptive decision algorithm, in order to formally and precisely describe the decision behavior, and (2) each "normative" decision algorithm—in order to arrive at a final "correct" recommendation—makes a priori methodological assumptions for deciding about a host of meta-decision choices.

Formally, let $\boldsymbol{A} \neq \emptyset$ be defined as a nonempty set or vector of alternatives (also called policies, actions, strategies, or feasible solutions) of a decision problem.[2] Further, in a most generalized sense, let a multi-criteria outcome function $\boldsymbol{f}$ be defined as follows:

$$(1)\_\_\_\_\_\_\_\_\_\_ \boldsymbol{f}\colon \boldsymbol{A} \rightarrow \boldsymbol{R}^x$$

Each function $\boldsymbol{f_k} : \boldsymbol{A} \rightarrow \boldsymbol{R}$ with $f_k(a) = z_k$ $(k \in \{1,\ldots,x\},\ a \in \boldsymbol{A})$ and $f(a) = (z_1,\ldots,z_x)$ is defined as a multiple value function. In the most general sense, $\boldsymbol{\phi} = (\boldsymbol{A}, \boldsymbol{f})$ is defined as a multiple criteria decision-making (MCDM) problem, wherein $\boldsymbol{\phi}$ is a matrix showing a generalized decision problem involving a set or vector of Alternatives $\boldsymbol{A}$ faced by n decision makers and containing $\boldsymbol{f}$ outcomes. The decision makers measure the outcomes by z_x values. More specific formulation of decision problems is undertaken by adding future events (e.g. decisions under uncertainty) and/or replacing multi-criteria values with a utility function. Some examples of specific formulation of decision problems can be seen in the literature cited in Table 1.

For defining and solving the decision problems in public decision-making contexts, next, the formal version of four meta-decision problems—choosing the alternative set, criteria set, weighting methodology, and method set—are presented in the decision problem formulation context of equation 1. Other meta-decision choices mentioned in Table 1 are not explicitly addressed to delimit the scope of this paper. A brief review of the meta-MCDM problem is then undertaken to demonstrate that algorithmic solutions to model and understand meta-MCDM problems face severe constraints in the case of designing environmental policies.

2.1. Choice of Space–Time Boundaries

The first meta-decision problem concerns whether the set of alternative paths $\boldsymbol{A}$ is a finite set (as defined by many Expected Utility and Multiple Attribute Decision-Making (MADM) theorists) or is it infinite (as defined by Multiple Objective Decision-Making (MODM) theorists) or is it fuzzy (as defined by Fuzzy set theorists). Further, what meta-criteria, such as space–time boundaries of a decision problem, should be used to include or exclude an alternative path from A? What is the logic of establishing space–time boundaries by which an alternative is included in the set of policy and planning alternatives? These questions can be referred to as the meta-decision problem of the

2 The set of alternatives is always nonempty because the alternative of "no action" is always an alternative in any decision problem.

alternative set.

The set of policy alternatives can either be bounded by the alternatives that have shorter space–time scales, or they can be unbounded to include the policy alternatives at medium and longer term space–time scales. The complex problem is where to set the boundaries and how to bound the set of alternatives.

2.2. Value Ambiguity

Which values are/should be included in the criteria set of evaluation to measure the outcomes of our actions? Is the value set compact and closed or is it non-compact and open? Do human societies only care for the values of cost-effectiveness, fairness, efficiency, social justice, and environmental preservation in evaluation of any environmental policy decision; or are there/should there be some additional values such as eco-system health, animal welfare that are/should also (be) included in the evaluation process? Concisely, what is the logic of a meta-choice that a value is/should be included in the criteria set of evaluation? In the rest of the paper, value ambiguity is referred to as a meta-decision problem of the criteria set.

Formally, the second meta-decision problem concerns the decision as to which value/criteria z_k $(k \in \{1,\ldots,x\})$ shall be included in the multiple value function of equation 1. Restricting the value set to 1 element concatenates the MCDM problem to a scalar problem.[3] In the case of $x \geq 2$, we have a multiple-value decision problem. The meta-decision problem remains: which values shall be included in the valuation function f to determine the desirability of actions faced by decision makers?

The decision-making models shown in Table 1 do not explicitly prescribe which set of values should be preferred by human societies, nor do they predict or describe which set of values will be preferred by human societies. These decision-making models merely lay out scenarios of various outcomes (measured for decision criteria) based on the modal logic of possible combinations of various value variables. The meta-decision choice confronted in creation/implementation of a decision-making model thus concerns which values should be included to generate a scenario set. Further, which values (or mixes of values) should be preferred is also a meta-decision choice problem. The preferences on the values can be modeled as weights associated with each value, which is another meta-decision choice problem, as explained next.

2.3. Choice of Weighting Functions

How shall the weights be assigned to the pluralistic values and alternative mixes on the basis of which we measure the outcomes of our actions for judging good actions/decisions? This is called as the meta-decision problem of weighting methodology. Formally, the third

3 For example, the cost–benefit function concatenates any decision problem with multiple valued outcomes to a single-valued outcome. All the values are thus represented by monetary units, which are *commensurable* scalar quantities.

meta-decision problem concerns which weighting methodology shall be used to weigh the z_x 2 values or $a_k \geq 2$ alternates. Should the value (or alternate) trade-offs be set up as a zero-sum game with $\sum_{h=1}^{x} w_h .z_h = 1$ or a positive-sum game with $\sum_{h=1}^{x} w_h .z_h > 1$? Furthermore, which methodology should be used to ascertain the values of the weights w_h for the criteria z_h (where $h = 1,\ldots,x$) or alternate mixes ($a_k!$)?

2.4. Choice of Decision Rules

Given the multiplicity of decision models and algorithms, policymakers and planners are confronted with the problem of how to choose which descriptive or normative decision rule/algorithm to apply in a given situation. This is called as a meta-decision problem for determining the decision rule set.

Formally, the fourth meta-decision problem concerns which decision rule τ (decision algorithm, decision method) shall be used to solve the decision problem $\phi = (A, f)$. Table 1 shows a list of nine descriptive and normative decision algorithms that are frequently used to solve environmental policy or planning design problems. The leading representative authors of each algorithm are also listed in Table 1. The last column in Table 1 shows the specific situations that arise while applying these decision algorithms that require a meta-decision choice. There is however no meta-algorithm that tells the users when to apply one decision algorithm and when the other.

The choice of a decision algorithm may affect the choice of weights on values and/or alternatives, such as SAW only adds, while the weighted product only multiplies the expected values. There is however not a single meta-decision algorithm that lets the policy/decision makers choose the appropriate decision model for specific design problems.

2.5. Can Meta-Algorithms Be Devised to Solve Meta-Decision Problems?

A deeper analysis of the nine descriptive and nine normative decision algorithms represented in Table 1 reveals that the assumption that it is possible to find algorithmic solutions has blocked most decision theorists and planners from addressing truly wicked environmental policy design problems because the real problem of meta-decisions is assumed to be resolved through means that are exogenous to their models (for more discussion on the limits of algorithms and meta-algorithms, please see Zia, Kauffman, & Niiranen, 2012). This theoretical block is pervasive in decision theory because the methodological assumptions for deciding about meta-decisions have not been critically analyzed. The emphasis has rather been on finding an algorithm that provides the best and most optimal decision. Wicked environmental design problems cannot by definition have singular, optimized solutions because exogenous decisions on meta-choices foreclose the real issues and reduce the decision problem to mere application of pre-defined algorithmic decision rules, while in actual policy contexts, these meta-choices make a real difference in each stage of evaluating the policy and planning decisions.

Hanne (2001), for example, interprets the meta-decision problem as just the choice of another suitable MCDM methodology. Hanne (2001, pp. 25–31) reviews the following four approaches in previous MCDM literature that have been used to resolve the meta-decision problem of method selection for a decision problem: (a) by analyzing type of a decision problem; (b) by analyzing solution concepts; (c) by analyzing implementation of the proposed solutions; and (d) by analyzing specific decision situations. Hanne (2001) treats the meta-decision problem as a problem of method design: First, he shows that the MCDM decision algorithms are basically parameter optimization problems, and these decision algorithms are not capable of making meta-choices. Second, he shows that all of the MCDM decision algorithms share the ontological commitment of finding efficient solutions and maintaining partial order in formal mathematical and logical terms. Third, he proposes that meta-decision problems are solvable by constructing new methodological designs for MCDM problems, such as neural networks and evolutionary learning algorithms, which can act as meta-algorithms that can find optimal solutions through constantly updating the parameter values of the selected MCDM methods. The updating of parametric values is carried out by the learning mechanisms incorporated in the meta-algorithms such as neural networks and evolutionary models.

A survey of decision theoretical literature in multiple social science disciplines (references in Table 1 and Hanne, 2001) shows that many decision theorists still cherish the hope of finding decision algorithms that will find optimal solutions to (multiple criteria) public decision-making problems. It is contended here that decision researchers will not be able to resolve the complex decision problems, especially the meta-decision problems, unless they give up the ontological commitment of finding singularly best and optimal solutions through decision algorithms. Furthermore, it should also be accepted that decisions—both descriptive and prescriptive—are part of larger continuous decision processes, which are riddled with uncertainty and ignorance. Policy design problems are wicked in nature and require extremely difficult decisions on meta-choices, such as choices of $\boldsymbol{A}$, z, w and $\boldsymbol{\tau}$.

(3) A Generalized Methodology of MDMs

In an MDM, environmental policy decisions are modeled at two interactive levels: at the level of action, descriptive analysis is undertaken to ascertain the current state of the world (or the baseline scenario), such as existing environments and policies, and the outcomes ensuing from current policies/decisions. At the meta-level of reflection, normative analysis is employed to determine the socially desirable values by which outcomes of (alternate) policy and planning actions are measured (Norton, 2005).

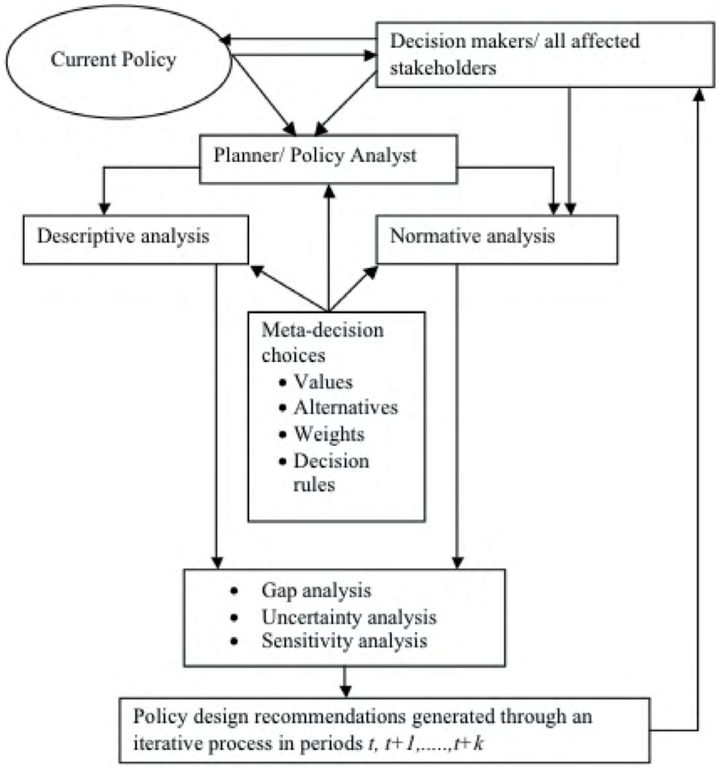

Figure 1. A flow diagram showing an idealized application of MDMs for iteratively eliciting the structure of the wicked policy design problems.

At the meta-level of reflection, the planners and policy designers could compare the outcomes measured at the level of action with the outcomes that are deemed normatively desirable within the space–time horizon of environmental policy decisions. At this level, meta-decision choice problems are resolved through iterative experimentation and participatory collaboration between expert and lay decision makers. The normative analysis at the meta-level of reflection results in policy prescriptions/recommendations that aim at getting "there" from "here" given all the uncertainty, ignorance, and incomplete information.

Figure 1 shows a very generalized and simplified flow diagram representing an iterative process of using MDMs for modeling the wicked environmental policy design problems. The most important aspect of MDMs concerns the explicit representation of meta-decision choices on $\boldsymbol{A}$, x, w *and* $\boldsymbol{\tau}$. These choices are not made for all the temporal periods that exist between now and the planning horizon; rather the meta-decision choices are revisited and revised at each iterative evaluation of the then current state of environment and policies/plans.

The idealized MDMs can be applied to a range of existing decision evaluation models, environmental impact assessment models, scenario analysis models and so on; and the MDM application can be used to determine the specific meta-decision choices that were made/assumed while applying these other models. Broadly understood, the MDMs provide a synthesis methodology to compare the various decision models that are used in environmental policy and planning.

A more concrete application of MDMs in designing tropical environments are presented in the next section. Here, a generalized methodology is expounded. First, various competing definitions of the decision problem $\boldsymbol{\phi} = (\boldsymbol{A}, \boldsymbol{f})$ are elicited. Second, meta-decision choices from various concerned parties are elicited in participatory settings. Third, the elicited meta-decision choices are used to do a descriptive and a normative analysis of the environmental design problem. Fourth, a gap analysis is undertaken to estimate the gaps on various value dimensions of desirable outcomes between current and future environments. An uncertainty analysis and a sensitivity analysis are also undertaken at this stage. Fifth, policy analysts/planners devise specific recommendations for an informed discussion among all the concerned parties. Sixth, this process is iteratively repeated at periodic intervals.

The aim of the proposed six-step MDM methodology is not to declare that a new meta-algorithm has been created that can be used to once and for all model the wicked environmental policy design problems. Rather, the proposed MDMs aim at illuminating the limitations of the current valuation models as well as providing general stakeholders with specific information on various meta-decision choices, such as space–time boundaries of decision horizons, value trade-offs, emerging/new alternatives, and newer decision models emerging over multiple iterations spanning multiple generations.

(4) Demonstrative Application of Meta-decision Modeling Approach in Three Tropical Countries

Three 3-day multiple stakeholder workshops were organized in Tanzania (May 2009), Peru (June 2009), and Vietnam (July 2009) to understand a variety of trade-offs involved in resolving conservation versus development-related landscape planning decisions in the sampled hotspot sites. In Tanzania, the eviction of pastoralists and farmers from the villages neighboring Ruaha National Park were in focus. More details on the case study site and workshop participants are presented in Zia et al. (2011). Similarly, Vietnamese case study focused on protecting Ha Long Bay and Bai Tu Long National Park arenas from a variety of economic development drivers such as mining, housing, and agriculture. More details about the Vietnamese workshop and case study are available in Zia et al. (2015). Compared to Tanzanian and Vietnamese cases, the Peruvian case was perhaps the most challenging, intransigent, and remained unresolved at many levels. The case study is focused on the ongoing conflict in the Madre De Dios Amazonian watershed region in Peru along Brazilian and Bolivian borders. Under a continent wide "Integration of Regional Infrastructure in South America" (IIRSA) program, a roadway project is being proposed to be built in Madre De Dios region. In addition to the roadway project, Brazilian national government has offered Peruvian national government to design, build, and operate three large-scale hydropower projects and sell the electricity to the Brazilian under a long-term bilateral agreement. While Peruvian national government is interested in undertaking roadway and hydropower projects in Madre De Dios region, the local and regional stakeholders are intransigently opposed to these development projects. International stakeholders such as IUCN and WWF are also not very supportive of these development projects, but these international agencies do not have much financial power as World Bank and Inter-American Development Bank who are financially underpinning roadway and hydropower projects in the Peruvian region. Next, I summarize the key findings from the three workshops vis-à-vis four meta-decision choices (aka space–time boundaries, identification of stakeholder values, weights on stakeholder values, and decision rule choice).

4.1. Space–time Boundaries

In all three case study countries, stakeholders did not arrive at a consensus about the specific space–time boundaries to structure the conservation versus development planning problem. While there was a general agreement that the costs of the conservation are borne by local communities (such as foregone economic development opportunities and loss of local livelihoods) and benefits of the conservation are derived by global communities (such as carbon mitigation from conserved tropical forests), there was considerable disagreement about the process to measure costs and benefits in all three countries. Despite the efforts of the workshop facilitators to draw strict spatial boundaries around the case study sites, local community stakeholders continue to protest any delineation of spatial (or temporal) boundaries. Peruvians, for example, mentioned global corporate interests as the key driving forces behind underpinning roadway, hydropower, and gold mining projects in Madre De Dios region as important players not bound by the case study spatial boundaries. Similarly, Tanzanians and Vietnamese stakeholders were concerned about Chinese and other multi-national companies eying the natural resources in their respective case study sites. Though there was an understanding about "nested" spatial scales in all three countries (e.g. local, regional, national, and international), there was considerable concern among the local community representatives about the political power and governance regimes at different levels of the nested spatial structure. In general, all mediation efforts to strictly delineate space–time boundaries for the case study sites remained ineffective.

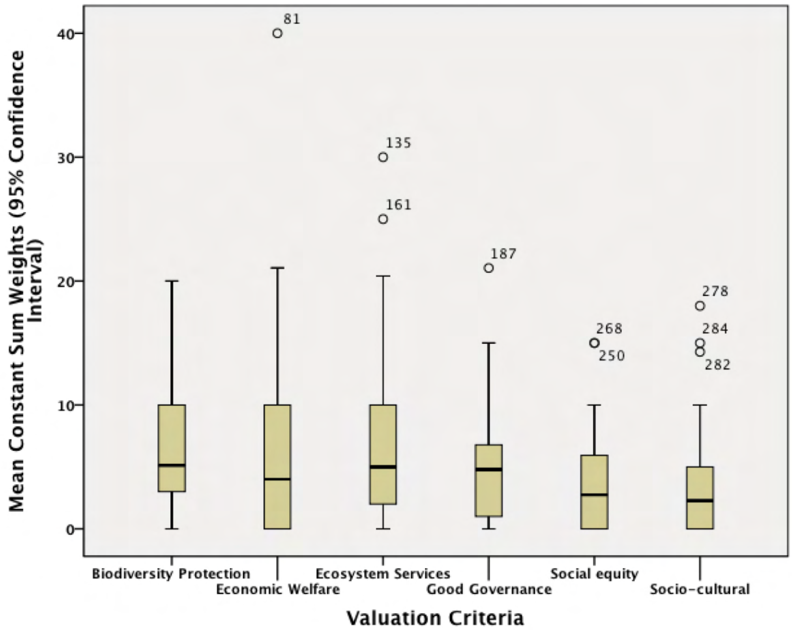

Figure 2. Mean weights with 95% confidence interval on values agreed upon in Tanzania (N=21).

4.2. Values and Weights on Values

Considerable effort and time was spent in each of the three countries to elicit the values and weights on those values to compare baseline (descriptive) management scenarios with alternate (normative/prescriptive) management scenarios for the case study sites. There were significant linguistic and translation challenges in all three countries. Despite these obstacles, we were able to develop a value and weighting strategy for Tanzania and Vietnam; however, these efforts were not consensually agreed upon in Peru. More specifically, Figure 2 shows the values and weights on those values agreed upon in the Tanzanian workshop. There is considerable variability in the weights assigned to these values, as different stakeholders prefer different (and often times conflicting) goals and values.

Similarly, Figure 3 shows the mean weights assigned for the values mutually agreed upon in Vietnam. A comparison of x-axis in Figures 2 and 3 reveals that stakeholders in Tanzania and Vietnam do not necessarily choose similar values to compare alternate landscape planning scenarios. While maximization of economic welfare, protection of ecosystem services, and good governance were echoed as important values in both countries, Tanzanians appear to be also concerned about socio-cultural values, social equity issues, and biodiversity protection. Vietnamese, on the other hand, were concerned about accessibility to the landscapes as well as the price of the land under different planning scenarios.

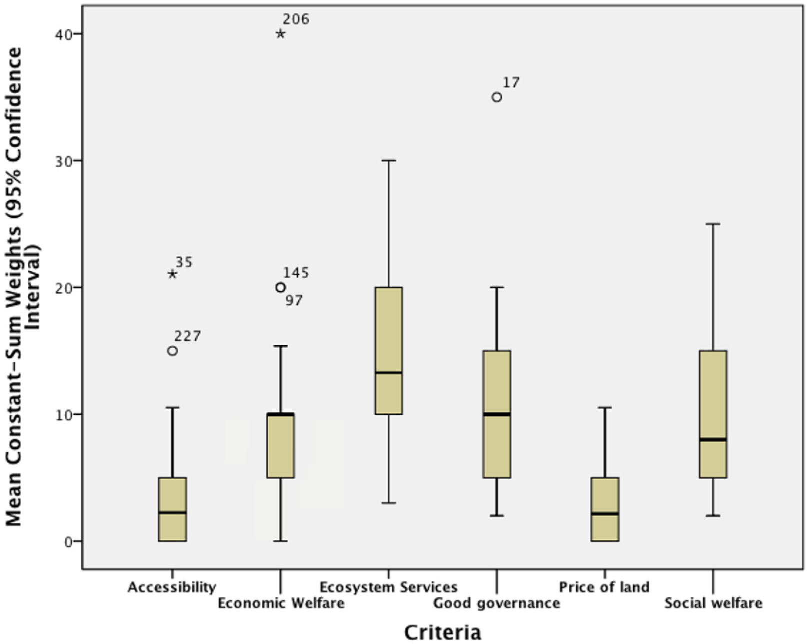

Figure 3. Mean weights with 95% confidence interval on values agreed upon in Vietnam (N=18).

Compared to both Tanzanians and Vietnamese, the Peruvians instead emphasized that the value of "human rights" was considerably more important to them. More importantly, the Peruvian stakeholders did not agree upon a mutually consensual set of values to compare planning scenarios as did the stakeholders in Tanzania and Vietnam. They contested the definitions of economic welfare criteria, social welfare, ecosystem services, or any other possible values that were signaled by different workshop participants. Instead, many stakeholders kept on insisting that human and animal rights were the most important considerations for them in making such planning decisions. Consequently, no quantitative data on values or weights on values was collected during the Peru workshop.

4.3. Choice of Decision Rule

Both Tanzanians and Vietnamese agreed to use "simple additive weighting" (SAW) algorithm that is generally used in Multi-Criteria Analysis. For more details on SAW algorithm, see Zia et al. (2011). The Peruvians however contested a fundamental feature of the algorithm itself: This feature has to do with a central distinction that is generally made in multi-attribute decision-making literature (e.g. Hwang & Yoon, 1981) about "compensatory" versus "noncompensatory" decision rules. Compensatory decision rules such as SAW and weighted product decision rule assume that losses on one attribute/criterion could be "compensated" by gains on another (incommensurate) attribute/criterion in a decision problem. Noncompensatory decision rules, on the other hand, do not assume the existence of such compensation across the attributes. Lexicographic method, or elimination by aspects, are examples of noncompensatory decision rules. For Peruvian stakeholders, human rights was an example of an attribute, a loss on which could not be compensated by a gain in another attribute such as economic or social welfare. In essence, Peruvians rejected SAW and embraced Elimination By Aspects as a preferred decision rule, but the discussion could not move beyond that in Peruvian workshop due to the fundamental disagreements about the set of design alternatives to compare with the baseline (descriptive) scenario. In contrast, both Tanzanians and Vietnamese worked through applying SAW decision rule to compare alternate planning regimes in their respective case study sites.

Figure 4 shows the mean (with 95% confidence interval) expected values elicited from Tanzanians about the five alternative planning scenarios for Ruaha National Park. The five planning scenarios included baseline national park scenario, compared with alternate scenarios of converting Ruaha National Park into a game reserve area, game control area, multiple (mixed) land-use area, or open area available for economic development without any national or local conservation regulations. Different stakeholder groups had different scenario preferences: Except for international stakeholders, nation-

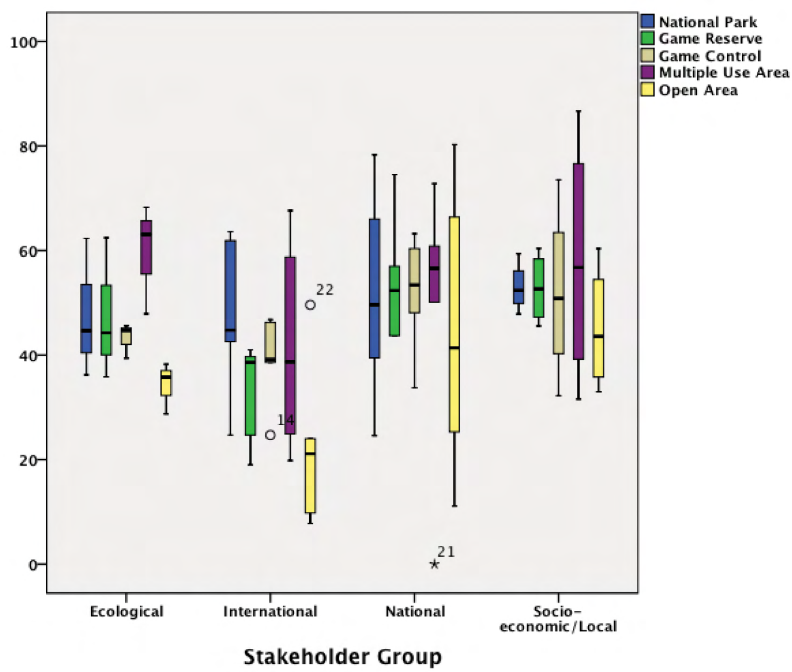

Figure 4. Mean expected values with 95% confidence interval on planning scenarios elicited in Tanzania (N=21).

al, local, and ecological groups rejected the baseline national park scenario as their preferred scenario. Multiple use area emerged as the preferred scenarios for these three stakeholder groups in Tanzania; however, upon further investigation with the national forestry ministry, it became clear that they were not open to changing the status of Ruaha national park to a multiple land-use area as recommended by the workshop participants. This points to the wicked problem of participation in such meetings as well as complex power dynamics that drive decision-making in developing countries.

Figure 5 shows similar mean expected values for baseline and alternate planning scenarios evaluated in the case of Vietnam. When compared with Tanzania, Vietnamese wanted to consider a "community- owned" planning scenario for Bai Tu Long national park as one of the alternate planning options. This particular option, however, did not rise to the top when evaluated through SAW algorithm for the local stakeholder group as shown in Figure 5.

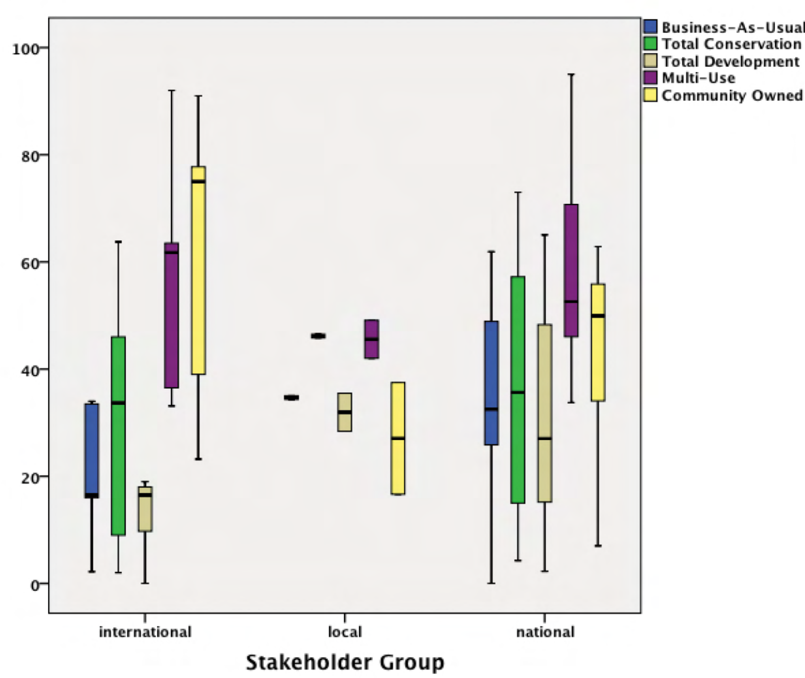

Figure 5. Mean expected values with 95% confidence interval on planning scenarios elicited in Vietnam (N=18).

In contrast, the community-owned option was the most preferred scenario for international stakeholders present in the Vietnam workshop. For local and national stakeholders, multi-use planning scenario appeared the most preferred option. As in the case of Tanzania, the Vietnamese policymaking authorities were not too keen on changing the planning scenario to any of the proposed alternative planning regimes in Bai Tu Long despite the fact that the baseline planning scenario appeared to be the least preferred scenario for national-level stakeholders who participated in the Vietnam workshop.

(5) Conclusions

This paper shows that environmental policy design problems are wicked because they involve choices on meta-decisions, for which no "optimal" or "correct" choices exist. Some examples of meta-decision choices include the choice on the sets of alternatives, values, weights on values, and decision algorithms. Other examples of specific situations giving rise to meta-decision choices in descriptive and normative decision algorithms are also briefly discussed in this paper. In order to openly discuss meta-decision choices in public decision-making arenas involving environmental policy designs, a formal theoretical concept of MDMs is introduced in this paper. The proposed MDMs are also applied in the three tropical countries to demonstrate their iterative nature in structuring complex decision problems for finding adaptive resolutions of the wicked design problems. It is found that some consensus across different stakeholder groups about meta-decision choices appeared to emerge in Tanzania and Vietnam; however, Peruvian stakeholders remained diverged and skeptical about choosing any specific set of meta-decision choices. Meta-decision analysis revealed that mixed land-use planning options dominate extreme land use (e.g. development-only or conservation-only) planning scenarios in Tanzania and Vietnam, but these preferences do not necessarily translate into public policy in these countries.

There is no one best or optimal scenario, weighting combination, or decision algorithmic outcome that can be ordained for all times as the best choice for modeling wicked environmental policy design problems. Only a continuous process of evaluation and experimentation can enable us to learn more about the policy and planning alternatives in a given space–time context. The proposed MDMs may thus be applied iteratively, at multiple points in time, while the wicked environmental policy design problems can at best be only temporarily resolved and re-resolved through a continuous process of dialogue, modeling, experimentation, and learning. We will have to discuss and learn more, and perform more experiments, if we want to keep on improving the models of the wicked environmental policy design problems. The proposed MDMs may only aid the planners, policy analysts, and a broad range of decision makers in making informed choices through a process that lays bare the assumptions behind expert and lay decision-making processes.

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A Systems Thinking Approach for Targeted Population Health Management in the United States: Recommendations for Caregivers, Biotechnologists, Digital-technologists, and Policymakers

H. H. Hugo Caicedo[1,2]

[1] *Corporate Sustainability and Innovation, Harvard University, Cambridge, MA, USA*

[2] *Connection Science, Media Lab, Massachusetts Institute of Technology, Cambridge, MA, USA*

caicedo.hugo@gmail.com

Abstract

Faced with deep-rooted systemic failure, increasingly soaring expenditures, and poor health outcomes, the U.S. healthcare system is experiencing one of its most dramatic structural and functional changes in modern history. This paper explores the use of systems thinking to both improve our understanding and perception of the traditional structure of the U.S. healthcare system based on broad population health management and analyze how health policy, the digital economy, and real-world evidence are reshaping that structure, enabling a focus on targeted population health management. Findings reveal how biopharmaceutical companies are being asked to bring more to the table than just new drugs, by proving stronger comparative effectiveness with alternative therapies; providers are assuming more financial risk and engaging in contracting models that reflect more value; payers are required to do more to keep costs under control and are assuming responsibilities for care and clinical outcomes; patients are becoming more proactive with digital technology thus, generating real-world medical-relevant information; and new Digital Healthcare Entrants are eager to either compete or offer new forms of nonexclusive partnerships with all of the traditional healthcare players. The paper finishes indicating that despite regulatory policies, the U.S. healthcare system is still plagued by systemic inefficiencies and inappropriate business practices that preclude both fair competition in an open economy

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and the delivery of affordable value to patients and consumers. We argue that, to improve systemic performance, beyond new reimbursement models and digital transformation, broad cultural management transformation is needed among all stakeholders. This could include, raising the standards on which senior management make fundamental decisions that affect the entire value chain and not just their organization, enacting uncompromising enforcement of antitrust laws by which policymakers limit powerful lobbies, and restricting anticompetitive behaviors within health providers and manufacturers.

Keywords: system's archetypes; zero-sum competition; health policy; digital economy; real-world evidence; digital health; value strategy; value-based competition; targeted population health management

Un Enfoque de Pensamiento Sistémico Para el Manejo de la Salud de Poblaciones Específicas en los Estados Unidos: Recomendaciones Para Profesionales de la Salud, Biotecnologos, Tecnólogos Digitales y Legisladores

Resumen

Al enfrentar una falla sistémica profundamente arraigada, gastos cada vez más altos y resultados de salud deficientes, el sistema de salud de los Estados Unidos está experimentando uno de sus cambios estructurales y funcionales más dramáticos en la historia moderna. Este documento explora el uso del pensamiento sistémico para mejorar tanto nuestra comprensión como la percepción de la estructura tradicional del sistema de salud de los EE. UU. basado en el manejo de la salud de la población general y analiza cómo la política de salud, la economía digital y la evidencia del mundo real están cambiando la estructura, permitiendo un enfoque en el manejo de la salud de una población específica. Los hallazgos de este estudio revelan cómo se les está pidiendo a las compañías biofarmacéuticas que traigan a la mesa mucho más que solo nuevos medicamentos, demostrando una mayor eficacia comparativa con terapias alternativas; los proveedores están asumiendo un mayor riesgo financiero y están participando en modelos de contratación que reflejan más valor; a las aseguradoras de salud se les solicita que hagan más para mantener los costos bajo control y están asumiendo responsabilidades por los resultados clínicos y la atención de salud; los pacientes son cada vez más proactivos con la tecnología digital, generando información médica relevante en el mundo real; y los nuevos participantes en el sector de la salud digital están ansiosos por competir u ofrecer nuevas formas de asociaciones no exclusivas con todos los actores tradicionales del sistema de salud. El documento termina indicando que, a pesar de las políticas regulatorias, el sistema de atención médica de los EE. UU. todavía está plagado de ineficiencias sistémicas y prácticas comerciales depredadoras que impiden la competencia leal en una economía abierta y la entrega de valor asequible a pacientes y consumidores. Argumentamos que, para mejorar el desempeño sistémico, más allá de los nuevos modelos de reembolso y la transformación digital, se necesita una amplia transformación cultural entre todas las partes interesadas. Esto podría incluir, elevar los estándares sobre los cuales los líderes tomandecisiones fundamentales que afectan a toda la cadena de valor y no solo a sus organizaciones, promulgar la aplicación de leyes antimonopolio por las cuales los legisladores limitan los lobbys poderosos y restringir las conductas anticompetitivas dentro de los profesionales de la salud y fabricantes de medicinas y dispositivos médicos.

Palabras clave: arquetipos del sistema, competencia de suma cero, política de salud, economía digital, evidencia del mundo real, salud digital, estrategia de valor, competencia basada en el valor, gestión de la salud de la población dirigida

美国有针对性的人口健康管理的系统思考方法：对看护人，生物技术专家，数字技术专家和政策制定者的建议

摘要

面对根深蒂固的系统性失败、日益高涨的消费支出和不尽人意的健康结果，美国医疗体系正经历着现代历史上最具戏剧性的结构和功能改革之一。本文探讨了如何运用系统思维来提高大众对基于广义人口健康管理的美国传统医疗体系结构的理解和认知。笔者还分析了卫生政策、数字经济和现实世

界证据是如何重塑这一传统结构从而将重点放在定向人口健康管理上的。研究结果揭示了生物制药公司是如何通过证明替代疗法相对而言更为有效而被要求提供更有价值的产品，不仅仅是新药；供应商承担更多的财务风险，并参与反映更多价值的承包模式；付款人需要采取更多措施来控制成本，并承担护理和临床结果失败的责任；因此，病人越来越主动地运用数字技术提供真实世界的医疗相关信息；而数字医疗行业的初创企业渴望与所有传统的医疗公司一较高下抑或开展全新形式的非排他性合作。本文最后指出，尽管存在监管政策，美国的医疗体系仍然面临体系效率低下和掠夺性商业行为的困扰。这两种做法既阻碍了开放经济中的公平竞争，又破坏了病人和消费者在可承受范围内的价值获取。笔者认为，为了改善体系绩效，除了新的补偿模式和数字改革之外，所有利益攸关方都需要进行广泛的文化管理变革。这可以包括提高高级管理层做出影响整个价值链而不仅仅是自身组织的根本决策时所依赖的标准，毫不妥协地执行政策制定者限制游说团体权力的反托拉斯法，并限制医疗服务机构和制造商的反竞争行为。

关键词：系统原型，零和竞争，卫生政策，数字经济，现实世界证据，数字健康，价值战略，价值竞争，定向人群健康管理

1.0 Introduction

Currently, among high-income countries, the U.S. healthcare system is the most expensive, worst performing, and less equitable in terms of access, efficiency, and quality (Schneider, Sarnak, Squires, Shah, & Doty, 2017). One of the fundamental problems in healthcare is that, historically, the value created for patients and health systems has not correlated with spending levels. For years, the U.S. federal government has increased taxpayers-based expenditures without improving medical and financial outcomes in a healthcare system based on broad population health management (Elton & O'riordan, 2016), where healthcare organizations defined populations based on single medical conditions (e.g., all diabetics, all pancreatic cancer patients, etc.). In this realm, growing financial compensations have been paid for volume of performed procedures (health providers) and prescribed therapies (health manufacturers) but not for the value that those medical interventions were supposed to accomplish.

Now we are seeing unique drivers of change in healthcare. At no other time in the history of the United States has the entire healthcare ecosystem been so challenged by regulatory, financial, and technological drivers. On the one hand, a value-based care model mandates health systems to measure medical and financial outcomes. On the other hand, the advent of a digitally disrupted world, influencing social and behavioral trends, is dramatically changing how individuals interact with digital technology, thus generating medical-relevant information from social footprints and outside of traditional clinical settings. This is enabling a focus on targeted population health management (TPHM), an approach that leverages strategic management, science, technology, and medicine directed at an individual or targeted populations that share similar determinants of health.

While a healthcare system comprises a massive and broad enterprise with many important interdependent relationships involved in the delivery of healthcare, providing a complete and detailed description of all the healthcare players is beyond the scope of this paper. Nevertheless, the most influential stakeholders are described and the nature of their behaviors and interrelationships are analyzed to shed light on the underlying structure of the U.S. healthcare system: how they distribute themselves and their resources, place value on things and distribute that value among each other. The recognition of *system structure* and how that structure is perceived are important constructs of this paper. What structures generate specific patterns of behavior? How can such controlling structures be recognized? How would such knowledge help us to both be more successful in understanding the complex U.S. healthcare system and provide sustainable policy recommendations to address challenging problems faced today?

Traditional forms of analysis focus on separating the individual pieces of what is being studied. While this makes it easier for us to see how individual parts function in isolation, it also hampers our intrinsic sense of connection to a larger whole, the system. If we consider that a system is a perceived whole, made up of parts that interact with one another toward a common goal, and we agree that that perception is also part of what causes the system to stand together. Then, the quality of that perception will determine the quality of our understanding of the structure of the system as well as our ability to identify high-leverage points from where interventions can be implemented. *Systems thinking* is intended to helps us improve the quality of our perceptions of the whole, its parts, and the multiple interactions that take place (Peters, 2014). It is a discipline that helps us improve our understanding of how a complex system works. Not just how individual parts function in isolation but also the different interdependencies and interrelationships within and between levels. Importantly, it helps us identify system's archetypes, which are system structures that produce common patterns of problematic behaviors. System's archetypes represent specific points from where interventions can be executed (Meadows, 2008; Senge, 1990).

This paper conducts a systems thinking-based research, analysis, and synthesis on the feasible implementation of TPHM in the United States, from a structural and functional description of the traditional service-centered healthcare ecosystem toward its regulatory-driven evolution into a much more patient-centered ecosystem. In the midst of intense volatility and uncertainty, this research also attempts to provide recommendations for antifragility in TPHM. We also took a look into medical error as an under-recognized leading cause of death, while highlighting shortcomings in medical practice, health policies, and commercially available medicines. Further, we described opportunities and challenges in incorporating digital health and scientific innovation in TPHM, while providing policy recommendations to improve the performance of the overall healthcare system.

2.0 Methodology

Healthcare is a complex system where multiple interacting agents operate within a context that keeps changing and exhibits dynamic complexity. According to Peter Senge, systems thinking is a discipline for seeing wholes. He argues that the real leverage lies in improving our perspective by understanding dynamic complexity, rather than detailed complexity with thousand of variables that distract us from seeing the patterns and major interrelationships of a whole (Senge, 1990). To improve our understanding of the U.S. healthcare system's perspective, specific frameworks including general systems theory, causal loop diagrams (CLDs), system mapping, and system archetypes were used in this paper. These frameworks are part of a body of systems thinking theories, methods, and tools (Peters, 2014) used in our research to analyze and synthesize publicly available information from sources such as health policies, peer-reviewed publications, print media, and disclosures from the department of U.S. Health and Human Services.

Perspectives integrate knowledge, experience, biases, mental models, and point of view. To gain and improve our perspective of a system, we must look beyond events and confirmation bias information. In this research, we focused on causality instead of simple cause and effect relationships. We searched for underlying structures that influence established patterns of behaviors that ultimately drive the events we observe in healthcare. We continuously tested and revised our understanding of our system's perspective by using CLDs and general systems theory. CLDs are tools that produce qualitative illustrations of mental models or people's understanding of how elements of a problem are related to each other. They focus on highlighting causality and feedback loops that can be either reinforcing or balancing (Peters, 2014).

The way we communicate influences the way we think and perceive the world around us. By necessity, we try to communicate in a linear, logical order. Words and sentences come only one at a time. Thus, we are intrinsically wired for linear thinking. However, complex systems happen all at once and they are not entirely linear or logical. To discuss them properly, it is necessary to map them, that way we can see all the parts and interconnections at once (Meadows, 2008). When mapping a system, we can engage in visual thinking. Visual thinking is the act of thinking through visual processing and analysis, which greatly enhances reasoning including thinking, cognition, and intellect (Ware, 1990). In this paper, by using CLDs and Kumu software, an online data visualization platform that helps organize complex information into interactive relationship maps, we developed two system maps. One for broad population health management (Figure 1) and another one for TPHM (Figure 3). Systems thinking provided continuous feedback or information about the structure of the maps and the development of this manuscript, helped explain the role of feedback loops within healthcare, aided with the identification of system's archetypes, and better informed our thought process to provide recommendations to address challenging problems faced today in the U.S. healthcare system.

In each map, each circle represents an interacting agent and each arrow represents a causal relationship. Whether it is a positive ("causes more") or negative ("causes less") relationship, it is indicated by a plus or minus sign and the style of the line (solid is "causes more," while dashed is "causes less"). The halo around some circles indicates that those agents have a central role within the system (Note that each map is accessible online on "Kumu." http://kumu.io). By continuously improving the quality of the healthcare maps, this paper reviewed and analyzed the structure of healthcare in the United States, the performance of healthcare based on broad population health management, and the current drivers of change in the healthcare market. This revealed system-wide interrelationships and loops of influence, which improved our understanding of the U.S. healthcare system. Further, based on an improved system's perspective, we explored the feasibility of TPHM and what antifragility would look like in the context of a changing healthcare system where health policies might drive a shift toward better performing health insurances, stratified medications and medical interventions, and promising digital technology.

2.1 Healthcare Structure in the United States

Healthcare is not a single system but an ecosystem and each subsystem is very complex itself. In the United States, healthcare is provided by a convergence of multiple organizations. Traditionally, as shown in Figure 1, there have been four main healthcare players: health providers (clinics, hospitals, and caregivers delivering medical interventions and services), health manufacturers (biopharmaceutical and medical device companies providing products), private health payers (private insurance companies), and the U.S. government (public health payer and regulatory agencies). Figure 1 is a color-coded high-level representation of broad population health management. It shows dynamic complexity rather than detailed complexity with multiple connections, as it is intended to empower visual analytics and visual thinking, thus improving the quality of the perceived system under study (Senge, 1990). Individual circles represent elements associated with the U.S. federal government (red circles), manufactures of healthcare products (blue circles), providers of medical treatment (purple circles), private insurance companies (yellow circles), and patients (green circles). Note that Figure 1 highlights causality and feedback loops as the fundamental building blocks of three systems archetypes that will be described shortly.

Even though most healthcare practices are grounded in humanitarian principles that aim at diagnosing and treating disease to maintain and restore health (Nasser, Tibi, & Savage-Smith, 2009), traditional healthcare players have not always benefited the public good. Historically, healthcare organizations have defined populations based on single medical conditions (e.g., all diabetics, all pancreatic cancer patients, etc.). Segmenting the market in this way made it easier for companies to focus on developing solutions for specific illnesses in well-defined therapeutic areas, but pushed a broader and more comprehensive interest on the patient to the side. Notoriously, patients have been either passive or reactive recipients of disease care. Testing, validation, and approval of most therapies have been performed in randomized and controlled clinical trials that assess statistically significant standards of safety and efficacy in broad populations instead of using medically relevant metrics in targeted populations that share similar determinant of health (i.e., genetic predisposition, environmental susceptibility, and ethnographic risk factors).

The U.S. federal government is the largest single payer of healthcare. As such, the U.S. government plays a powerful role as regulator, shaper, and payer of the healthcare market. Whether it is the Department of Health and Human Services (DHHS) with its flagship agency the Food and Drug Administration (FDA) granting or denying approval of drugs or medical devices; the Centers for Medicare and Medicaid Services (CMS) determining which medical interventions and technologies are covered and how much they reimburse for them; the Agency for Healthcare Research and Quality (AHRQ) determining quality and safety standards of health care services; or the current but yet-to-be-modified Patient Protection and Affordable Care Act a.k.a. Affordable Care Act (ACA) setting the standard for benefit packages throughout the health insurance system, it is certain that the U.S. government and its agencies have a powerful influence on the delivery of health benefits, technology innovation, and the overall framework of the health market (Tevi, 2015).

Significantly, the U.S. government is a key source of revenue. This makes it highly important to the private insurance industry, which is a major contributor of reimbursements for the rest of the healthcare players. In fact, the government covers 64% of the insurance industry's revenue compared to just 6% coming from employers (Him-

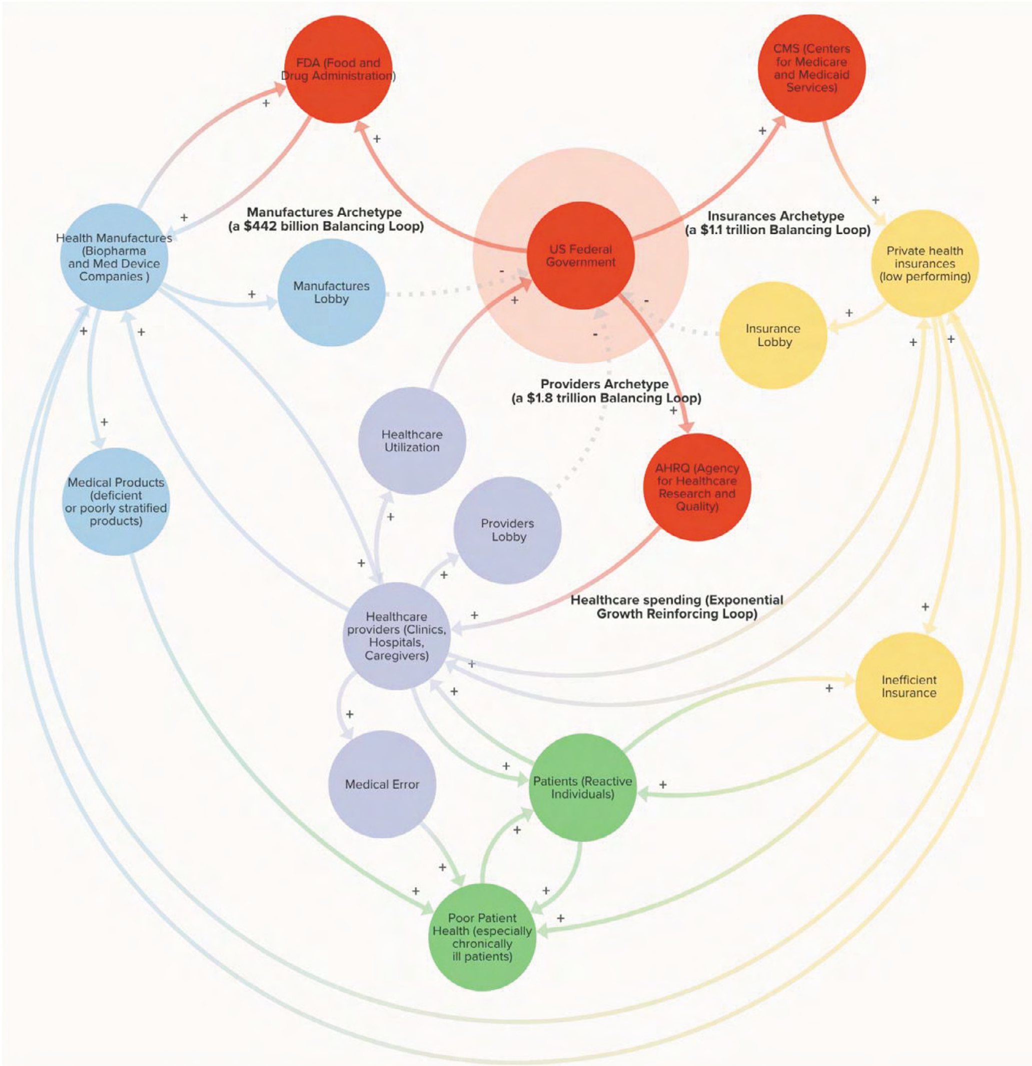

Figure 1. Traditional U.S. healthcare market place-based broad population health management. Three systems archetypes are identified: manufactures, providers, and insurances (Caicedo, 2019a).

melstein & Woolhandler, 2016). In particular, healthcare government expenditure is done via social programs such as Medicare (provides health insurance for adults 65 and older), Medicaid (provides health insurance for low-income families and individuals of all ages), the Children's Health Insurance Programs (a.k.a CHIP, covers uninsured children in families with incomes that are moderate but too high to be eligible for Medicaid), and the Veterans Health Administration (executes the medical assistance program of the military veterans affairs). The CMS contracts around 40 private insurance companies for the administration of Medicare, Medicaid, and CHIP. Typically, Medicaid and CHIP are cost-sharing partnerships between federal and state governments (Altman & Frist, 2015). Prevalent matter is the fact that military veterans, poorer and older patients tend to be sicker than average, increasing costs for both health systems and government-sponsored programs.

As noted before, systemic structure influences patterns of behaviors, which drives events and reveals implicit purposes. A system's function or purpose is not necessarily written or expressed explicitly. It is easy to say that patients are at the center of an organization and have talented marketing and advertising teams conveying that purpose. However, purposes are deduced from behavior, not from rhetoric or well-articulated mission statements. The poor value that the U.S. healthcare industry has provided for many chronically ill patients (the most expensive patients) and payers (including tax payers) does not correlate with the significant revenues the healthcare industry has provided to insurance companies, the biopharmaceutical industry, and healthcare providers. That is an inexorable reflection of how remarkably profitable this industry is when people are sick.

As stated before, the U.S. federal government is a major source of revenue for the other three traditional main healthcare players (health providers, health manufacturers, and health insurances). Historically, reimbursements have been made on a fee-for-service basis (in which providers and manufactures are paid for each service and product provided to a patient) but not for the value that those medical interventions were supposed to accomplish. As it will be shown shortly, judging from the healthcare industry's behavior, disease has been an asset for this industry and the main purpose of the industry has not been to keep people healthier but to maximize financial revenue.

Whenever there is a goal-oriented behavior, a balancing (or stabilizing) feedback loop is operating. There is a self-correction that attempts to maintain the goal. Figure 1 shows system-wide interrelationships and loops of influence, highlighting balancing loops acting as engines of sustained growth for shareholder value creation, ensuring strong market positions, pulling in taxpayers-based revenues, and providing little value to patients and health systems based on the poor patient healthcare outcomes that are continually measured and compared against other developed countries (Schneider et al., 2017). The manufactures archetype, a $442 billion market, encouraged key decision makers at provider and payer organizations to get their products prescribed as frequently as possible (Centers for Medicare and Medicaid Services, 2016b; Elton & O'riordan, 2016). The provider archetype, a $1.8 trillion market, used to reward caregivers to do "more" with the most talented clinical personnel, in order to "code" as highly as possible to optimize revenues. Additionally, there still is a widespread practice among many providers that discourages empowered consumers to consider price and value, thus limiting competition among providers. In the United States, it is extremely difficult to get a quote from a hospital. For instance, most hospitals do not provide information about costs associated with childbirth, which is the leading cause of hospital admission (Xu et al., 2015). The private insurance archetype, a $1.1 trillion market, did little to manage risk while reimbursing across large populations of patients, nurturing a volume-oriented instead of a value-oriented marketplace. Ironically, the U.S. government has been benefiting from the manufactures archetype. Almost 50% of the FDA's budget is generated through "user fees" charged to life sciences companies (Topol, 2012). Unfortunately, for patients and health systems, this makes the FDA exceptionally risk-adverse.

It is worth mentioning that lobbying in the United States, influencing the federal government and congress, has become a multibillion-dollar business, with companies and trade associations hiring advocates and lawyers to push their agenda and shape policymaking. According to the Center for Responsive Politics (CRP), through its website www.opensecrets.org/lobby/, among the seven biggest spenders in lobbying, over the last 20 years, are included the U.S. Chamber of Commerce, the American Medical Association, the American Hospital Association, the Pharmaceutical Research & Manufacturers of America, and Blue Cross Blue Shield (an association of 36 separate U.S. health insurance companies); shelling out more than $2.8 billion to lobby. Thus, even though the U.S. government plays a powerful role as regulator, shaper, and payer of the healthcare industry, there has also been strong policy resistance through lobbying. Systems thinking has a name for the behavior exhibited by lobbying: "compensating feedback"—the harder you push, the harder the system pushes back. Figure 1 shows compensating feedbacks through the dashed lines on each of the three archetypes. Providers, manufactures, and insurers consolidate and use collective influence to push and protect their agenda, depending on how much attention the federal government is giving to their issues.

2.2 Healthcare System Performance in the United States

In most markets, companies develop products and services that bring tangible benefits to their customers or end users, in turn; customers are willing to pay up to a maximum price. That maximum is the *value* that customers attribute to the product (McKinsey & Company, 2000). The intrinsic nature of healthcare has, for many years, precluded the practical idea of healthcare being a real market. Traditionally, patients as end users have neither been the key decision makers in product and service selection nor have been the entity that pays for the bulk of those medical interventions.

In the United States, healthcare has been a high commodity instead of an affordable human right for everyone. Currently, global healthcare expenditure is around $8.5 trillion/year. The United States alone spends more than one-third of that (over $3.3 trillion/

year, roughly 18% of its GDP), a number that is projected to grow to $5.7 trillion by 2026 (Centers for Medicare and Medicaid Services, 2016a). Yet the U.S. population has poorer health compared to other high-income countries. Presently, among 11 high-income countries, the United States ranks last in healthcare system performance in terms of access, administrative efficiency, equity, and healthcare outcomes (Schneider et al., 2017). On a global scale, the United States ranks 48th for life expectancy, two places below Cuba (United Nations, 2015). Prices of labor and goods, including pharmaceuticals, and administrative costs are the major drivers of the difference in overall cost between the United States and other high-income countries (Papanicolas, Woskie, & Jha, 2018). Notably, the United States is the only high-income country that does not provide universal health insurance coverage and access to all citizens. Some health experts state that an incomplete insurance coverage may serve as a causal factor for the poor performance of the U.S. healthcare system (Rice et al., 2014).

In the United States, private health insurances administer major government social insurance programs such as Medicare, Medicaid, and CHIP, thus providing significant revenue for the traditional three main players in healthcare (health providers, health manufacturers, and health insurances). However, insurers have not played their role keeping costs under control and ensuring that tangible value is delivered to patients. Additionally, over the last decades, healthcare providers and health insurers have become increasingly consolidated, boosting their bargaining power (Fulton, 2017; Gaynor, Ho, & Town, 2015). As a result, patient quality of care suffers from lack of competition. Previous research has shown that in markets with both high provider and insurer consolidation, insurers have leverage to control and reduce the prices they pay; however, consumers and government-sponsored social insurance programs do not usually benefit (Dafny, 2018; Gaynor, 2018; Scheffler & Arnold, 2017).

Lack of available therapies that really work may also account for the poor performance of healthcare, globally. The biopharmaceutical industry is the biggest sector of the life science industry, which also includes biotechnology, medical devices, and medical diagnostics. The United States is the largest market for prescription medications, accounting for more than one-third of the global market with over $338 billion in annual sales (Kesselheim, Avorn, & Sarpatwari, 2016; The Statistics Portal, 2018; Topol, 2012). Military veterans and individuals 65 and older (Medicare eligible patients) are usually struggling with co-morbidities and poly-pharmacy regimes, taking between two and five drugs each day. The most chronically ill patients typically have five to eight diseases and at least 15 medications (Topol, 2012). The strikingly disappointing reality is that while many of these drugs help patients who take them, the majority of those prescriptions do not work and cause major side effects. Yet, patients and the health payer system have been charged for every prescribed therapy, even when patients that use them do not derive any benefit from the drugs (Topol, 2012). An increasingly growing challenge that the life science industry faces is its historical dependence on broad population health management based on single medical conditions, where the "one therapy fits-all" approach is prevalent instead of TPHM where patients are stratified, segmented, and clustered based on specific and similar determinants of health, including pharmacogenomic predisposition and ethnographic factors.

Traditional medical practice is rooted in an advanced knowledge of diseases, their most appropriate treatment, and an adequate proficiency in its applied practice. But like any other practice, medicine is prone to errors. In November 1999, the U.S. National Academy of Science, an organization representing the most highly regarded scientists and physician researchers in the United States, published the report *To Err Is Human*. The manuscript stated that perhaps as many as 98,000 people die in U.S. hospitals each year as a result of medical errors due to faulty systems, processes, and conditions that could have been prevented. Unfortunately, at that time, physician and hospital malpractice killed more people than car accidents and breast cancer combined and produced more deaths than AIDS. The report exposed how poorly patient data was being collected, aggregated, and shared even within the same health system. In addition to the lost lives, these errors cost approximately $29 billion (Institute of Medicine, 2000).

Healthcare spending in the United States has exhibited exponential growth since 1965 (Davis, 2013). One factor for the exponential growth was the enactment of Medicare and Medicaid in 1965, triggering government social insurance programs to pool resources and spread the financial risk associated with major medical expenses across the entire population to benefit more people. Another factor is the exponential growth of chronically ill patients such as military veterans, low income, and older patients, which represent higher medical and financial risk for both health systems and government-sponsored programs. The cost of pharmaceuticals is a major cause of concern as well, but in the United States, the government is forbidden by law from negotiating drug prices for Medicare. Currently, per capita, the United States spends more on pharmaceuticals than any other country; however, pharmaceuticals expenditures only represent 10% of total U.S. healthcare costs (Centers for Medicare and Medicaid Services, 2016b). Typically, these type of exponential growth patterns indicate the presence of a reinforcing loop (Meadows, 2008; Senge, 1990). In this case, the U.S. healthcare system has not collapsed because the United States is a rich economy and its net cash flow has not gone negative, but that spending pattern will not be sustainable forever. From the healthcare spending reinforcing loop shown in Figure 2, we can infer that the larger the population of chronically ill patients, the higher the reactive care action from individuals (patients and caregivers).

This requires more symptomatic therapies, which are not meant to serve as a cure of disease but palliative treatment of late-stage chronic diseases, leading to higher health system utilization. Ultimately, the government is required to spend more on expensive care duplication, multi-morbidity treatment, and inefficient poly-pharmacy therapies. Concurrently, the higher the government healthcare spending, the more private insurance programs that are needed for the administration of Medicare, Medicaid, and CHIP. Likewise, the more inefficient the health insurance operates (not assuming responsibilities for lowering healthcare costs and not ensuring improved health outcomes), the poorer the health of patients (worsening of current medical condition and emergence of new co-morbidities).

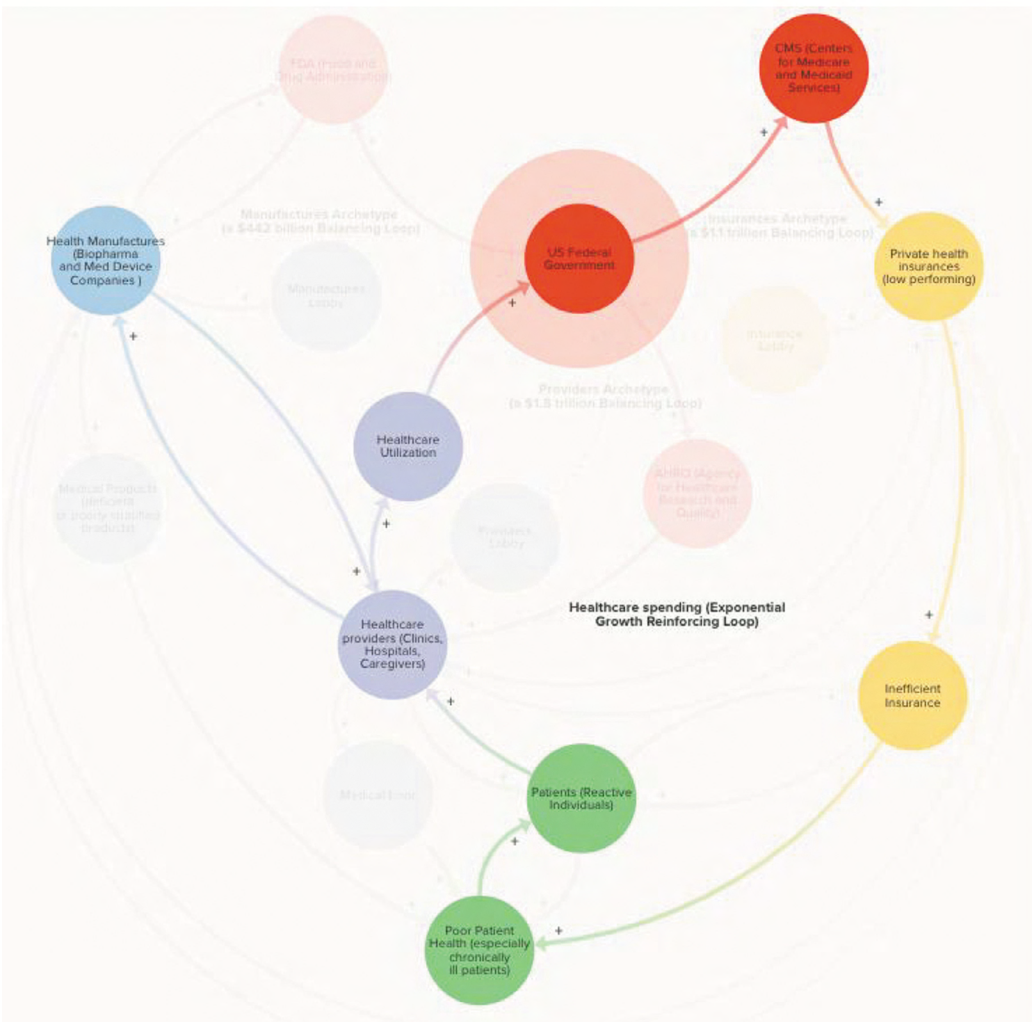

Figure 2. Healthcare spending reinforcing loop (Caicedo, 2019a).

2.3 Drivers of Change in the Healthcare Market

In our view, in order to improve the poor performance of the U.S. healthcare system and to contain the increasingly soaring expenditures, the Obama administration, aware of the presence of eco-systemic deficiencies, attempted to address deep-rooted problematic system structures and expanded government insurance programs through the formulation and implementation of a set of legislation bills including the Health Information Technology for Economic and Clinical Health Act (HITECH) in 2009 and the Patient Protection and Affordable Care Act (PPACA a.k.a ACA) in 2010. HITECH was meant to incentivize the digitization of patient medical information, support hospitals to become users of electronic health records, and optimize clinical and operational effectiveness through the use of health information technology (HIT). Under the ACA, healthcare providers are required to change their practices financially, technologically, and clinically to improve health outcomes, reduce costs, and enhance the experience of care. Moreover, the legislation commissioned major changes in health insurance. It expanded Medicaid coverage and mandated insurers to accept all applicants and charge the same rates regardless of pre-existing conditions or sex (Blumenthal, Abrams, & Nuzum, 2015; Remler, Korenman, & Hyson, 2017). While the ACA has been instrumental in reducing the number of uninsured individuals and likely prevented an estimated 50,000 preventable patient deaths from 2010 to 2013 (Remler et al., 2017), unfortunately, under the law, insurance premiums and deductibles skyrocketed, consumer choices of insurance on state marketplaces have quickly disappeared, and caregiver choices have narrowed dramatically (Blumenthal et al., 2015).

The fee-for-service model is deeply flawed. Financial compensations paid for volume of performed procedures and prescribed therapies to a broad population have not correlated with the value created for patients and health systems. In many cases, such chronic disease treatment, this situation resembles zero-sum economics; in which whatever is gained by one side, it is lost by the other side. In 2006, more than a decade ago, world-renowned strategy expert and Harvard Business School professor Michael Porter, together with innovation expert and University of Texas professor Elizabeth Teisberg, introduced the concept of value-based competition for healthcare (Porter & Teisberg, 2006). The authors argued that zero-sum competition in healthcare was taking place at the wrong level and on the wrong things—shifting costs, increasing bargaining power, capturing patients, and restricting choices and services—rather than creating real value for patients by providing better diagnosis, therapies and treatment, and preventive healthcare. Yet, none of the traditional players took relevant voluntary steps in the direction recommended by Porter and Teisberg (2006). It took regulatory action, in 2010, from the Obama administration to force providers and insurers to change their practices. In turn, this is forcing life science companies to evaluate their own practices to create more meaningful value for patients and health systems.

Now, government-led financial and technological policy regulations are bringing fundamentally new economics and structural changes into the healthcare market place. This is signaling the emergence of a new system that requires a new understanding. Figure 3 illustrates how the interconnectedness and interdependency among healthcare systems' players are becoming more intricate compared to the traditional ecosystem shown in Figure 1. Individual circles represent elements associated with the U.S. federal government (red circles), worldwide healthcare reform (pink circle), manufactures of healthcare products (blue circles), providers of medical treatment (purple circles), private insurance companies (yellow circles), and patients (green circles) and digital technology companies (gray circles). Regulatory links contain "delays," interruptions in the flow of influence, which make the consequences of actions to occur gradually, often over the course of several years. Figure 3 shows system-wide interrelationships, highlighting balancing and reinforcing loops of influence. Notably, the move from volume to value is part of worldwide healthcare reform and variants of that approach have been incorporated in the United States as part of the ACA. Now, when it comes to improving the way health providers are paid, the federal government wants to reward value and care coordination rather than volume and care duplication. In fact, by the end of 2018, performance-based reimbursement approaches are expected to account for 50% of Medicare payments (Elton & O'riordan, 2016). Additionally, in 2016, the 114th U.S. Congress passed the 21st Century Cures Act, which encourages healthcare organizations to evaluate the potential of real-world evidence (Hubbard & Paradis, 2015) (RWE) to help support the FDA approval process of new therapies or new indications on existing drugs.

As shown in Figure 3—*Provider Value-Based Balancing loop*—, a fundamental change is taking place; the U.S. government is shifting financial risk from the payer to the provider. Accordingly, providers are becoming increasingly determined to measure the real-world true effectiveness of the treatments they perform and therapeutics they prescribe. This is also changing how physicians organize in risk-bearing "Organized Provider" groups in order to create and measure patient-centered value. Both insurers and physicians are now interested in real-world data and evidence to support value-based purchasing and contracting that maximizes the patient experience throughout the full cycle of care. Most of these Organized Providers are being reimbursed based on value-based performance via alternative payment models (APM). Approximately 40% of Organized Providers express using RWE as the most important information, outpacing even clinical trial data (Rose, Hassan, Saitta, & Kim, 2017).

Critical to measuring real-world health outcomes is the availabil-

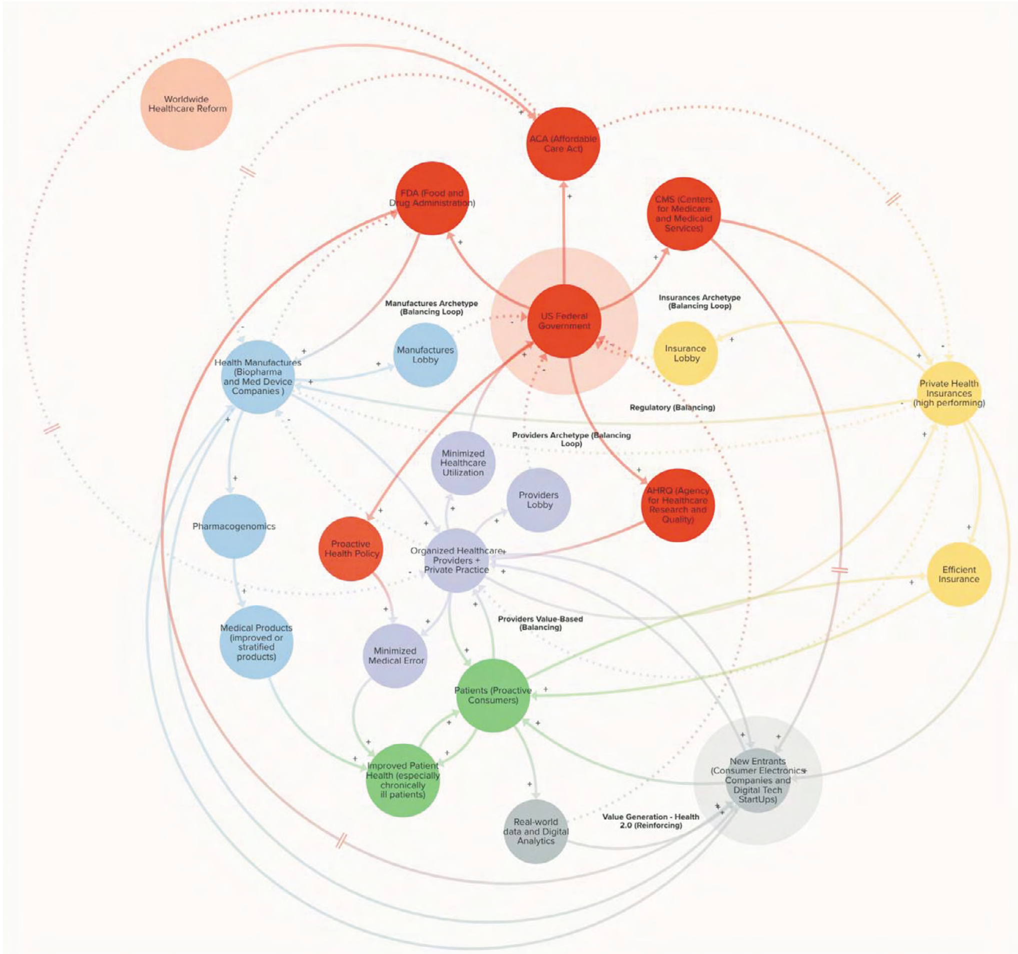

Figure 3. Current U.S. healthcare market place aiming at TPHM. Regulatory and value loops have been put in place to curb systems archetypes' practices. New entrants are poised to collaborate and compete with traditional healthcare players. The interconnectedness and interdependency among healthcare systems' parts are becoming more intricate (Caicedo, 2019b).

ity of compelling health information technological capability. Over the last few years, New Healthcare Entrants (PwC, 2016) such as consumer electronics companies and digital technology startups have made unprecedented progress in engineering and digital technologies, from cloud computing, wireless wearable sensors, and the Internet of Things (IoT) to big data, artificial intelligence, and smart machines. As seen in Figure 3, digital technology is dramatically enabling consumers, researchers, and patients to generate real-world medical-relevant information (a.k.a. digital phenotypes (Jain, Powers, Hawkins, & Brownstein, 2015)) from social footprints, hospitals, and outside of traditional clinical settings, respectively (Burke, 2013; Topol, 2015).

Conversely, progression of emerging biomedical scientific areas such as genomics, immunotherapy, the microbiome, biocomputing, and gene therapy are enabling efforts toward personalized medicine. The timing of these disruptive innovations is fortuitous, now patient-centric real-world data can be captured, aggregated, and assessed; thus enabling healthcare reforms efforts to create standards for how care is delivered and outcomes are measured.

Value-based contracting and reimbursement are increasingly becoming the new normal and the U.S. healthcare market is progressively leaning toward value-based pricing for therapeutics, devices, and care services. Moving forward, organizations that compete providing services and products to the healthcare ecosystem will find it increasingly difficult to secure reimbursement without formal evidence of the value being provided to target or specific populations of patients. In many U.S. health institutions, TPHM has emerged as an approach to implement value-based care rather than volume-based care. The goal of TPHM is to improve the health of specific populations, reduce the cost of care, and ensure that care delivery is efficient and of high quality. TPHM aggregates clinical and real-world digital phenotype data, uses advanced digital analytic technologies, and generates relevant actionable insights (Burke, 2013; Elton & O'riordan, 2016); thus informing and guiding decision-making to develop proactive healthcare solutions that help improve both medical and financial outcomes.

3.0 Antifragility in Targeted Population Health Management

Antifragility is the ability of a system to gain from disorders, harmful stressors, or volatility. It is a concept developed by Professor Nassim Nicholas Taleb in his 2012 book, *Antifragile,* and it is currently applied in risk analysis, molecular biology, engineering, and computer sciences. According to Taleb (2012), antifragility is different from the concepts of resiliency and robustness. The basic concept is that, when exposed to external harmful stressors, neither the robust nor the resilient improve, as occurs with the antifragile. Notably, antifragile systems do not require predictability of external stressors as occurs with robust or resilient systems (Taleb, 2012). Amid intense volatility and uncertainty in the U.S. healthcare industry, we attempt to describe how antifragility could be explored in TPHM. Since fragility and antifragility come on a spectrum of varying degrees, the idea is to focus on fragility and ideate what to do to improve its condition, rather than focusing on predictability of external stressors. The fragile wants tranquility, comfort, and forecasting. Table 1 shows items relevant to TPHM that are classified into three categories: fragile, robust, and antifragile.

Presently, in the United States, the ACA is perhaps the most uncertain aspect of healthcare. In our view, the New Healthcare Entrants are the players that are better positioned to become antifragile if they are able to exploit the

Value Generation—Health 2.0 reinforcing loop (Figure 3) ideating a compelling value strategy that gains from the fragility that traditional players have and the uncertain future of the ACA. In fact, as long as such value strategy is put in place, New Entrants would not require predictability of the ACA. Fundamentally, they have to focus on enabling an ecosystem of technological capabilities that reliably capture and measure outcomes of medical and financial interventions.

The fundamental difference between top digital technology powerhouses and traditional health players is not just that the revenues of the former overshadow that of the latter, but the fact that digital technology companies are consumer-centric organizations instead of product- or provider-centric organizations as has happened with traditional health players. As such, for digital technology companies, consumers' real-world experiences direct their internal decisions, the businesses they go into, the R&D goals, and the overall go-to-market strategy. Digital technology companies are measured in a true market competition environment and are defined by the superiority of the technologies they advance and the positive changes these bring to their customers' lives (Elton & O'riordan, 2016).

As shown in Figure 3, the leverage lies in the *Providers Value-Based* balancing loop; capturing, aggregating, and leveraging real-world data in support of clinical integration is imperative for providers seeking to participate in a targeted population health model. This can be challenging unless providers can access core technological capabilities such as longitudinal real-time monitoring of clinical data and digital phenotypes, interconnectivity, interoperability, and advanced data analytics. New Healthcare Entrants may serve as enablers of value generation by facilitating efforts toward care coordination and delivery, measuring therapy effectiveness and health outcomes, and stratifying patients by medical and financial risk, so the appropriate care management strategy is put forward to offset the risk. In turn, the patient, for the first time, may request for a formal assessment of the effectiveness of chronic disease medical intervention.

4.0 Discussion

The U.S. healthcare system is going through a dramatic transformation. Health policy, the digital economy, and real-world evidence are the new foundation of value-based competition in healthcare. However, the healthcare market is still plagued by systemic inefficiencies and inappropriate business practices that preclude both fair competition in an open economy and the delivery of affordable value to patients and consumers; from insurance consolidation that narrows consumer and caregiver choices (Fulton, 2017; Gaynor, 2018) and personal consumer genomics companies that use and abuse people's curiosity about ancestry and make remarkable profits based on people's genomics ignorance and personal data (Molteni, 2018) to pharmaceutical companies that believe it is a "moral re-

Table 1. The Central Triad: Three Types of Exposures in Healthcare

	FRAGILE	ROBUST	ANTIFRAGILE
Healthcare	Product-centric, broad disease care, reactive, diagnosis, treatment, co-morbidities (several chronic diseases), poly-pharmacy, volume-based	Personalized disease care, few chronic diseases to treat	Customer-centric, personalized health care, proactive, tracking, pre-emption of triggers of disease (both body processes and environmental factors), few atypical diseases to treat, value-based
Disease care	Chronic stressor		Acute stressors
Medical error	Unreported, not studied, penalized, epidemic		Reported, studied, not penalized (except preventable pervasive cases), minimized
Biotechnology	Product-centric research driven by misleading science and shareholder value creation, first to market, volume-based		Patient-centric research driven by top-notch science and stakeholder value creation, value-based
Biopharma-ceuticals	Rudimentary scientific methods (pharmacokinetics (PK)/ pharmacodynamics (PD)), broad population, poor performance (safety and efficacy), volume-based		Sophisticated scientific methods, pharmacogenomics (PK/PD + genomics), targeted population, high performance (safety and efficiency), value-based
FDA	50% of the budget from "User fess"	10%–20% of the budget from "User fess"	Financial independence, fiscal responsibility
AHRQ	Rationalism		Real-world evidence-based
CMS	Fee-for-service, volume-based reimbursement	Performance-based reimbursement	Value-based reimbursement
Expenditure	Debt	Equity	Venture capital
Clinical trials	Broad population, volume-based care	Targeted population	The individual, value-based care
Engineering and digital technologies	Product-centric, Directed research, focused and undeveloped: insulin pumps, bulky ECG devices	Opportunistic research	Customer-centric, stochastic tinkering, multi-disciplinary and developed: Cloud computing, wireless wearable sensors, the Internet of Things (IoT), big data, artificial intelligence, smart machines, advanced analytics

quirement" to raise the price of life-saving medication over 400% (Crow, 2018) and hospitals that charge astronomic bills by increasing the cost of life-saving interventions over 32,000% (Terhune, 2018) because they are in the "business of making money." Below we discuss additional topics that require immediate proactive action from health policymakers and regulators.

Incomplete and inefficient health insurance coverage contributes to the poor performance of the United States on healthcare outcomes, affordability, administrative efficiency, access, and equity. Currently, among high-income countries and based on overall healthcare performance, the top-ranked countries are the UK, Australia, and the Netherlands (Schneider et al., 2017). All three provide universal insurance coverage and access, but do so in different ways. Notably, the UK and Australia have a single-payer system, whereas the Netherlands has a multi-payer system. This indicates that when it comes to achieving high performance, there is not one particular system that should be used as a role model across countries. Moreover, each country has a unique set of cultural, social, political, and financial interdependencies and interrelationships, which set the framework for systemic structure. Nevertheless, the United States could take a look at other countries' approaches to help generate actionable insights that enable the development of a more affordable high-performing healthcare system that serves all of its citizens. One hallmark characteristic that top-ranked countries have is a more efficient insurance system. For instance, in the Netherlands, unlike in the United States, insurance is actually considered a social service and it is much more heavily regulated. Insurers are typically private companies that sell their plans to consumers that are subsidized by federal government programs (Schneider et al., 2017). In both, the U.S. and Europe, sustained payer focus on value and evidence is an imperative. The pressure is strongest in Europe where clinical efficacy alone is now not enough for reimbursement and launches may be restricted to stratified populations (Elton & O'riordan, 2016). Payers want to see real-world benefit in support of their decision to allow access and reimburse at specific price tags. All of which makes future adoption of outcome and value-based pricing more likely.

The biopharmaceutical industry is arguably a fundamental sector of our complex healthcare ecosystem. The World Health Organization (WHO) defines 433 drugs as essential medicines for addressing the most important public health needs globally (WHO, 2017). Yet, the biopharmaceutical industry has to come to good terms to meet its social contract duties while ensuring its own corporate sustainability and profitability. A few years ago, Severin Schwan, the CEO of Roche, expressed that half of all diseases can be considered untreatable and for the other half the drugs only work half the time and cause huge side effects (Economist, 2009). This has profound implications when we talk about patient medication adherence. Some folks resort to Design Thinking and Artificial

Intelligence to try to influence behavior modification in patients, overlooking the fact that a lot of patients do not adhere to certain medications just because they are not getting any benefit from those drugs. Deriving profits from deficient or poorly stratified biotherapies that are commercially available creates shareholder value but carries no moral agency and delivers little value to patients and health systems. “Shareholder value is an imperfect proxy for the value we create for society,” asserts Kenneth Frazier, CEO of Merck & Co. (Ignatius, 2018). We need true purpose-driven leaders and bio-citizens that like, Severin Schwan and Kenneth Frazier, are not afraid to express the shortcomings of the biopharmaceutical industry and are proactively working to close the gap.

Patient-centered drug risk and effectiveness assessment is an area with a lot of room for improvement. RWE has emerged as the core foundation of TPHM as RWE reflects “what does work” (effectiveness), instead of just “what can work” (efficacy). This enables unique opportunities for life science companies to not only innovate in marketing and advertising but also to guide and improve internal research and development (R&D). For instance, our response to every drug is controlled by our intrinsic determinants of health, which include genetic and ethnographic factors. In particular, every person has a unique genome, and this sheds light on why there is that much variability in the effect of drugs in terms of safety and effectiveness. One way to improve patient-centered drug risk and effectiveness assessment is by using pharmacogenomics. Pharmacogenomics is the study of the role of key genes involved in a drug’s therapeutic action (Tan-Koi, Leow, & Teo, 2017). For manufactures, pharmacogenomics represents a compelling patient-centric capability to help predict which patients are likely to respond to most therapies, either deriving benefit from the drugs or experiencing side effects. Additionally, drugs with strong genetic data could be very beneficial for patient or population stratification. This could be a patient-centered genome-based competitive advantage that can be monitored and measured in the real world using digital capabilities; delivering value to patients, health systems, and a company brand-name therapy versus alternative therapies. Despite this observation, a significant amount of commercially available drugs do not include pharmacogenomic information. The FDA seems to be invested and supportive of the science and regulation of pharmacogenomics (PwC, 2016). Going forward, every new drug should have a pharmacogenomic study into its development and labeling to increase efficiency and effectiveness in patient-centered care not only during clinical trials but also throughout the full cycle of care during established medical interventions.

Medical practice needs to be rebooted. The report *To Err Is Human* (Medicine, 2000) noted that medical error was a leading cause of patient deaths killing up to 98,000 people in the United States every year. One hypothesis that came up was that patient data was being poorly collected, aggregated, and shared among different hospitals and even within the same health system. Health policies such as the Health Information Technology for Economic and Clinical Health Act (HITECH) in 2009 and the Affordable Care Act (ACA) in 2010, primarily focused on optimizing clinical and operational effectiveness through the use of health information technology and expansion of government insurance programs, respectively. However, they did not effectively address the issue of medical errors such as poor judgment, mistaken diagnoses, inadequately coordinated care, and incompetent skill that can directly result in patient harm and death.

According to a study published in 2016 by researchers at Johns Hopkins University School of Medicine (Makary & Daniel, 2016), medical error is no longer the leading cause of death in the United States. However, it still ranks up as the third leading cause of death, after heart disease and cancer, causing at least 250,000 deaths every year. A figure that the authors of the study acknowledge represents an undercount, because they were unable to capture data from deaths in outpatient clinics and nursing homes. In fact, other study (James, 2013) reported the number of deaths from medical error to be over 400,000. Regardless of what the most accurate estimate is, they are big numbers that reminds us how inefficient healthcare still is and how patient death due to medical error is an under-recognized and under-addressed epidemic in the United States. A revealing finding mentioned in the report is that medical error is not included on death certificates or in rankings of cause of death. Every year, the Centers for Disease Control and Prevention (CDC), using death certificates data, compiles the list of the most common causes of death in the United States. Therefore, in the United States, there is no pragmatic effort to raise public awareness and inform national research priorities to study medical errors and implement effective safeguards for patients.

The 21st Century Cures Act passed in 2016 encourages healthcare organizations to use real-world evidence (RWE) to help support the FDA approval process of new therapies or new indications on existing drugs. However, that RWE does not account for the systematic and comprehensive recording of physician and hospital malpractice. The idea that medical personnel start recording medical errors trustworthily, or without worry for malpractice liability is not realistic. What is needed is proactive federal-level legislation that provides some legal protection to caregivers against lawsuits when it is found that they did not intentionally incur in medical malpractice. The same type of state-level legal protections that already exists when physicians report morbidity and mortality minutes within their institutions; a.k.a. medical peer review privilege (Goldberg, 1984). Notably, those minutes are not discoverable in a court of law and cannot be used by plaintiff's counsel in a malpractice action. However, in the context of federal court, a peer review privilege produced by state law does not always apply because the federal rules of evidence only recognize privileges incorporated in the federal common law and privileges produced by federal law (Young, 2003). The Patient Safety and Quality Improvement Act of 2005 (Nash, 2011) tried to address those shortcomings, but it has been limited in scope. It is not an error-reporting system *per se*. It safeguards documents submitted into an organization's patient safety evaluation system followed by submission to a recognized Patient Safety Organization (PSO). If an organization fails to follow these steps, courts will not allow the organization to make a formal request of the medical peer review privilege.

Medical error is an issue that cannot just be addressed with health information technology and artificial intelligence (AI). HITECH has enabled massive development of electronic medical records and advanced predictive analytics to implement clinical decision support systems that better inform medical interventions throughout the full cycle of care. However, as noted before, medical errors are not documented in electronic medical records. The solution is not to replace medical personnel with AI-powered machines. Despite ethical concerns and even though there has been unprecedented progress in the fields of AI and machine learning, current artificial neuronal networks applications in healthcare are highly specialized, incapable of generalize out of context information, and perform very specific assignments such as pattern recognition and classification tasks. In contrast, the human brain is capable of performing more general and complex tasks with a great deal of self-awareness and counterfactual thinking. Moreover, recent news have shown that one of the most advanced healthcare AI assistants have delivered unsafe and inaccurate recommendations for treating cancer (Ross & Swetlitz, 2018).

Regulatory policies are changing reimbursement models and shifting financial risks across the healthcare system. Table 1 suggests additional changes that should be performed in order to enable the full implementation of TPHM shown in Figure 3. However, we are aware that some of those suggestions might not be implemented in the short term. For instance, for health manufacturers, that have traditionally defined market share as the largest possible proportion of the total druggable patient population, stratifying the patient population by using pharmacogenomics would mean creating a micromarket, which may impact their the cash flow and overall net income. Furthermore, according to the Center for Responsive Politics (CRP), spending of the biggest U.S. lobbies continues its rising trend. This behavior is an example of shifting dominance of the feedback loops shown in Figure 3. Dominance is an essential concept of systems thinking because systems frequently have several competing loops operating at the same time. Those loops that dominate the system will establish behavior and determine the event we see.

To be clear, lowering high healthcare costs while delivering superior value to patients and health systems is not just about changing reimbursement models and engaging in digital transformation, but also about changing the standards on which senior management and policymakers make fundamental decisions that influence the value chain throughout the entire healthcare ecosystem and not just their organization. This is not the traditional change management, but a cultural management transformation that operates with patient centricity and digital economics in mind as opposed to zero-sum economics.

5.0 Conclusion

In the United States, traditional healthcare system archetypes have reinforced structures that have operated for a period of time to mainly provide shareholder growth and little value for patients and health systems. The ACA, incorporating global healthcare reform principles, is acting as a regulatory structure to limit the dominance of these archetypes and improve the poor performance of the U.S. healthcare system. Notably, powerful consumer-centered digital technology companies have entered the healthcare market and are eager to use their resources to claim and defend a beachhead. They are enabling individuals to have intimate interaction with products that ubiquitously collect real-world medical-relevant data. This is a significant change poised to enable government reforms efforts aimed at creating better standards for how care is delivered and outcomes are measured, ultimately empowering a shift from broad population health management to TPHM. Nonetheless, so far, the policies and regulations that have been put in place have partially addressed systemic failure by focusing on clinical and operational optimization through the use of HIT. Yet, there is still a fundamental disconnect between what patients need in order to be healthy individuals and what they actually get as consumers: more services and treatments that generate revenue in addition to more medical error. Efforts targeting digital transformation and healthcare utilization alone are unlikely to reduce the growth in healthcare spending in the United States; a more determined approach to both address medical error and reduce prices of labor, goods, and administrative costs is needed. Moreover, proactive public policies that enhance competition in healthcare markets are needed, such as uncompromising enforcement of antitrust laws that limit powerful lobbies, limiting massive consolidation of health systems, restricting anticompetitive behaviors within health providers and manufacturers, and holding the FDA accountable for the approval and labeling of stratified therapies that deliver value outside clinical trials. The systems maps developed in this work, while not fully comprehensive, helped improve our understanding and perception of the U.S. healthcare system and supported the development of recommendations to guide enhanced policy and decision-making. As patients, physicians, biotechnologists, policymakers, and legislators actively debate the future of the U.S. healthcare system, systemic analysis such as this report are needed to inform policy decisions.

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Reflections On the Use of Complexity-Appropriate Computational Modeling for Public Policy Evaluation in the UK

Dr. Pete Barbrook-Johnson

Department of Sociology, University of Surrey, UK

p.barbrook-johnson@surrey.ac.uk

Dr. Corey Schimpf

The Concord Consortium, USA

cschimpf@concord.org

Prof. Brian Castellani

Department of Sociology, Durham University, UK

brian.c.castellani@durham.ac.uk

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Abstract

In the UK, calls for the application of insights from the study of complex adaptive systems to public policy evaluation are beginning to be taken seriously in government. Policymakers and analysts are accepting the fallibility of overly simplistic, definitive, or linear analysis, or are finding traditional forms of analysis and evidence less appropriate or feasible. Through our work in CECAN (the Centre for the Evaluation of Complexity Across the Nexus), we reflect on our experiences and the practical challenges of using complexity-appropriate computational modeling with policy ana-

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lysts and evaluators in UK central government. As an example, we discuss our work with the COMPLEX-IT toolkit, which uses a selection of case-based computational modeling approaches. We end by suggesting ways forward for applied complexity scientists, and policy evaluators and analysts to make more effective use of these methods.

Keywords: complexity; policy; evaluation; social complexity; research impact

Reflexiones Sobre el Uso de Modelos Computacionales Adecuados a la Complejidad Para la Evaluación de Políticas públicas en el Reino Unido

Resumen

En el Reino Unido, los pedidos para la aplicación de conocimientos del estudio de sistemas adaptativos complejos a la evaluación de políticas públicas están comenzando a tomarse en serio en el gobierno. Los formuladores de políticas y los analistas están aceptando la falibilidad de un análisis demasiado simplista, definitivo o lineal, o están encontrando formas tradicionales de análisis y evidencia menos apropiadas o factibles. A través de nuestro trabajo en CECAN (el Centro para la Evaluación de la Complejidad A Través del Nexo), reflexionamos sobre nuestras experiencias y los desafíos prácticos del uso de modelos computacionales con analistas de políticas y evaluadores en el gobierno central del Reino Unido. Como ejemplo, analizamos nuestro trabajo con el kit de herramientas COMPLEX-IT, que utiliza una selección de enfoques de modelado computacional basados en casos. Terminamos sugiriendo formas de avanzar para que los científicos de complejidad aplicada y los evaluadores y analistas de políticas hagan un uso más efectivo de estos métodos.

Palabras Clave: complejidad, política, evaluación, complejidad social, impacto de la investigación

对运用适度复杂的计算建模评估英国公共政策的反思

摘要

对于从研究复杂适应系统到评估公共政策应用洞察力的呼声开始受到英国政府的关注。决策制定者和分析人员逐渐认可过于简单和决断的直线性分析不太可靠，抑或发现传统形式的分析和证据难以实现或不太合理。笔者通过在CECAN(Nexus复杂性评估中心)的研究工作向来自英国中央政府的策略分析人员和评估人员总结了运用计算建模时所面临的实际挑战和经验教训。举例来说，笔者通过运用一系列基于案例的计算建模方法讨论了COMPLEX-IT 项目工具箱的研究工作。最后，笔者关于应用复杂性科学家、政策评估人员和分析人员如何更为有效地利用这些方法提供了建议。

关键词：复杂性，政策，评价，社会复杂性，研究影响

1. Introduction

The growing interest in the application of insights and methodological approaches from the study of complex adaptive systems (from now on referred to simply as "complexity") in public policy in the UK is well documented (see, for example, Byrne & Callaghan, 2014; Byrne & Uprichard, 2012; Anzola, Barbrook-Johnson, & Cano, 2017). In ex-post policy evaluation in particular—which is a significant component and focus of public policy analysis in the UK—interest has grown steadily over the last 20 years (Reynolds, Forss, Hummelbrunner, Marra, & Perrin, 2012; Gates, 2016).

In the evaluation literature (not constrained to UK only), focus has also shifted from early discussions of the theoretical implications of complexity for evaluation (e.g. Sanderson, 2000), to more practical explorations of the contexts in which complexity can be usefully applied (e.g. Barnes, Matka, & Sullivan, 2003). The fit of complexity with other theoretical, methodological, and empirical traditions has been considered (e.g. Callaghan, 2008; Stame, 2004). In the last few years, as we do here, authors have reflected and reviewed the use of complexity in evaluation, for example, its use directly in evaluation scholarship (Gates, 2016; Mowles, 2014; Walton, 2014), the acceptance and use of complexity in practice (Reynolds, Gates, Hummelbrunner, Marra, & Williams, 2016), and reflections on which parts of the typical evaluation process it can be most useful to (Williams, 2015). The shifting focus of these authors through time reflects the growing use and acceptability of complexity in public policy analysis and evaluation; this shift is representative of the evaluation community in the UK too. This is further evidenced by the recent creation of flagship research centers on evaluation, as in the case of the Centre of Excellence for Development Impact and Learning (CEDIL), and CECAN, which have a strong focus on addressing complexity.

We aim in this paper to continue the development of complexity-appropriate evaluation and further elaborate thinking on one particular strand—the use of complexity-appropriate computational modeling in practice—by sharing our experiences and reflections on its use. We combine our experiences with recent contributions on how to have greater impact from the computational modeling (Gilbert, Ahrweiler, Barbrook-Johnson, Narasimhan, & Wilkinson, 2018) and policy research (Cairney & Oliver, 2018) communities.

We use as an example, the case-based computational modeling approaches used in the COMPLEX-IT and SACS toolkits (Castellani, Rajaram, Gunn, & Griffiths, 2015a; Castellani, Rajaram, Buckwalter, Ball, & Hafferty, 2015b; Castellani, Barbrook-Johnson, & Schimpf, 2019), which we have recently used with policy evaluators and practitioners in environmental policy domains in the UK. Importantly, for our purpose here, COMPLEX-IT (which is the companion software for the SACS toolkit, see below) employs specific complexity-appropriate computational modeling approaches including cluster analysis, artificial intelligence and artificial neural nets, data visualization, and case-based microsimulation. Focus on the issues of application of these types of modeling is underdeveloped in the public policy and evaluation literature and deserves further attention (Gilbert et al., 2018). Modeling of these types can be seen as more technically sophisticated and appeal to policy users' excitement around data science and artificial intelligence approaches, but also as expensive, time-consuming, and difficult to understand. We hope to articulate these issues, and others, and plot practical ways forward for applied complexity scientists, and policy analysts and evaluators wanting to use computational modeling.

The rest of this paper is structured as follows. Section 2 introduces COMPLEX-IT, SACS, case-based complexity, and CECAN, and discusses in detail the barriers to the use of computational modeling we encountered. Section 3 introduces contributions from the computational modeling and policy research communities on ways forward, and proposes practical steps for applied complexity scientists. Section 4 summarizes and concludes with a call for more pragmatism, modesty, and co-production.

2. CECAN and COMPLEX-IT

CECAN is a research center hosted by the University of Surrey, in the UK, and made up of partners from nine universities and five policy practitioner and consultancy organizations. It is co-funded by research councils and four government departments or agencies: the Department for Business, Energy and Industrial Strategy (BEIS), the Department for Environment, Food and Rural Affairs (Defra), the Environment Agency (EA), and the Food Standards Agency (FSA). These four departments and agencies give the center its policy focus on food, energy, water, and environment (or "nexus") domains. A nexus approach involves considering the interactions of food, energy, water, and environment domains in a number of ways, see Cairns and Krzywoszynska (2016) for a full discussion.

CECAN's mission is to pioneer, test, and promote innovative evaluation methods and approaches. The work of CECAN is underpinned by complexity and a nexus approach, and the use of co-production and Agile (Senabre Hidalgo, 2018) working methods (CECAN, 2018). As part of its work, CECAN has conducted a range of co-produced case studies with the four departments and agencies and run a fellowship program. One element of this work has involved exploring the application of COMPLEX-IT and case-based methods.

Case-Based Complexity

Within the world(s) of computational modeling and interdisciplinary mixed-methods, case-based complexity constitutes one of the major methodologies for modeling complex social systems or, more generally, social complexity (Byrne & Callaghan, 2014; Castellani et al., 2015a). When employed using the techniques of data mining, it is particularly useful for analyzing and modeling policy-based data. To date, there are several different (albeit inter-related) approaches to case-based complexity, such as Ragin's qualitative comparative analysis (QCA) and fuzzy set analysis (Rihoux & Ragin, 2009) and Hayne's Dynamic Pattern Synthesis, which explores the dynamical relationships among cases (Haynes, 2017).

Regardless of the method used, a case-based complexity approach is grounded in four core arguments; which also deeply resonate with the majority of computational methods used in modeling policy data: (i) the case and its trajectory across time and space are the focus of study, not the individual variables or attributes of which it is comprised; (ii) cases and their trajectories are treated as composites (profiles), comprised an interdependent, interconnected sets of variables, factors, or attributes; (iii) the social interactions among cases are also important, as are the hierarchical social contexts in which these relationships take place; and (iv) cases and their relationships and trajectories are the methodological equivalent of complex systems—that is, they are emergent, self-organizing, nonlinear, dynamic, network-like, etc.—and therefore should be studied as such.

To this list, our approach to case-based complexity adds three more points which situate case-based complexity even more squarely at the cutting-edge of computational modeling methods: (i) cases and their trajectories are dynamically evolving across time/space; and therefore should be explored to identify their major and minor trends; (ii) in turn, these trends should be explored in the aggregate for key global-temporal patterns; and (iii) the complex set of relationships among cases is best examined using the tools of network science.

COMPLEX-IT and the SACS Toolkit

Now that we have a basic sense of case-based complexity, we need to quickly review one of its key methodological platforms, the SACS Toolkit (Castellani et al., 2015a), and its companion software, COMPLEX-IT (Castellani et al., 2019), which we have been using with policy evaluators. The utility of the SACS Toolkit (Sociology and Complexity Science toolkit) is that it is a mixed-methods, computationally grounded approach to modeling complex systems, particularly large datasets (Castellani & Rajaram, 2012; Castellani et al., 2015a; Rajaram & Castellani, 2015). The purpose of the SACS Toolkit is to provide users with a series of steps and procedures for modeling complex systems in case-based terms; this is supported with full mathematical justification. In line with case-based complexity, the purpose of the SACS Toolkit is to model multiple trajectories (particularly across time/space) in the form of major and minor trends; which it then visually and statistically data mines for both key global-temporal dynamics and unique network-based relationships. The SACS Toolkit also data mines its results to either (a) predict novel cases or trends or (b) simulate different case-based scenarios. For an in-depth overview of the SACS Toolkit, including its mathematical foundation, see http://www.art-sciencefactory.com/cases.html.

The software companion to the SACS Toolkit is COMPLEX-IT (http://www.art-sciencefactory.com/complexit.html). The COMPLEX-IT toolkit is an open-source web-based application in beta development. It was built using the R shiny framework (see, https://shiny.rstudio.com/). It uses a tab-driven interface to allow users to easily employ a suite of computational modeling approaches from traditional k-mean cluster analysis to a self-organizing neural network map (SOM), and case-based microsimulation. It is designed to require no prior experience with the techniques so that nonexperts may begin using these methods quickly, and thus whet their appetite to understand the methods more deeply and be encouraged to begin applying them more meaningfully in their analysis. Advanced users can examine, download or modify COMPLEX-IT's algorithms, results, and codebase.

Using COMPLEX-IT with UK Policy Analysts and Evaluators

Between July 2017 and March 2018, we facilitated a series of workshops with policy evaluators and analysts in order to explore the practical challenges faced when using such tools, and to further develop COMPLEX-IT's functionality and usability. Of the various workshops we held, one in particular was relevant here, primarily because it was emblematic of the experiences we had in our other workshops. It is also of interest because the nature of its focus—exploring the application and implementation of a new analysis approach in government, and how complexity-appropriate modeling can help—gave the discussions a high level of practical detail.

The workshop was co-organized with Natural England, and attended by officials from Natural England, Defra, the EA, and the Forestry Commission; these are all public bodies with a range of roles in policy design, implementation, and evaluation, aimed at environmental protection. The UK government as a whole (and thus all of these public bodies) has adopted the use of a natural capital approach as a decision-making tool in its environment policy (HM Government, 2018). The natural capital approach involves an effort to value the stock of fresh water, land, air, species, minerals, and oceans which underpin the economy by producing value for people (Natural Capital Committee, 2017). This approach and its predecessors have been controversial for a range of technical and moral reasons (O'Neill, 2017), but is now being adopted and used across a range of government departments. These departments and agencies are now in the process of adapting their existing data collection and analysis efforts to bring them into line with, and allow them to support effectively, a natural capital approach. To this end, this workshop and the discussions around it were aimed at exploring the potential for COMPLEX-IT and the computational modeling within it to support and complement the implementation of a natural capital approach.

The participants emphasized the tension between natural capital as a theoretical backdrop and approach, and its application. At the core of this tension are a range of practical difficulties around data availability, analysis, and communication. We explored these issues in detail with the participants and considered how a case-based computational modeling approach might help. The following potential benefits were discussed:

- **Analysis**: (i) how these approaches could provide analysis tools for the overview of stocks being developed by the natural capital approach; (ii) the ability of these methods to explore trajectories of change in natural capital stocks in the search of those in high risk of collapse or significant damage; and (iii) how these methods could explore the interaction of cases (e.g. stocks), and the knock-on effects of improving one or a few, on others.

- **Dealing with poor data**: (i) how these approaches might offer greater flexibility on data sources used and gaps in data, than other approaches; and (ii) how feasible it is to transform existing data sets into case-based forms.

- **Communication**: finally, we discussed how outputs of the analyses in COMPLEX-IT can be turned into qualitative narratives and vignettes for communication purposes.

Underpinning all of these discussions was the fundamental question of "what is a case?" for these policy practitioners using the natural capital approach. Is it an individual natural asset (such as a peat bog, a forest, or a lake), is it some aggregate of these by geography or type, or is it some geographical or administrative area? For each potential type of case, there is already data collected in one form or another, but the question of which might be best to use first, and how this might maximize the potential of any analysis, was a cornerstone of discussion throughout. It is not our aim here to explore these potentials in detail, but rather to reflect on the other side of discussions we had, the practical barriers for their realization.

Barriers to the Use of Computational Modeling: Access and Ability

Participants described, and we have observed in our own work and that of CECAN, a profound inflexibility, conventionality, and inertia in the research and evaluation commissioning process in UK government. Broadly, this appears to come from one of two sources. First, it can arise for technical and bureaucratic reasons. Various layers of oversight and quality assurance can make the hurdles which a "new" analysis or modeling approach needs to be guided through too high to allow for exploration and healthy risk-taking with methods. In addition, highly simplified models of the policy process (known to be simple, but still used to structure workstreams) can restrict the permitted points of access for research and evaluation methods to clearly contained "moments" of input. In effect, policymakers limit the access and input of research into policy processes, to clearly defined and controlled points. For complexity-appropriate computational modeling, which seeks to develop broader system understanding and inform discussions and thinking (rather than only make forecasts), through iteration and reflection, this is a serious problem. These methods are not well suited to momentary, singular, and definitive inputs into an otherwise rolling or closed process. This makes accessing them, for policy evaluators and analysts, very difficult.

The second cause of this inertia described to us by participants is driven by perceptions of what is politically necessary, rather than by technicalities. Participants described, despite a growing interest in complexity, a strong push and demand for (false) reliability in analysis and modeling. Senior civil servants, communicating with senior policymakers and politicians, want to be provided with certainty and with "numbers" that give the impression of accountability and credibility. Again, methods and modeling which take into account wholistic views of the social and policy space, and embrace uncertainty and lack of data, are not well suited to meeting these demands, meaning this demand for certainty tends to make these methods less viable and accessible for analysts.

Setting aside these barriers for analysts being able to "officially access" complexity-appropriate modeling, there is another key barrier for their use; the ability to use them, both easily, and in combination with others. This ability is driven by two key factors, skill and data. The complexity-appropriate computational modeling approach we used, and related approaches, require specific technical competencies and skills which are not standard on undergraduate, or even many postgraduate, taught courses. This means analysts must gain these skills while in work. UK civil servants do have time for personal and skills development, but this time is inevitably constrained. On specific projects, the standard learning curves for using these methods don't work in the face of tight deadlines; it would be unacceptable, for example, to suggest an analysis project was 30%–50% longer in duration, so that analysts could learn and test an approach before actually applying it. We have observed many policy evaluators trying to circumvent this problem by testing out "new" methods on smaller projects, or asking for help from researchers and others informally, or pro bono. This can work to build skills but does nothing to address the systemic technical and political accessibility barriers described above. Furthermore, in UK government, staff training schemes are, in effect, highly regulated and monopolized by a few providers. This means content can be inflexible and only changes at these providers' discretion. In addition, it means that individual analysts accessing courses outside the standard scheme is the exception, not the rule.

The second significant barrier to strengthening the ability to deploy complexity-appropriate modeling approaches is the perceptions and realities about the need for good data. First, the perception which we have encountered on many occasions is that models need substantial amounts of data to be validated. Thus, in complex social settings, where there is rarely lots of good data, models will not be helpful due to a lack of data. This perception is dangerous for complexity-appropriate modelers. It seems to stem from the overriding influence of economics models, in which unvalidated models are valueless, owing to their purpose of forecasting. Complexity-appropriate computational models (and COMPLEX-IT) are typically aimed at a broader set of purposes, perhaps encompassing some forecasting, in addition to improving understanding and providing an entry point for improved discussion and thinking (Gilbert et al., 2018; Johnson, 2015). Policy analysts have an acute awareness of the poor quality of their data, it is the bread-and-butter of their work, but they may also hold these economics-inspired views of what models need, and so may falsely perceive low value in them.

A more prosaic issue around data, which can lead to an inability of use, is having data in the "right" format. Though this point is simple on a conceptual level, it forms a profound barrier. If existing data cannot quickly be transformed or plugged into complexity-appropriate methods, then it is likely, they will not be used. This issue was particularly relevant in the discussions we had on natural capital, where there are many existing data sets, but they would require considerable transformations and processing to be used.

All of these issues around accessibility of modeling, and ability to use modeling, can come together to make modeling's use a serious challenge. Individually, most barriers can be overcome, but if two or three intersect at once, there is little chance they can all be negotiated. In our experience, only the most innovative teams within departments with the right mix of resource and flexibility can overcome them routinely; others are regularly stopped by them, even where there is interest, good will, and resource.

3. Discussion

Before we plot a way forward for applied complexity scientists, and policy evaluators and analysts, we want to briefly outline some recent contributions from the modeling and policy research fields in the UK, which might help direct our path. First, Cairney and Oliver (2018) review the advice given in the academic and grey literature to researchers wishing to have policy impact with their research and relate this through their understanding of the policy making process (as researchers of public policy and evidence use). They find relatively consistent advice across the literature they examine, revolving around eight core suggestions to researchers: (i) do high-quality research; (ii) make research relevant and readable; (iii) understand the policy process, actors, and context; (iv) be accessible to policy makers; (v) decide if you want to be an "issue advocate" or "honest broker"; (vi) build relationships and ground-rules with policy makers; (vii) be entrepreneurial or find someone who is; and (viii) reflect continuously. They suggest these recommendations appear consistent because they are vague and safe, but they also ignore the inherent complexity of the policy process, and all the unwritten rules and structures within it. Cairney and Oliver reject the idea that researchers can easily use these "how to" guides to have impact, but rather suggest that the political and social structures of the policymaking process and its complexity, mean no impact can be guaranteed. They suggest researchers are better placed accepting these difficulties and making a more fundamental decision about how they want to spend their time; if it is on impact-related activities, they suggest prioritizing this at the expense of time for research.

Second, as modelers, Gilbert et al. (2018) provide some reflections on the use of computational modeling in public policy and outline some "key lessons" for policy modelers to realize the full potential of what modeling has to offer public policy analysis. Their key lessons are that: (i) the process of modeling is often as important as the outputs; (ii) the decision about levels of abstraction in a model is key; (iii) data and validation issues must be recognized but not used as an excuse not to model; (iv) modelers should work in an Agile and collaborative fashion; (v) modelers should take more interest in the ethics of policy modeling; (vi) communicating the process and outputs of modeling requires careful planning; and (vii) models need to be maintained after initial development, or after researchers have moved on.

At first glance, these lessons sound a little like the "how to" guides Cairney and Oliver (2018) critique. However, because they are focused on the practice of computational modeling, rather than solely on the activity of individual researchers, and they are focused on the success of modeling, rather on the more abstract "impact of research," we believe they are still useful. Our aim here is to combine the brutal pragmatism and realism of Cairney and Oliver (2018) and Gilbert et al.'s (2018) more optimistic lessons, with our reflections on the use of complexity-appropriate computational modeling. This combination, we hope, will provide a realistic path forward for how to arrive at a point where complexity-appropriate computational modeling can be a standard analysis approach for evaluators and analysts to use when appropriate.

To break down the barriers of accessibility of methods—recall the inflexibility and inertia of the commissioning process described by our participants—we believe applied complexity scientists need to widen their efforts beyond just the methodological and analytic innovations they hope to make, but also consider the implications of these approaches for the commissioning and research design process in government. The call for more flexible and iterative commissioning and study designs is beginning to be heard (e.g. CECAN, 2018), but we now need to know what these might look like in practice. Researchers need to put forward promising examples, and push for their use in practice. Examples might include those on how to encourage experimentation, as proposed in Brian and Carter (2016), or those which place trust in practitioners' motivation and support their learning (rather than evaluation), as in Knight, Lowe, Brossard, and Wilson (2017). Complexity scientists need to pick up on these examples, others, and their own designs, and take them to government. As Cairney and Oliver (2018) tell us, this may be at the cost of the time and effort on the methods themselves, but this is exactly the refocusing of effort by researchers which may deliver more meaningful use.

A second path here is to give complexity-appropriate methods the "official seal of approval." Following Cairney and Oliver's bluntness, we suggest doing this merely as a means to an end; the effort in doing this is unlikely to meet many standard research organizations' objectives. To do this, researchers need to understand what documents and institutions legitimize and lend credibility to methods and analysis (in the eyes of government), and then target these with their advocacy for complexity-appropriate methods. In the UK, this includes documents like the Treasury's "Magenta Book" on evaluation (HM Treasury, 2011), "Green Book" on ex-ante policy appraisal (HM Treasury, 2018), and "Aqua Book" on producing analysis for government (HM Treasury, 2015). This approach is already being developed in the UK; for example, CECAN is contributing to a revised version of the Magenta Book, and computational modelers are engaging with the Aqua Book (see, Edmonds, 2016).

On a more diffuse front, applied complexity scientists need to fight the demand for false, singular, definitive, and inappropriate certainty in public policy analysis. This involves a whole host of different activities, many of which they already undertake, but requires continuously challenging and reclaiming the discussion of rigor and generalization within policy analysis. Researchers should have examples on hand that highlight both success stories of complexity-appropriate methods and the failures of traditional approaches when applied to questions and issues they were not suited to. Where they do not have published examples, they should consider finding or generating their own.

To address the issues, our participants identified around skills and capacity, we suggest there is a need for a range of resources for policy evaluators and analysts, to be developed by researchers and their organizations. For example, training courses should be provided at a range of lengths, modes, and levels of study. Traditional long form courses, such as masters' modules, should be opened up to policy analysts. This will require creative thinking, such as evening classes, or semester long modules being condensed to week-long intensive courses. Standard shorter form courses can also be developed, targeting four hours or less, and located near the offices of policy analysts, meaning government staff actually have the time to attend. The popularity of online courses should also offer inspiration. We hope the CECAN syllabus (CECAN, 2017) is useful resource for developing such training courses.

On our participants' data issues, efforts should be made to unpack, and push back against, perceptions about the need for large amounts of rich quantitative data. Moreover, researchers may wish to be bolder in their articulation of the need for multiple cycles of theorizing, modeling, and data collection. When starting from a low base (i.e. little or no modeling done previously, and little useful theory or data) in a particular domain, it is almost always necessary for a prototype model to be developed, for theory to be gathered or developed, and for researchers to realize little usable data exists for model validation (Barbrook-Johnson, Badham, & Gilbert, 2017). Researchers need to manage expectations around this and make clear that after one cycle of "theory-model-data," they probably won't have a model or analysis ready to be deployed directly, but rather may require several iterations with government taking part the entire time to develop something valuable. Articulating the end value here is difficult but essential; Barbrook-Johnson et al. (2017) give us one example of how to attempt it, focusing on nonpredictive uses of models in public health. There will be many other ways to do this. Addressing this issue effectively will deliver on Gilbert et al.'s (2018) request that data issues be acknowledged but not used as an excuse to not model.

Implicit in many of these suggestions is a need for more co-produced and participatory use of complexity-appropriate methods. Cairney and Oliver (2018) remind us that this will mean ceding control of projects, but we believe this is a price worth paying if we care about making policy analysis more grounded, reflexive, and complexity-appropriate. Co-produced participatory projects will also be slower, more difficult, and perhaps even less publishable than others. Researchers need to work out ways to deal with this, and proceed nonetheless. Gilbert et al.'s (2018) suggestion of the process of modeling being often more valuable than the outputs is of high relevance here, researchers should keep this in mind for themselves in co-produced projects, just as much as articulate it to policy users.

4. Conclusion

We have outlined the growing interest in complexity-appropriate modeling in policy evaluation and analysis and described some of our recent efforts to use these methods with UK government. The main barriers we find to the use of these methods, include: (i) approaches rendered inaccessible by the inflexibility and inertia of government processes; and (ii) the inability to use methods created by lack of skills and issues around data. By combining our reflections and some recent contributions from the modeling and policy research communities, we outline paths forward for applied complexity scientists to have greater success in applying complexity-appropriate methods. In condensed form, these are:

1. Put forward new complexity-appropriate commissioning approaches and study designs for policy research and analysis.

2. Help give complexity-appropriate methods the "official seal of approval" by advocating for them in the venues and institutions that government looks to for quality assurance.

3. Constantly push back against policy makers' wish for wrong, singular, definitive, high-certainty answers.

4. Be generous, creative, and flexible in providing training and courses; make courses more accessible for policy analysts.

5. Be bold in articulating the need for methods to be developed iteratively through multiple theory-model-data cycles.

Implied in all of these, and our discussion, is a need for researchers to work with government in a co-produced and participative manner. Beyond this, we believe researchers need to be modest and pragmatic when working with government. If we want complexity-appropriate methods to be used, relatively widely, in public policy evaluation and analysis, we need to go where the demand is for these methods, and we need to do co-production properly.

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Modeling Evolving Agency in a Social Context

E. Dante Suarez

Associate Professor, Department of Finance and Decision Sciences
Trinity University, San Antonio, TX

esuarez@trinity.edu

Abstract

This article intends to increase the understanding and application of advances in evolutionary biology and economics as described in the growing paradigm of complexity science. The basic premise here is that agency is an evolved trait, and that in the context of emergence, natural processes manage the exploration versus exploitation tradeoff by increasing agency at some levels while decreasing it in others. Agency in nature exists to the degree that organisms can act independently from their environment, and is here considered to be the result of an evolutionary process that takes place hierarchically and in multiple dimensions. The article proposes further discussion on the need to create appropriate common languages that capture the multiple levels of reality, particularly in the social and biological realms. Such methodologies should allow for the joint representation of micro, meso, and macro ontological levels of agency. This work proposes the methodology of Distributed Agency as a means to represent the fractal nature of the agents that may more realistically capture the contextualized interaction present in social, biological, and psychological phenomena.

Keywords: complex adaptive systems; emergence; agency; distributed agency; multilevel selection; technological lock-in; exploration versus exploitation

Modelando la Agencia Evolutiva en un Contexto Social

Resumen

Este artículo pretende aumentar la comprensión y la aplicación de los avances en biología evolutiva y economía como se describe en el paradigma creciente de la ciencia de la complejidad. La premi-

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sa básica aquí es que la agencia es un rasgo evolucionado, y que, en el contexto de la aparición, los procesos naturales gestionan la compensación de la exploración frente a la explotación mediante el aumento de la agencia en algunos niveles mientras que la disminuyen en otros. La agencia en la naturaleza existe en la medida en que los organismos pueden actuar independientemente de su entorno, y aquí se considera que es el resultado de un proceso evolutivo que tiene lugar jerárquicamente y en múltiples dimensiones. El artículo propone una discusión adicional sobre la necesidad de crear lenguajes comunes apropiados que capturen los múltiples niveles de realidad, particularmente en los ámbitos social y biológico. Dichas metodologías deben permitir la representación conjunta de los niveles de agencia micro, meso y macro ontológico. Este trabajo propone la metodología de la Agencia Distribuida como medio para representar la naturaleza fractal de los agentes que pueden captar de manera más realista la interacción contextualizada presente en los fenómenos sociales, biológicos y psicológicos.

Palabras clave: sistemas adaptativos complejos, aparición, agencia, agencia distribuida, selección multinivel, bloqueo tecnológico, exploración vs. explotación

社会环境下的演化能动性建模

摘要

本文旨在提高并加强大众对进化生物学和经济学进步的理解与应用。日益增多的复杂性科学范例对这些进步有所描述。这里的基本前提是，能动性是一种不断演化的特征，自然过程在突现的背景下通过在一定程度上增加能动性，而在另一些程度上减少能动性来权衡勘探与开发之间的利弊。自然界中的生物甚至因为能动性的存在可以独立于它们的环境之外。因此能动性被认为是依等级多层次发生的演化过程的结果。本文关于是否需要创造合适的共同语言以反映现实的多个层面展开了进一步探讨，尤其是在社会和生物领域方面。这套方法应该共同呈现能动性的微观、中观和宏观本体层面。本研究提出了分布式能动性的方法，其可作为呈现能动性分形特征的一种手段，从而可以更现实地捕捉社会、生物和心理现象中的语境互动。

关键词：复杂适应系统，突现，能动性，分布式能动性，多级选择，技术锁定，探索与开发

1. Introduction

This essay incorporates well-known concepts developed by the nonlinear scientific revolution of complexity to the analogous disciplinary discussions found at the core of evolutionary biology and neoclassical economics, which we argue share a common historical background. The aim is to incorporate concepts such as emergence, technological lock-in, and the exploration versus exploitation tradeoff to an increased understanding of the evolution of agency.

This essay works to provide a common language in which previously siloed disciplinary explanations for evolutionary adaptation can communicate findings and share common challenges. The ultimate purpose is to aid the development of a new type of nonlinear social science and increase the consilience of disciplines that focus on agency and individual versus group dynamics in the context of complex adaptive systems. The essay is partly a result of reactions to presentations and conversations at the Complexity and Policy Studies (CAPS 2019) cross-disciplinary conference, held in Washington, DC, in the Spring of 2019. The meeting brought together researchers, practitioners, and funders to explore the application of insights from the study of complex systems to public policy, with a special emphasis on the social good.

2. The Historical Context of Complexity, Evolution, and the Social Sciences

Complexity is a nonlinear paradigm that proposes a more holistic view of the scientific endeavor. Just like an art movement is born in a chronological and dialectic setting, complexity is normally defined in contrast to the linear view of science, in which complex wholes are analytically reduced to atomic parts, and then reconstituted as wholes that are equal to the sum of its parts. As it is envisioned in paradigms such as that of Methodological Individualism (see Udehn (2002) for a good survey treaty of this debate), this process of simple aggregation can be appropriate in part because of an assumption of a lack of relevant agent interaction and contextual structure. At their core, these disciplines are based on selfish and unitary agents whose interactions cancel out in the aggregate. These approaches implicitly claim that all macro complexity can be traced back to the micro level of the system, without regard to the context and structure in which these agents live. The idea of emergence, however, reflects the fact that different and irreducible levels of interaction will naturally arise in complex systems such as the ones studied by linear disciplines (Cilliers, 1998). Classical economics, for example, grants zero agency to upper-level entities, as the selfish actions of individuals are carried by an invisible hand to a plateau of the overall organization, without regard to the structure of the system or the topology of their interactions. Moreover, standard economic representations have focused on individuals as the smallest unit or the ultimate irreducible atom of the paradigm, but such units may actually be agglomerates, the products of internal networks that deserve attention (Kahneman & Thaler, 2006). Models in this discipline normally take either a macro or a micro approach, but not both simultaneously (as a representative counterexample, see Binmore and Samuelson (1994) for an economics description of the evolution of norms).

In contrast, structuralism ascribes little agency to the individual when compared with the group or social structure (Culler, 2007), such as they do in the classical sociology treatments of Emile Durkheim and Talcott Parsons. As it applies to evolutionary biology, the dimension created between individualism and structuralism represents the core of the controversy between individual selection theory and group selection theory (Wilson, 1997a). Significant advancements have been made in evolutionary biology to consider the possibility of other relevant levels for adaptation (Wilson, 1997b), but there is a core of proponents of the promises of reductionism who dissolve away any aggregate level to its individualistic source, or even further to the genetic level, as it is seen in Richard Dawkins' (2006) treatment of the selfish gene, or the Austrian Economics version of methodological individualism (see Udehn (2002) and Grafen and Ridley (2007), for a historical discussion of these matters in biology and the social sciences). Along this linear perspective, if we see an act of altruism in nature, it is assumed that it must be because the individual performing it is expecting something in return, as in reciprocal altruism (Trivers, 1971). This reductionist thinking can also be seen in kin selection theory, which in simple terms implicitly states that if a mother gives her food away to nurture her babies, it is because a possible copy of her genes is being benefited (see, for example, Griffin & West (2002)).

The literature on the matter has often focused on broadly defining altruism as actions that negatively affect the individual who performs them, while at the same time benefiting someone else. It is commonly shown in the proposed models that altruistic cooperators can survive in the end, mainly because their resulting stronger groups can defeat other groups formed by noncooperators (see, for example, Flack and De Waal (2000) or Fletcher and Zwick (2007)). With that result in mind, we can think of less myopic agents, or some created by eons of evolution, which are forced to give up their lower-level objectives in return for upper-level ones. The true altruism of natural organisms is to act today to guarantee the existence of tomorrow. For its part, traditional economics offers some instances of inter-level analysis, such as in the study of agency problems: the conflict of interest that arises from the disjointed objectives of the ultimate owners of a corporation—the stockholders—and the administrators who actually make the decisions for a company (Fama, 1980).

The vast and growing amount of computing power has opened research avenues that were impossible a few years ago, as well as forced researchers to reconsider the basic premises of the reductionist paradigm on which traditional linear sciences—such as neoclassical economics and individual selection theory in evolutionary biology—are built. Traditional linear science had been forced historically to assume away all interactions between the components of a system, such as the buyers and sellers in the stock market or the ants in an anthill; not because they were considered irrelevant, but because studying them was impossible (Goldspink, 2000). This is because the mathematics necessary to explain the whole system and its interactions quickly becomes intractable (Tolk, 2012). The answer to the conundrum was to find systems that could be described without considering the interaction between the component agents, and this gave rise to disciplines such as the highly mathematized neoclassical economics of the twentieth century, in which culture and society do not exist.

The interaction and structure is often the actual phenomena that needs studying, or that creates the observed behavior of interest, such as when we analyze the cohesion of an army unit, the coordination of the best football team, the culture of an enterprise, or the checks and balances of a government. Systems in which multiple, heterogeneous, interacting, and adaptive entities influence the behavior of each other quickly became intractable for traditional mathematical techniques. To continue the advancement of science and technology, most disciplines generally opted for the simplification of the agents in the system, commonly describing them as homogeneous, independent, and altogether exogenous. As such, the classical economic paradigm of Adam Smith (Smith, 1937/1776), in which selfish agents acting independently are guided by an invisible hand to maximize the greater good, followed in the steps of Newtonian physics—where atoms interact in predictable patterns to compose aggregate objects (Beinhocker, 2006). Similarly, Darwin's (Darwin, 1872) revolutionary theory of evolution describes independent agents that survive based upon their individually defined fitness. These three paradigms delineated the boundaries of research done for more than two centuries in many physical, biological, and social realms—even though they represent branches of the same tree; a tree rooted in a linear description of the world around us.

Repeated interaction gives rise to structures that deserve attention, and can become much more important than the atoms, parts, components, or agents that the system is built out of (Bowles & Choi, 2003). Aggregates are therefore more than the sum of their parts, and we refer to such aggregates as *emergent*. To understand them, we cannot simply reduce the system's aggregate behavior to its minimal components, study them in isolation, and then rebuild the system by multiplying the behavior of the average piece by the number of pieces in it. In the emergent, nonlinear, nonreducible world of complexity, nature exists in many nonorthogonal levels, with each level potentially being governed by different laws, granularities, and structure (Bar-Yam, 2004). If we believe in that proposition, then we should expect to find a world full of emergent phenomena, with distinctive levels of interaction that have agency of their own (Tolk, 2012).

In summary, the linear paradigm prevalent across many scientific disciplines until the later part of the twentieth century was chosen by necessity. In it, complex phenomena can be *reduced*, that is, analyzed by looking at the behavior of the average agent and then building the aggregate environment back up, disregarding in the process any structure or topology created by the interaction between the (potentially adaptable) parts in the system. In a linear system, any variable can be parsed out and can be studied independently, the way a multivariate linear regression can dissect a dataset and express it as an addition of variables, linear coefficients, and random errors. The nonlinear view of reality, on the other hand, says that such reductionism, simplified analysis, and partitioning are not possible.

3. Three Complexity Concepts Worth Considering

In this section, we describe three concepts of complexity that deserve attention: emergence, technological lock-in, and the exploration versus exploitation tradeoff; all in the context of the general evolution of agency. This essay is built on the idea that the definition of agents and agency is outdated, as it does not allow for the incorporation of a fractal, hierarchical, and multidimensional view of the world that the complexity paradigm has revealed (Tolk, 2019). In the emergent, nonlinear, nonreducible world of complexity, nature exists in many nonorthogonal levels, with each level potentially being governed by different laws, granularities, and structure. Given this fact, it follows that evolution must also be multilayered.

This conception stems directly from the core concept of complexity, in which *wholes are more than the sum of their parts* (Abbott, 2006; Bar-Yam, 2004; Tolk, 2019). Describing each level of reality brings about significantly different challenges, with entities of interest that have aspects of their nature reflected in related but distinct dimensions (Tolk, 2012). The mind exists in a completely different *dimension* than the physical, chemical, and biological world of the neurons and the brain. In this sense, when we speak of nonlinearity in our field, we are often not speaking about *nonproportionality*, in the way that two plus two equals five, but rather we are referencing *emergence* and the different dimensions or *levels of reality* that this creates. As such, two plus two might equal the color pink.

We build on the definitions of emergence as defined in Tolk (2019) who detangles the concept of emergence and separates it into two categories: *epistemological* and *ontological*. Epistemological emergence refers to situations where a system has rules that can be understood, but it is irreducible to one single level of description for conceptual reasons. Following Tolk (2019), we refer to this type of true emergence as ontological.

The idea of multiple levels of reality also has immediate repercussions for the way we think about natural selection and the evolution of organisms, norms, and institutions (Bögenhold, 2018; Hodgson, 2007). Contrary to the implicit assumptions of a traditional linear paradigm, real-world agents do not exist in a vacuum—agency needs to be contextualized (Edmonds, 2010). We must use a framework in which a multilevel selection theory is appropriately expressed, both in biology and in the social sciences (Damuth & Heisler, 1988). Such a multilayered language must be able to capture situations where selfishness is defined in terms of the survival of an organism with many (potentially "selfish") genes (Wilson, 1997a), but also in the context of what benefits the group that it belongs to (Wilson & Wilson, 2007). Sexual organisms, for example, must find mates that increase the diversity of their offspring's gene pool, making other organisms of the same species competitors in one dimension and potential reproductive partners in another. Analogously, similar businesses, such as ethnic restaurants or trendy bars, tend to clump up in small areas of a city, because even though they compete for clients, they help each other attract a common clientele.

To describe a more general theory of social interaction, we need models in which we drop customary assumptions made in linear paradigms about what is considered a decision-making unit. The relevant agents in a novel nonlinear conceptualization are intermediate in the sense that they are both influenced by an upper level with its own degree of agency, while at the same time, they are determined by relatively independent subcomponents that must be 'subdued' into acceptable behavior. Any observed action is considered to be the result of the interplay of multiple distinguishable actors. If we redefine collections of individuals as operational units—such as bees forming an indivisible beehive—then we must redefine what we mean by ubiquitous concepts such as altruism and selfishness (Gilboa & Samet, 1989).

We build here from a benchmark position in which all actions are revealed as selfish once one understands what the benefited acting agent is. Traditionally, we began with a clearly defined agent and tried to understand its actions as a maximization of objectives given constraints. In the proposed paradigm, we assume maximization occurs, and then work toward the delineation of the benefited entity involved. Such an understanding of an individual as an agglomeration of relatively independent aims can serve as a starting point for a broader theory that describes the formation of complex hierarchical objects. Suarez and Castanón-Puga (2010) refer to this conceptualization as *Distributed Agency (DA)*. It is a language that allows us to deconstruct agency, based on the idea that an agent's behavior can be seen as an emergent property of a collection of intertwined aims and constraints. The intent is to establish a way in which we can refer to many different levels of reality with one general methodology. Such a general language is needed since, after all, the levels of ontological agency have the common thread of being based on a singular reality.

We consider a deconstructed agent that is formed by multiple and relatively independent components. Part of the resulting agent's task is to present alternatives, or 'fields of action' to its components. Correspondingly, the composed agent is itself constrained by a field of action that the superstructure to which it belongs presents and can thus be ascribed partial agency and modeled in at least one dimension as an agent. To arrive at this methodology, we must redefine what a unit of decision is by unscrambling behavioral influences to the point of not being able to clearly delineate what the individual is, who is part of a group and who is not, or where a realm of influence ends. The artificial boundary between an individual self and its social coordinates must be dissolved. The proposed intermediate agent can be thought of as a person, a family, a social class, a country at war, or an anthill, and thus bridge the gap between such disparate approaches as Methodological Individualism and Multilevel Selection Theory (this type of consilient approach may be found in works such as Wilson, Van Vugt, and O'Gorman (2008)).

Aside from the ubiquitous and foundational concept of emergence, the concept of *technological lock-in* reminds us that in a recursive and adaptive complex system, accidents will matter. Wikipedia defines this concept as "a form of economic path dependence whereby the market selects a technological standard and because of network effects the market gets locked-in or stuck with that standard even though market participants may be better off with an alternative." This phenomenon is often a result of positive feedback loops. The more people speak the language that you speak, the more valuable your language is. For this reason, a language that may have originally not been a particularly efficient one for conveying information may become prevalent if enough people speak it at first. This is a concept that comes in various forms, and can be conflated with path dependence or the phrase that "accidents matter," in the sense that what may have been originally an accident sets the system in a historical path that does not come back to any type of optimum, average, or norm (see one the original treatment of this idea in Arthur, 1989). This is comparable to a Markovian process with long or infinite history.

The final concept of complexity that this essay draws upon is the *exploitation versus exploration* tradeoff, arguably one of the most important ideas riding on the wave of this scientific revolution. And yet, regardless of its importance, a definition cannot be currently found in Wikipedia. The idea is that any complex problem that cannot be solved with conventional optimization methods or numerical techniques must be solved by managing the tradeoff between these two forces: exploitation (the force of individuality) and exploration (the force of collectivity). Imagine such a problem as a giant lattice with valleys and peaks. Somewhere in there lies Mt. Everest, the global optimum for this particular problem, but throughout this space lie innumerable hills which represent improvements over the valley next to them, but nonetheless only local optima. The tradeoff between exploration and exploitation means that in order to find the global optimum, the search must find a way to examine the whole lattice, recognizing that when there is a positive slope we must exploit it, go up, and find how high it goes. Because the lattice can be infinite, and infinitively complex, we must not get immediately stuck in the first hill we find, for we must continue exploring to see if there are no other higher mountains to climb. Such a problem can be something as impossible to solve as to how to best organize society (Byrne, 1998).

In the complex world of the socially possible, creating an appropriate agent or cohesive group in society is no simple task, for the optimized phase space of possibilities represents a multidimensional moving target which may be plagued by nonlinearities (Axelrod & Cohen, 2001). Any adaptive process that aims to exploit an environment by solving such a complex optimization problem must ably manage the tradeoff of these opposing forces, whereby the adapted agent "learns" how to take advantage of the aspects in which it does get closer to the global optimum (exploitation), while at the same time not "getting stuck" too quickly in a local optimum (exploration). The adapted entity must have a way of preserving useful information as well as the capability of gathering more.

4. Distributed Agency

The idea behind a model of DA stems from a view of the world in which emergence is pervasive, in which we find wholes that are irreducible to their parts, and therefore can be thought of as existing in different dimensions. In such a world, the independence that is assumed in classical statistics theory no longer applies, and a holistic approach is necessary.

Agents, as they are historically most commonly defined, are often thought of as having a high degree of agency, or even unbounded, exogenous agency. Often, the idea of an agent refers to a human, but as we argue, humans are not necessarily units and definitely not independent. Instead, in this work, we accept the possibility that a person is an agglomerate and that groups may behave as a unit. A person's incentives now may be in contradiction with the same person's incentives a year later (Schelling, 1984); alternatively, a military coalition, racial subgroup, or social class may behave as a whole with properties that emerge in the aggregate. Individual humans may not necessarily possess much agency, as we may actually exemplify machine-like structures that react to the incentives presented, based on a utility function that is endogenously determined.

In other words, we can think of humans as agents because we have a utility function—that is, an input–output relationship in which the inputs are the choices presented by the situation and the outputs are the choices made—

but this may actually be completely controlled by the environment (Stigler, 1950). One could only dread to wonder, for example, what a suicide bomber feels as he presses the deadly button, but it must nonetheless be something that he would not have felt in the absence of social pressures. This is not exactly a standard conception of an agent, since the utility function may itself be a product of the upper levels that gave rise to it, and in this sense, it is only a portion of the whole. A society may consciously decide to close its ranks, follow rules, establish norms, or stand united so that the resulting, more efficient group can more effectively compete with peer groups. To encapsulate the complexities of a fractal, potentially hierarchical and multidimensional agent, its conception must be generalized to allow for entities that can be thought of as more or less of an agent, depending on how much autonomy they have from upper levels and how much autocracy they have in controlling their internal lower levels (Mandelbrot, 1982). The upper level may force lower-level members into behaviors that are only optimal for the former, and it is in this sense that we can understand the behavior of an unselfish soldier (Wilson, 2019).

DA redefines agents in two ways. First, in this conception, there are no obvious atomic agents, for all actors represent the emerging force resulting from the organization of—potentially competing—subsets. The subcomponents in turn form an internal system that is actively reorganized, and shall be referred to as the "lower level" of a structure. On the other hand, agents are to be described within a group to which they belong, which will be defined as the "upper level" of the hierarchical representation, and will constrain its subcomponents' behavior. Individuals or groups of individuals may wholly or partially belong to an agent, in many different coordinates and according to drastically different definitions. The agency of a group is defined by the network that composes it, representing a system interconnected with varying intensities. The main contribution of DA is that it allows for the description of macro-level realities that are captured with a top-down model, as well as the mirco-level strategic interactions of individuals, captured accordingly with a bottom-up model (Castañón-Puga, Rodriguez-Diaz, Licea, & Suarez, 2008).

With this view in mind, we can think of some societies as more of an agent than others, with a society full of working institutions such as the United States as much more "in control" of the majority of its American agents and therefore considered an agent in its own right. On the other hand, a developing and relatively dysfunctional society such as Mexico can be described as much closer to a simple aggregation of individuals, and therefore not an upper-level agent. Methodologically, we begin by observing the agency displayed in these levels, and then use backwards induction to portray the forces at play that could have given rise to the observed behaviors and structures. The benchmark position is the one in which all behavior is optimal, so long as we identify the actual agent that is enforcing its will, recognizing that such will or behavior may actually be the resulting force of the interactions of several abstractly defined and multidimensional agents. Traditionally, we have begun with a clearly defined agent and tried to understand its actions as a maximization of objectives given constraints. Here, we assume maximization occurs, and then work toward the delineation of the benefited entity involved.

In the context of the DA methodology, when we arbitrarily zoom in and analyze a relatively well-defined agent, we may classify its behavior as irrational or suboptimal in relationship to its own abstract objective function, but only because we would be artificially studying it in isolation, or without regard for the struggles of its internal nature (Chavas & Cox, 1993). For this reason, we can refer to these types of intermediate agents as fuzzy agents (Suarez, Rodríguez-Díaz, & Castañón-Puga, 2008) or, based on the seminal work of Arthur Koestler, as holonic agents that are at the simultaneously part and whole (Koestler, 1967/1990; Marik, McFarlane, & Valckenaers, 2003).

5. Evolved Agents

How does an agent come into existence? From its origins in classic times, the question has been reframed, reconsidered, and reformulated in increasingly sophisticated terms, and although humanity has achieved significant technological feats, the essence of the epistemological and ontological question remains, particularly in the social and biological sciences. How does an agent evolve? How does nature "decide" how much agency to grant it?

The conception proposed in this article is also heavily influenced by the groundbreaking work of Herbert Simon (Simon, 1981). Simon's work in artificial intelligence brought about the involvement of modularity and levels of selection to the discussion, transforming the watchmaker analogy, made famous by the English philosopher William Paley, into an analogy that reflects the need for robust internal subcomponents of complex entities. For evolution to work most efficiently, it must continuously and simultaneously adapt different levels of an organism. Part of what this work proposes can be considered a generalization of this idea to include the conceptualization of how agency evolves in a realistic, contextualized, and complex environment; one in which many different levels of agency are tinkered with, enhancing and diminishing agency in order to create a multifaceted organ, organism, or group that can best exploit a changing environment. While the Bill of Rights enhances Americans inalienable rights (agency), the laws and regulations of the nation diminish the choices (agency) of its citizens.

The agent, as is defined in this work, is both subject and object. It is a combination of levels of interaction. Organisms are thus a product both of the struggles of their ancestors, but also the reflection of an environment that begs to be exploited. They are part exogenous and part endogenous to Mother Nature. The somewhat accidental and imperfect individuals and groups that exist at any given moment are presented with opportunities for adaptation, with resulting intertwined creatures that were created out of recursive processes, feedback loops, and circular causalities.

Organisms thus represent the current stage of long, recursive processes that have searched vast phase-spaces to find the combination of complicit levels that sustain the information they entail. Random mutations are generally not the best tool for such processes; rather, controlled ways of adapting to an ever-changing environment will naturally develop. In other words, exchanging a known successful situation for an alternative that will be drawn from an infinite space of unknown possibilities is unfeasible—too chaotic. For example, the emergence of sexuality provides a systematic way for the mixing of populations with information that has proven useful and constantly recreates the organism in order to stay ahead of predators and parasites. It also creates within-species heterogeneity which represents as many experiments as there are individuals, always looking for the best forms to exploit a given situation. We could think of an enhanced sexuality that provides other improvements to the population, such as superior genetic material that is phenotypic and recognizable.

By definition, the action of an agent brings about a reaction from the environment it inhabits. If we rank all possible environmental reactions according to how they affect the acting agent, we can then conceive of an agent-environment reward function. The *Reward Functions* that individuals and groups face may themselves be curated spaces that an upper-level agent created with the purpose of extracting a particular behavior from them, just like a savvy manager may develop incentives for her workers to follow her commands out of their own free will, or a society may make becoming a serial killer a risky and expensive endeavor.

How does the upper level or environment "communicate" to its inhabiting agents where optimality lies? Are there threads that communicate where optimality lies which are invisible to some agents but visible or intuitively attractive to the fittest agent in the group? The management of this tradeoff is an essential way in which multileveled evolution explores the immense combinatory fields of adaptive interaction, looking for peaks ever closer to the global optimum. It is in this sense that we can talk about more fit individuals, but also about more fit selection processes in which the method of adaptation is itself being fine-tuned, or, in other words, that we are witnessing the "evolution of evolvability" (Wagner & Altenberg, 1996).

Generally, the incentives for cooperation and trade are obvious for individuals who could normally not survive in isolation (Traulsen & Nowak, 2006). The nature of atomic decision makers is the one intrinsically possessing an appetite for abstract resources that social superstructures can provide. Individuals are born into predetermined arrangements, and thus, the behavior of complex organisms is not reducible to genetic coding—which only represents an adaptable basic model acquiescing to the realities presented by its species—but is also a product of its epigenetic processes, sexuality, relatedness, education, culture, and ecological immersion. Therefore, the contextualized individual will normally face a payoff structure that allows him to survive if he stays with the proposed boundaries of the upper level to which it belongs.

If we optimize the nature of relationships within a group, searching an ever-changing space of possibilities in search of a kind of species that would be fittest for such an environment, what we would find is that a cooperative one would be at least as well equipped as its noncooperative counterpart, by definition. This process, however, is not the one that actual organisms encounter, for the nonlinear world of increasing returns to scale and technological lock-in is the one where history matters (Arthur, 1989). We can think of reality as a product of what exists and what wants to exist. In a similar fashion, economists think of a transaction as a product of the interplay between the abstractly defined concepts of supply and demand. In this sense, the optimized phase space of the environment represents a series of demands for exploitation, while the existing species represent a series of supplies. When the two meet, a recursive and self-sustaining entity is produced. According to this view, we can think of evolutionary pressure as a situation in which one group of individuals is in position to mutate and fill up a niche that the environment presents. Evolution is therefore not a process in which autarkic individuals compete to be the fittest, but rather a historical multiplex of intertwined levels of adaptation (Frank, 2012).

We can think of the prisoner's dilemma payoff matrix as an environment, one that cooperating humans participating in real-life experiments are better able to exploit than their unrealistic and yet "rational" theoretical counterparts (Axelrod, 1980). Real humans exploit this environment better by extracting more money from the experimental researcher in charge than they would have if they did not cooperate with each other (Davis & Holt, 1992; Smith, 1994). By acting as they do, these cooperating "prisoners" are able to exploit the hyper-productivity provided by the upper-level coalition agent that their cooperation represents. A staunch linear biologist may ask: "but how can the upper level, this cooperating pair, protect itself from infection by the free-riders or rational prisoners?" That remains an open question (Joyce et al., 2006). But Mother Nature is savvy, and through the ages has figured out ways in which these upper levels can become more cohesive and binding to their subcomponents, thus restricting their individual agency. The force of exploration acts here to create ever-larger, internally cohesive agents. Humans have evolved to cooperate and to see the long-term effects of their actions (Axelrod, 1981; Mason & Phillips, 2002).

At the 2019 CAPS conference, David Sloan Wilson, one of the leading proponents of the multilevel selection theory in biology, pointed out that there needs to be a recognition of the two types of *complex adaptive systems* that exist. What he brands as CAS1 are complex adaptive systems that are adaptive as a system, such as a brain or a eusocial insect colony. CAS2, on the other hand, are complex adaptive systems that are composed of agents following their own adaptive strategies. The position we have laid out in this essay is that we can consider "hybrid" types of complex adaptive systems, such as a semi-autonomous military battalion at war. Most importantly, however, Professor Wilson stated that CAS2 will not easily transform into CAS1 systems. In other words, systems of agents following their own adaptive strategies do not robustly self-organize into the cohesive whole that a CAS1 represents, and as such, the metaphors of the invisible hand in economics and the balance of nature in ecology are both profoundly mistaken. Wilson's insight forces us to rethink public policies where the complex aggregate behavior of a CAS1 is erroneously expected to quickly appear out of a CAS2, such as with the expectation of some that democracy would quickly flourish in places like Iraq and other Middle Eastern countries after their Arab Spring. It is nonetheless undeniable that CAS1 have evolved "naturally" out of CAS2 systems on earth. How exactly these processes happen remains an open area of research—one that the countries of the earth, for example, need to figure out sooner rather than later in the process of creating global solutions to a problem such as climate change (Wilson, 2019).

All organisms are incomplete, for they only represent a link in the long recursive process that gave them life, and that forces them to maintain it. To have a meaningful life in the evolutionary sense, sexual animals are required to find a partner and mate. Many species, including all mammals, are even further constrained by the fact that the young need constant care as they grow up. In a social species, where the optimal scale of environment exploitation requires the coordination of more than one individual, a peer may possess aspects of both a competitor and a potential partner. The optimality of the upper level correspondingly implies subdividing the agents until it finds cohesive subcomponents that are cooperating or competing in nature. This phenomenon appears in treaties such as the Geneva Convention, where countries that expected to have further bloody wars accepted common laws that would benefit the global upper level. In other words, a process of morphogenesis will insure the appearance of structures that better exploit an environment, even if these require constant energy to achieve relative homeostasis (Maturana & Varela, 1980). Once these structures appear, they are ontologically undeniable.

In the multidimensional world of nonlinearity, multiple levels of agency vie for existence, and in the process create increasingly complex and robust entities. The interaction among these multileveled agencies can take on many different shapes, including all-out war. Nonetheless, even conflict may be institutionalized over time, eliciting the best aspects of competition while inhibiting the worst side effects. The resulting structures, institutions, or coalition agents that come about from these interactions can be thought of as linked by markets in which behavior can be traded, for there will always be actions that are minimally costly to one agent while extremely beneficial to another, if only because of the benefits of coordination. Traffic on both sides of the road, for example, would prove catastrophic, and so the institution of driving on one side of the road naturally arises.

Mastering the tradeoff between exploration and exploitation stands at the core of any evolutionary process in a nonlinear setting (Hazen & Eldredge, 2010). An adapted organism or group must have solved this dilemma in at least a rudimentary way (Talbot, 2005), with a resulting composition that matches the environment in which it is conceived. Such a tradeoff applies to the composition of all aspects of a human, including the way she thinks of herself in an intertemporal sense. For example, consider a general trend for wealthy countries and regions to be located in areas of the world that have a cold season, such as the northern hemisphere or the northern part of a country like Italy, which are relatively wealthier than a southern, more template, region. One way to think about this phenomenon is to consider the planning horizon of the agents that such a changing environment will produce: a cold winter forces the summer version of human or chipmunk to be hardworking, foreseeing the harsh conditions to be facing the winter-self. In this sense, the summer-self is not considered to be much of an agent, but rather a “slave” of the longer-term-horizon self. The size of the acting agent is thus larger in an environment with changing seasons. In contrast, the temperate climate does not promote this longer planning horizon, creating instead much more myopic agents. Extrapolating the idea of the size of the intertemporal agent, we can envision advanced Western societies and financial systems to be the result of these larger agents.

Most importantly, the point to make here is that the size of the agent will be a reflection of the environment in which it exists. The tradeoff between exploitation and exploration can be captured in what could be coined as the forces of *individuality* and *collectivity*. Both of these forces are necessary for adaptation. In this view, *left* and *right* political leanings can be thought of as manifestations of this tradeoff, with the right meaning exploitation (what you *are*) and the left meaning exploration (what you *can become*). In other words, the left always has a larger conception of *us*, while the right has a smaller, less inclusive one. The size of the agent will also be determined by the nonlinear characteristics of an environment that will always discretely allow for the existence of only certain agency sizes, thus describing an optimal scale of environment exploitation. The Law of Requisite Variety, sometimes known as *Ashby's Law*, implies that the variety in the control system must be equal to or larger than the variety of the perturbations in order to achieve control. To achieve homeostasis, the agent must therefore be at least as complex as that aspect of its environment that it wants to control (Ashby, 1958).

The tradeoff between the forces of individuality and collectivism reflects the essence of evolved agency. As the history of the world's game unfolds, evolutionary pressures will solicit more complex and adaptive organisms or networks of coordinated organisms that find themselves better at exploiting the ever-changing environments they encounter. These adapted organisms or cobbled groups will have a nature, a design that has been optimized for the exploitation of *that level*. The "agglomerate individual" will have to become cohesive, and organize its subcomponents in order to maximize its emergent utility function, since suboptimal internal coalitions can materialize, in the way a drug addict cannot overcome the desires of a strong drug-craving self, a tyrant may force a society to extinction, or the noncooperating countries of the twenty-first century can fail to act together on climate change, despite the common incentive to do so.

What is it that a newly formed agent maximizes? Its utility function. But why not forgo a myopic definition of the self and create a coalition? Why not break apart from the current coalition and form a group whose identity lies closer to the core identity of the main actors of the resulting subgroups? The world may begin with autonomous atomic agents, forming structures that are originally fragile but become increasingly larger and more complicated through a constant process of reorganization. Insights that complexity science is developing about the way that complex structures locally form—while the general trend is toward ever-increasing entropy—need to be incorporated to the fields of evolutionary biology and nonlinear social sciences.

6. Complex Adaptive Evolution

How do the upper levels enforce their will? How can an upper level inform you about the benefits that it can provide you? In other words, how does the flower develop the capability to attract the bee? We must consider the extent to which an agent is adapted, for its degree of adaptation will reflect the contour of the optimized environment in which it exists. The exogenous environment is what ultimately delineates the size and objectives of the adapted agent, providing the influential "sugar" or influence that elicits the creation of the particular intermediate agents and social structures we observe in reality, in a recursive process that may be path-dependent and irreducible. The interaction of multiple agency dimensions creates a kind of key that matches the keyhole that the optimally exploited environment characterizes. To open this door, the adapted agent mimics the outline of its context, but may also proactively or evolutionarily manipulate it to leave traces of information in it. When you eat a simple meal like rice and beans, you may not be aware that this perfect protein combination has been developed over hundreds of years. The environment is thus also adapted and because of the information, it retains we can speak of its "exointelligence" (Cohen & Stewart, 1999).

How does this co-evolutionary process take place? How should we model it? Can agents only be adapted in a traditionally Darwinian progression where the past chooses those who are fittest to survive? The focus of this essay is humans, but the general idea of this discussion should be applicable to any species, and other natural processes. The center of the argument is that humans are alive because they are fit to be so in innumerable ways. In line with the theme of this work, a human's utility function is not created in a vacuum, but is instead the product of a culture and millions of years of natural evolution. One of the many reasons why humans have been so successful is the fact that we learned how to cooperate with each other. In this perception, the space of possibilities before the advent of humans included many different possibilities for an emerging species to exploit. In particular, the human brain is an amazing feat of nature, one which can model the future and adapt its behavior to something that has not yet come to pass.

Humans can thus react to environments that have not existed. Is this unique in nature? Certainly, at some basic level, the answer is a resounding "no," since many animals can at least implicitly model and predict the trajectory of an approaching object and react accordingly. Plants, on the other hand, may be prepared for a season that they have not lived through, but their degree of adaptation to the environment may not be as adaptable to a possible unprecedented change like global warming (Diamond, 2006). We humans are a most amazing product of nature, the ultimate omnivores, manipulating the earth to produce our own genetically engineered food. We create, to some extent, our own environment. Can humans rise to the challenges of our time? We are beholden to the way we were created, and our individuality can still represent our peril. Let us hope that we will have the capability to create the social structures that will elicit joint action to conquest some of the biggest threats of our time: nuclear war, overpopulation, climate change, and environmental destruction.

In this way, the essay leaves the door open to the study of a new kind of evolutionary theory that is steeped in the corollaries of the complexity paradigm. In this setting, social agency may find improved evolutionary paths through processes that do not require natural selection, but are rather driven by routes closer to what the *least action principle* suggests. This principle is what makes light go through water in the way that is most efficient, without the need to try many different paths and come up with the best one suggested by a Darwinian selection process. Furthermore, the social agency levels that we encounter will be *dual*, in the sense that they are a response to lower-level agents seeking to organize upwards, but also a result of an environment that is sending signals describing to how to best be exploited.

The new capabilities of the computer bring about opportunities to benefit from a relatively unexplored field. The questions raised by this essay should be discussed using the muscle of the computer simulation and combine it with the depth of understanding present in the highest levels of social theory, complexity, systems theory, and multilevel selection theory. The computational capabilities of our times provide us with an amazing new power to understand our biological and social natures, let us use them to their fullest extent.

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Modeling Tax Distribution in Metropolitan Regions with PolicySpace

Bernardo Alves Furtado

Ph.D., Coordinator, Tenured Researcher
Institute for Applied Economic Research (IPEA), Brazil
National Council of Research (CNPq), Brazil

bernardo.furtado@ipea.gov.br

Abstract

Brazilian executive bodies have consistently vetoed legislative initiatives that ease the creation and emancipation of municipalities. The previous research confirms the negative impact of fragmentation on municipal effectiveness. In order to provide support for arguments for metropolitan unions, this paper attempts to quantify the quality of life for metropolitan citizens in four alternative distributions of municipal tax collection. Methodologically, a validated agent-based spatial model is simulated. Additionally, we apply econometric models using real exogenous variables and simulated data. The results suggest that the Municipal Participation Fund is the most progressive and the most relevant for improving the quality of life for residents in metropolitan municipalities. Furthermore, municipal financial merging would improve the overall quality of life for residents. Finally, the study presents quantitative evidence that compares alternative tax distributions for each of the 40 simulated metropolises. It identifies efficient forms of fiscal distribution and thus contributes to the literature and the contemporary parliamentary debate.

Keywords: agent-based model; ABM platform; public policy; fiscal analysis; municipalities; metropolitan regions

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El Modelo de la Distribución de Impuestos en Regiones Metropolitanas on PolicySpace

Resumen

El poder ejecutivo en Brasil ha vetado sistemáticamente las iniciativas legislativas que facilitan la creación y la emancipación de los municipios. La investigación anterior confirma el impacto negativo de la fragmentación en la eficacia municipal. Con el fin de brindar apoyo a los argumentos de los sindicatos metropolitanos, este documento intenta cuantificar la calidad de vida de los ciudadanos metropolitanos en cuatro distribuciones alternativas de recaudación de impuestos municipales. Metodológicamente, se simula un modelo espacial validado basado en agentes. Adicionalmente, aplicamos modelos econométricos usando variables exógenas reales y datos simulados. Los resultados sugieren que el Fondo de Participación Municipal es el más progresivo y relevante para mejorar la calidad de vida de los residentes en los municipios metropolitanos. Además, la fusión financiera municipal mejoraría la calidad de vida general de los residentes. Finalmente, el estudio presenta evidencia cuantitativa que compara distribuciones fiscales alternativas para cada una de las 40 metrópolis simuladas. Identifica formas eficientes de distribución fiscal y, por lo tanto, contribuye a la literatura y al debate parlamentario contemporáneo.

Palabras clave: modelo basado en agentes, plataforma ABM, políticas públicas, análisis fiscal, municipios, regiones metropolitanas

大都市区税收分配的策略空间建模

摘要

巴西行政机构一贯否决有利于创建和解放市政当局的立法举措。以往的研究证实了碎片化对市政当局效率的负面影响。为了支持推崇市政工会的观点，本文试图用四种市政税收备选方案分配来量化大都市居民的生活质量。在方法层面，本研究对经过验证的基于Agent空间模型进行了仿真。不仅如此，笔者还使用实际外生变量和模拟数据对计量经济学模型进行了应用。结果表明，市政参与基金是在提高都市居民生

活质量方面最为先进和最具现实意义。除此之外，市政财政合并将提高居民的总体生活质量。最后，本研究通过呈现定量证据比较了40个模拟大都市每个的税收分配备选方案。本文确定了有效的财政分配形式，为文献发展和当代议会辩论做出贡献。

关键词：基于Agent模型，ABM平台，公共政策，财政分析，市政当局，大都市区

Introduction

The post-Constitution period of 1988 was fruitful for the dismemberment and creation of new municipalities in Brazil. The number of municipalities in Brazil increased by about 35%, with 1,438 new municipalities by the 2000 Census (Fernandes & de Araújo, 2017). Most of the new municipalities are small, with a population of less than 10,000 inhabitants, and have less capacity to offer public services and collect local taxes than larger municipalities (Marenco, Strohschoen, & Joner, 2017).

The publication of the Constitutional Amendment number 15 of 1996,[1] which establishes stricter rules, led to a halt on new municipalities' creation. A recent veto message summarizes the arguments by which the creation and dismemberment of municipalities impacts the municipal Public Administration as a whole: (a) continued growth of expenses and administrative structure, (b) maintenance of revenues at the previous levels, and (c) pulverization of resources transferred from the Union to the municipalities.

Municipalities consider the positive features of dismemberment as:

(a) A new administrative structure is created, opening new positions in the Executive and Legislative (City Hall), and

(b) Newly created municipalities gain proportionally more resources, to the detriment of the rest of the municipalities of a state.

Such reductions occur because the amount transferred by the Union and distributed via Municipal Participation Fund (MPF) remains the same, but a larger number of municipalities participate in the division of funds. However, the reasons that suggest to the Union that dismemberment may not bring benefits to **society as a whole** are the same reasons that lead **individual municipalities** to engage in the direction of their permission. In fact, since 1996, several parliamentary initiatives

1 http://www.planalto.gov.br/ccivil_03/Constituicao/Emendas/Emc/emc15.htm.

have tried to argue in favor of the creation of new municipalities.

This debate between possible advantages of dismemberment and its associated costs is already present in the literature. We discuss the debate in the next section. However, we have no knowledge of quantitative analysis that simulates results from alternative resource distributions between municipalities. Thus, the proposal of this paper is to present simulations of alternative tax distribution for municipalities of Brazilian metropolitan regions.

Methodologically, we simulate a validated spatial agent-based model (Furtado, 2018). The results indicate that for the vast majority of the analyzed cases, the merger of the municipalities of the metropolitan regions is beneficial for the quality of life for its inhabitants in the period of 20 years. The exercise also reinforces the relevance of the progressive effects of MPF in the current configuration.

The contribution of this study lies in the presentation of quantitative evidence—produced from official empirical data—that incorporates dynamic effects of redistribution of the amount of public resources in alternative ways. With the results, we confirm other disciplinary aspects of the literature that argue that in most cases, the dismemberment is not socially beneficial.

Besides the introduction, we briefly discuss the literature (Section 2), describe the methodology used (Section 3), and present the results (Section 4). We conclude with some final considerations (Section 5).

Context and Literature

This section summarizes the recent debate in the legislature on emancipationist proposals and reports favorable and opposing arguments. The research proposal that derives from the context analysis and the availability of methodologies concludes the section.

The issues concerning the creation of new municipalities and municipal emancipation remain in evidence in parliament more than 20 years after the publication of Constitutional Amendment 15 of 1996. Recently, there have been two more attempts to alter the criteria for municipalities' creation even after the presidential veto 550 in 2013. The President again vetoed Bill 104 in the Senate (and Draft Complementary Law 397 of 2014), providing message 250 of August 26, 2014, with the veto reasoning. The veto states that "fiscal responsibility" and the imbalance of possible redistributions as its reasons.[2] In another parliamentary attempt, the Senate plenary approved Bill 199 of 2015. The House is currently processing the Bill, which has an urgency status as Draft Complementary Law 137/2015 of the Chamber of Deputies. Representatives proposed six additional initiatives to attach to the draft.[3]

A recent report currently in discussion in the House suggests that the creation of municipalities could take

2 http://www.planalto.gov.br/CCIVIL_03/_Ato2011-2014/2014/Msg/Vet/VET-250.htm.

3 http://www.camara.gov.br/proposicoesWeb/fichadetramitacao?idProposicao=1594899.

place between the time the elected mayor has taken office and the last day of the year before the year of municipal elections. Excluding, therefore, only the years in which there are municipal elections. Further, the report proposes some criteria for the approval of new municipalities:

(a) Minimum population quota for the new municipalities and for the remaining municipalities and

(b) That the Municipal Feasibility Study (EVM) supports dismemberment, and that the EVM includes economic and financial analysis, among other requirements.

Fundamentally, representatives propose similar criteria to those who were in effect until 1996 with little more rigorous enforcement and population minimums. Most likely, the approval of Bill 199 would generate hundreds of new municipalities (Sachsida, Monasterio, & Lima, 2013). This creation of new municipalities seems counterproductive to the debate in the literature.

In the context of metropolitan areas, the Organization for Economic Co-operation and Development (OECD) defines employment basins as "functional regions" (Ahrend, Farchy, Kaplanis, & Lembcke, 2014). They refer to economically unique regions, distributed throughout the diffuse territory in different political–administrative contexts. In Brazil, these functional regions are called Areas of Population Concentration (APCs) by the Brazilian Institute of Geography and Statistics (IBGE), the official statistics bureau (IBGE, 2015).

APC fragmentation among several municipalities brings a variety of negative aspects. First, more fragmented metropolitan areas are less productivity (Ahrend et al., 2014). Further, the peripheral cities experience increased levels of violence whereas receiving lower quality of public services such as transportation and housing. From a strictly fiscal point of view, the literature suggests not only that metropolitan municipalities receive more per capita tax revenue but also that they are more efficient in their application (Furtado, Mation, & Monasterio, 2013).

Fernandes and de Araújo (2017) describe the resulting weak financial capacity of metropolitan municipalities that have undergone such fragmentation. One of the major problems faced by the Brazilian federation is municipal incapacity due to the low fiscal, financial, and institutional capacity of local governments to absorb and account for all their constitutional functions, including urban policy (Fernandes & de Araújo, 2017). Overall, these difficulties of municipal policy execution are counterproductive to the residents of metropolitan areas, since it inhibits autonomy and fiscal effort in practice, makes the municipality dependent on transfers, and restricts its development (Carvalho, 2017).

In sum, the literature suggests that fragmented metropolitan regions with multiple municipalities possess the following disadvantages:

(a) They are less productive.

(b) They divide capacity between the metropolis and its neighbors.

(c) They concentrate diseconomies of agglomeration in the peripheries (violence and congestion).

(d) They concentrate economic agglomerations within the primary city.

(e) They restrict economics of scale and scope in the provision of network services, such as transportation, basic sanitation (water and sewage), and land use and occupation (social housing).

However, there are spatially local gains generated with emancipation. The arguments of proponents of emancipation suggest that the territorial extension of the municipality may make it difficult to serve distant districts with public services. Economically, there are favorable redistributions of public resources to the new municipalities and a completely new political–administrative structure, which generally leads to actual improvement of the public service.

For example, Rocha, Mattos, and Saiani (2017) indicate a significant increase in investments in the sector for new municipalities in the area of basic sanitation. Wanderley (2008) notes gains in health and education indicators without any significant losses in the remaining municipalities.

The creation of new states follows similar logic. The newly created state receives resources and structure, to the detriment of the remaining states. Therefore, inhabitants of the new territorial section expect to receive financial gains. For example, in the case of the state of Tocantins (Brazil), there are indications that its emancipation from Goiás in 1987 brought improved quality of life to its residents (Parente, 2014).

Proposed Approach

A more informed analysis of the gains and losses for society as a whole in the redistribution of tax resources, with the total amount fixed, would probably benefit from the inclusion of data-generating processes that could at least reflect the dynamics of the economy and, in particular, their effects and feedbacks. In fact, Tesfatsion (2017) characterizes the real economy as an open dynamic systems in which heterogeneous agents (firms, workers, institutions) interact in sequential games built locally. Sequential games are those in which multiple agents make decisions, one after another, based on their own previous decisions, as well as in the local context at each moment. Thus, the states of each agent and of the economy as a whole change and evolve over time.

One way to operationalize economic analysis as open dynamic systems is through agent-based modeling (ABM) (see Section 3). ABM is a computational environment simulation of agents and their attributes, in which agents interact among themselves and the environment according to deterministic, explicit rules (Edmonds & Meyer, 2017; Epstein & Axtell, 1996; Heppenstall, Crooks, See, & Batty, 2012).

In our view, the use of ABM allows the achievement of the intended exercise, that is, to evaluate dynamically and spatially relevant markets. Specifically, in the ABM used, public services offered represent quality of life index (QLI) gains in the municipality that receives the investment derived from the tax collection. This increase in QLI causes increases in real estate prices, bringing to the model the dynamic effect that places with the best QLI have properties that are more expensive. This effect, coupled with the mobility of households, affects, in turn, the demand for goods from firms and the supply of more or less qualified workers for production.

Hence, we argue for the need of a more informed analysis about the gains and losses for the whole of society in alternative redistributions of tax resources. The model intends to replicate in time and space the patterns and the financial environment in which we test alternative distributions of taxes, if not *in vitro*, at least *in silica*.

Our proposal is as follows:

1. Build a spatially empirical environment, which simulates three markets upon which we apply five distinct taxes for the years 2000–2020. Thus, replicating the *status quo* of generation and distribution of tax revenues for 40 Brazilian metropolitan regions.

2. Validate the results so that the model is capable of answering the public policy research question. Specifically: are there other forms of distribution of tax resources that improve the quality of life of the inhabitants at the metropolitan level?

3. Simulate alternatives and compare with current situation.

4. Present and discuss the results, in light of the available literature.

Methodology: Agent-Based Modeling

An agent-based model is the implementation of an artificial computing environment in which agents interact in time and space. Or as described by Epstein and Axtell (1996): ABM is a discrete and dynamic temporal system, explained by simultaneous generic equations. Among the advantages of using ABMs is the low cost (*in silico* experimentation), the possibility of conducting experiments (what–if questions), and its explicit spatial, dynamic, and modular construction which allows other users to develop additional resources to the available platform. In addition, open source software allows the reproducibility of the results and the full comprehension of the mechanisms used in the model.

Dawid and Gatti (2018) propose seven major families of ABM and their applications in public policy and economics. PolicySpace (Furtado, 2018) is a proposal of economic-spatial modeling that fits the Lengnick trait of models (Gaffeo, Gatti, Desiderio, & Gallegati, 2008; Lengnick, 2013). However, PolicySpace[4] differs from previous contributions as it adds intraurban spatial analysis, household mobility, population dynamics, and the use of distance as a criterion of choice in consumer and labor markets.

We use PolicySpace to analyze systematically four tax distribution alternatives among municipalities in 40 Brazilian metropolitan regions. After confirming the validity of the model, we apply econometric tests to the real and simulated data to evaluate the strength of the results.

PolicySpace in a Nutshell

PolicySpace counts on agents—citizens—who offer themselves in the labor market and organize into families. Families participate in the consumer and real estate market, so they are mobile and may change their residential location. Firms employ workers and offer a homogeneous product in the consumer market. They compete by prices in the consumer market, and for skilled workers in the labor market. It constitutes municipal governments according to geospatial real data from IBGE.

Municipalities invest the taxes collected on the improvement of the quality of life of its citizens in a linear way, weighted by current population. The model runs every month from 2000 to 2020 and the sequence of events happens as follows:

1. Firms perform its production function based on the number of current employees and their qualification (Lengnick, 2013).
2. Population dynamics occur. Citizens age, die, and are born.
3. Families save a variable percentage of their income and consume the rest from a sample of firms.
4. Firms serve families on a first-come, first-served basis, up to the limit of their offer available in stock.
5. Firms decide on the salaries of their employees (Neugart & Richiardi, 2012), on prices (Seppecher, Salle, & Lavoie, 2017), and on the need to participate in the labor market.
6. Firms paying higher salaries choose employees first, opting for those most qualified from the sample of candidates. Optionally, they can select a percentage of the workforce by criterion of proximity of the residence of the candidate to the employing firm.
7. Monthly, some families enter as buyers in the real estate market (Jordan, Birkin, & Evans, 2012) and there are always more empty houses than occupied ones (Nadalin, Furtado, & Rabetti, 2018).
8. The model uses hedonic housing pricing (Rosen, 1974) to calculate the offer price. Final transaction price is the average between the calculated offer price of the residence and the demand offer made by the buying family.

4 PolicySpace is open source, available at Github.com/BAFurtado/policyspace.

9. Municipalities collect taxes:
    i. at consumption,
    ii. on wages paid,
    iii. on company profits,
    iv. on property,
    v. on real estate transactions.

Validation

Validation of the PolicySpace model happens in three successive steps that indicate the robustness of the procedures.

Macroeconomic Indicators

The first step of the validation refers to the adequacy of the macroeconomic indicators. The model is not expected to replicate trajectories of inflation, interest rate (nonexistent), or unemployment as there is no credit market (Dawid & Gatti, 2018). However, we understand that a model with unemployment at 50% or inflation index at 100% per month are not reasonable and inadequate for public policy analysis (Fagiolo & Roventini, 2017; Gatti, Desiderio, Gaffeo, Cirillo, & Gallegati, 2011; Gräbner, 2015).

Hence, PolicySpace is adequate for large macroeconomic indicators. In fact, unemployment in the period 2000–2020 is always below 10%, ranging from 8.5% to 0.5%, for all metropolitan regions and the number of simulations performed. Note that, by construction, the model provides unemployment rates for all municipalities. In this case, peripheral municipalities with smaller populations have higher expected rates, but in the ACP as a whole, they remain below 10%.

Inflation remains around 0.5% per month for the first decade of the simulation and reaches lower values, close to 0.05% per month for the second decade, according to the basic parameterization of the simulation. GDP also shows significant (and variable) gains in the first few years of the simulation and reaches lower growth at the end of the period. Hence, PolicySpace replicates macroeconomics dynamics, although it is not required to reproduce the exact time-series of the simulated period.

Sensitivity Analysis: Parameters and Rules

The literature also recommends to verify that the model is robust to modifications that disrupt the model (Galán et al., 2009). This occurs, for example, when the results are dependent on a specific value of a specific parameter. In the case of PolicySpace, the program contains an automatic simulation module that allows you to select any parameter of the model (numeric or Boolean), choose initial and final values and number of intervals, recording in graphs all the indicators for each value of the parameter tested.

This allowed testing the influence of the individual parameters on the behavior of the model and its robustness of results. That is, although the results were different according to the choice of parameters, there was no structurally different response or unexpected economic outputs. For example, the increase test on the productivity parameter correctly improves consumption and the standard of living of families. Further, the increase in the number of families that participate in the real estate market and the consequent increase in economic output as a whole.

Finally, it is worth mentioning we also test rules implementation. That is, the presence or absence of certain choices of the model. As an example, we should mention the use of distance as a criterion of hiring in the labor market, or the choice of the firm to observe the level of unemployment (or not) in the decision of the salary level of the employees.

Empirical Replication of Tax Collection: Global and Distribution

In light of the research question of the paper—which serves the purpose of evaluating model capacities (Wilensky & Rand, 2015)—the most relevant validating factor is the ability of the simulation to replicate the tax collection results, both in terms of percent of GDP and in terms of the percentage of each tax in total.

The study uses two sources for such comparison. One is based on the literature (Afonso, Morais Soares, & de Castro, 2013) and another on data provided by the National Treasury Secretariat of the Ministry of Finance (STN). In fact, Afonso et al. (2013, p. 14) report that the tax collection transferred to the municipalities was about 6% of the total and 2% of GDP in 2010, whereas STN data indicated 8.7% of GDP. The simulated values presented in PolicySpace (Furtado, 2018) suggest transfers of 6.8% of GDP.

Among the five taxes present in the model, the simulated proportion is also close to that obtained in the literature. Specifically for the tax collection ratios in relation to the total, the simulated values for the MPF are 43% of the total, while the STN data analysis indicates 41% of the total.

In addition, the collective distribution for all ACPs are compared between real and simulated data, presenting similarities for the cases of GDP, total tax collection, MPF, IPTU (Property Tax), and ITBI (Tax on Property Ownership Transfers). When comparing the proportions in relation to the total, the IPTU is collected more intensively in the simulated case—in which the collection rules are always enforced—that is not the case for the observed data with some municipalities not collecting IPTU.

Testing Strategy for Tax Alternatives

We tested four alternative distributions of fiscal resources (Table 1). For each **Case**, PolicySpace simulates for the full 20-year period, several times, and computes the median results.

Case 1 serves as baseline and represents the *status quo*. Consumption tax is distributed at 18.75% for the municipality of origin and the remainder (81.25%) is passed on to the state and (theoretically) evenly distributed among the municipalities of the metropolitan region (see Table 1).

In effect, there are three criteria of division of taxes:

(1) Locally—resources collected in the

municipality are invested in the own municipality;

(2) Equally—resources collected in the metropolitan region (APC) are also distributed equally between the municipalities of the APC, weighted by the population, and

(3) MPF—whose proportionality follows the empirically observed distribution of real MPF. In the MPF rule, smaller municipalities receive proportionately more resources.

In **Case** 2, APC municipalities function as a single municipality for tax distribution purposes and there are no locally reverted resources. In this **Case**, taxes on consumption, property and property transmission are distributed **equally** among all the municipalities of the APC, weighted by the population. Taxes on labor and company profits are distributed equally between the municipalities (76.5%) and the rest is distributed according to the MPF rules for municipalities in the metropolitan area.

In **Case** 3, all taxes are distributed according to the municipalities of origin. That is, there is no progressive redistribution by MPF, nor consumption tax is distributed throughout the municipalities, as if the State was forced to apply all the resources **locally**.

Finally, in **Case** 4, 100% of the amount collected with the consumption tax is distributed **equally** among the municipalities, weighted by the population.

In short, the *status quo*, **Case** 1, is compared to the absence of the redistributive MPF (**Cases** 3 and 4) and the fiscal union of municipalities (**Cases** 2 and 4). **Case** 3 is the extreme **Case** wherein all taxes are **locally** distributed.

The research hypothesis is that **Case** 2 would be the most beneficial for the population with municipal merger and MPF progressiveness. **Case** 3 would be the least beneficial, with all taxes withheld and distributed locally. *Ex ante*, it is not possible to determine whether **Case** 2, which includes the progressivity of the MPF associated with local taxes, would be better or worse than **Case** 4, which does not include the progressiveness of the MPF, but distributes the taxes equally.

We emphasize that the exercise is only a redistribution of funds raised. There is no tax gain due to a supposed reduction in administrative bureaucracy or gains with a supposed improvement in efficiency (Gasparini & Miranda, 2011).

Econometric Strategy

The econometric strategy seeks to verify if the two parameters of the model: Alternative0 and MPF distribution that compose the four fiscal distribution alternatives (Table 1) are robust as determinants of the quality of life obtained in the simulation. As such, five econometric models are explored, three with simulation data (Simul 1–3) and two with real data, exogenous to the model (Real 1–2).

In all **Cases**, the dependent variable is the quality of life observed at the end of the simulation period. In addition, in all **Cases**, the two parameters

Table 1. Alternatives of Tax Distribution among Municipalities in Metropolitan Regions (APCs)

	Case 1			Case 2		Case 3	Case 4
Taxes	Municipalities	State	MPF	State	MPF	Municipalities	State
Consumption	0.1875	0.8125	—	1	—	1	1
Personal income	—	0.765	0.235	0.765	0.235	1	1
Transmission	1	—	—	1	—	1	1
Company	—	0.765	0.235	0.765	0.235	1	1
Property	1	—	—	1	—	1	1
Criteria	Locally	Equally	MPF	Equally	MPF	Locally	Equally

Source: Adapted from Furtado (2018).

Alternative0 and MPF represent the distribution alternatives exactly as depicted in Table 1. Alternative0 is true for the *status quo* and false when the municipalities are together for distribution purposes. MPF is true when the distribution rule is present according to the presence of MPF and false when the rule is not applied. Additionally, dummies of all APCs are used for Simul 1–2 **Case**s, with Simul 3 testing their absence. In Real 1–2, information was collected only for the main metropolises.[5]

In Simul 2–3, the controls are the variables of the average number of workers per firm, firm profit, GDP index value, inflation, unemployment, and number of municipalities in the APC. The latter was also used in model Real 2. Finally, in model Real 2, an HHI index, the log of the population in the APC and the percentage of inhabitants with complete higher education were included.

We highlight that quality of life in the simulation comes mainly from tax collection. Thus, no variables associated with taxes were included in the models. However, we know that GDP and population are highly correlated with tax collection. GDP (endogenous to simulation) was included in Simul 2–3 models and the population in Real 2 model. Nevertheless, Simul 1 and Real 1 models only rely on the presence of the two distribution parameters and the dummies of the APCs.

Results

The results are obtained for each APC independently and the policy recommendation can also be different for each **Case**. Indeed, several factors influence the configuration of each APC, including population, their age cohorts and distribution among the municipalities, the concentration of

5 The complete results (with APCs dummies), the database, and the code used are available in https://www.dropbox.com/sh/udke6c196stjzy9/AACljy9Cbb-zmR_-1AQoyFcMa?dl=0.

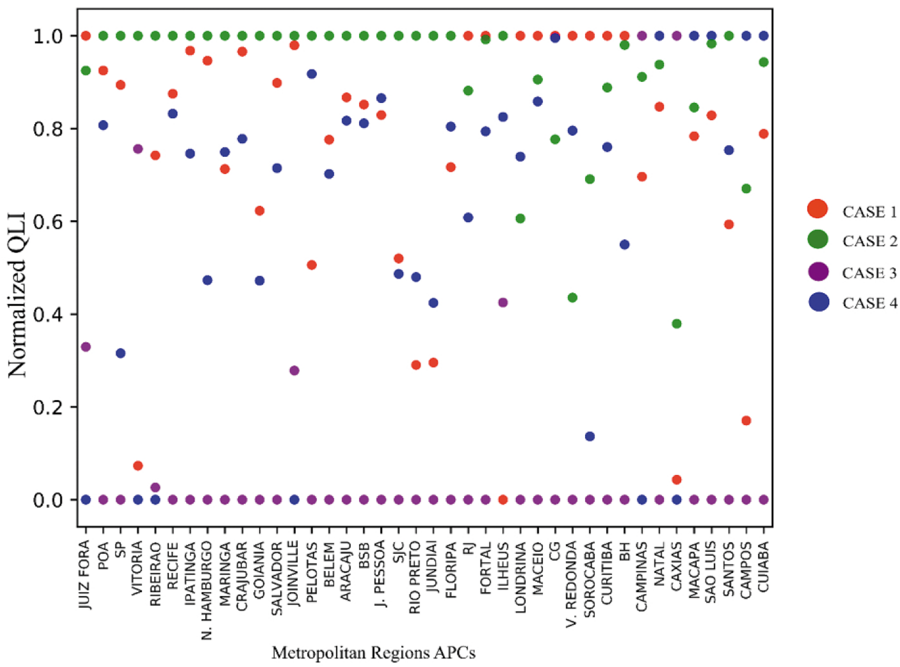

Figure 1. Result of simulations of alternative tax distribution APCs.

firms and the qualification of workers, besides the absolute number of municipalities.

We present a systemic result for the set of metropolitan regions (APCs) in Figure 1. QLI values for the last month of the simulation are normalized in order to distinguish more clearly the differences between the results and allow for comparison among APCs.

Results of the simulation of alternative tax distribution among metropolitan regions (APCs). **Case** 2, which represents the maintenance of the MPF distribution rules and the union of all municipalities in the APC, presents the highest number of maximum values among the options for the metropolitan regions. **Case** 3, which represents the withdrawal of MPF rule, leads to worse quality of life results in the greatest number of metropolitan regions. The results refer to simulation runs of 2% of the population and 3 simulations per APC.

Indeed, for 23 APCs, **Case** 2 with municipal merger and MPF maintenance is the result with a better quality of life indicator. The current situation (**Case** 1) shows the best result in 10 APCs.[6] Nevertheless, **Case** 3, in which all resources are distributed locally, has only two APCs with the best QLI results: Campinas and Caxias do Sul.

6 The abbreviations of APCs stand for the following names: POA: Porto Alegre, N. Hamburg New Hamburg, Crajubar, Crato, Juazeiro and Barbalha, Brazil: São Paulo, BSB: Brasilia, J. Person: João Pessoa, SJC: São José dos Campos, Floripa: Florianópolis, CG: Campina Grande, V. Round: Volta Redonda, Belo Horizonte and Campos: Campos dos Goitacazes.

Finally, **Case** 4, in which the municipalities are considered together, but there is no distribution according to MPF, is better for the **Case** of five APCs.

The results of the econometric exercise suggest that the fiscal distribution alternatives among the municipalities of the studied metropolitan regions are consistent and robust in all models tested (see Table 2). As mentioned earlier, variables Alternative0 and MPF_distribution are the ones being tested. Together they configure the four **Case**s of distribution as described in Table 1.[7]

The interpretation, as expected, indicates that when Alternative0 is **True**—in **Cases** where the municipal division remains as observed—there is loss of quality of life (negative sign). This indicates that there is a clear gain for all models when Alternative0 option is **False** and therefore, the municipalities are all together for fiscal distribution purposes.

Additionally, the presence of the MPF distribution rule (True) is also beneficial in all **Cases**. It is equivalent to say that when MPF is not present in the fiscal distribution (False), there would be a deterioration of quality of life.

The controls of the models lead to different values for the intercept and for the significance of each of the controls. However, they do not change the coefficients or the significance of the distribution rules and present similar adjustments.

Simul 2 model, with dummies for each APC and other control variables, appears as the most adjusted among the models simulated considering the log-likelihood criterion. However, Simul 1 model, with the dummies only, presents a very similar adjustment and seems more robust, from the point of view of the analysis of the APCs.[8]

Finally, in addition to the descriptive analysis of Figure 1 and Table 2, the simple econometric exercise seems to reinforce the suggestion of this work on the relevance of the presence of MPF and the gains in distributive efficiency of the merger of metropolitan municipalities.

Final Considerations

This paper uses official data from metropolitan regions to make a quantitative and dynamic exercise that simulates three economic markets, imposes taxes on them, cumulatively validates the model, and tests alternatives for fiscal distributions among municipalities.

Thus, this text provides additional quantitative arguments to guide the efficiency and effectiveness within metropolitan areas for the Brazilian case. In fact, based on the economic concept of metropolitan functional regions, the literature reports an unequal distribution, to the detriment of the peripheries, in relation to violence, congestion, access to public services, and

7 Note, however, as stated above, that for **Case** 3, chosen as the extreme **Case**, consumption tax is distributed locally in full.

8 See full results at https://www.dropbox.com/sh/udke6c196stjzy9/AACljy9Cbb-zmR_-1AQoyFcMa?dl=0.

Table 2. Compact Results of the Econometric Tests of the Tax Distribution Alternatives between APCs

	Simul 1	**Simul 2**	**Simul 3**	**Real 1**	**Real 2**
ALTERNATIVE0 [True]	–0.01***	0.01***	–0.01*	–0.01 ***	–0.01***
	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)
MPF_DISTRIBUTION [True]	0.02***	0.01***	0.02**	0.02***	0.02***
	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)
Intercept	0.60***	0.9	0.73***	0.61***	0.02***
	(0.01)	(0.64)	(0.03)	(0.01)	(0.00)
area.APC	—	—	—	—	–0.00***
	—	—	—	—	(0.00)
pib.index	—	0.00**	0	—	—
	—	(0.00)	(0.00)	—	—
inflation	—	–1.55	11.31***	—	—
	—	(1.10)	(3.15)	—	—
ln.population.APC	—	—		—	0.01***
	—	—		—	(0.00)
number.municipality. APC	—	–0.01	0	—	0.00**
	—	(0.01)	(0.00)	—	(0.00)
	—	—	—	—	—
Log-likelihood	506.85	510.85	267.02	260.65	260.65
R-squared Adj	0.98	0.98	0.6	0.98	0.98
AIC	–931.69	–929.7	–516.04	–477.31	–477.31
BIC	–806.65	–789.41	–488.59	–424.9	–424.9
No. of observations	156	156	156	80	80

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses.

restriction of opportunities. The understanding that such inequality affects the quality of life of the municipalities motivated us to investigate alternatives of tax distribution.

The analysis described in this paper allows us to suggest two central conclusions. The first is that the progressiveness of MPF is striking in the metropolitan regions and its maintenance is significantly positive. The second conclusion is that in most metropolitan regions, municipal merger for tax purposes would be beneficial. The effect, however, is not homogeneous and would have to be verified on a case-by-case basis. In some metropolitan regions, the gain of the merger is so relevant that it would be sufficient to compensate for the hypothesis of absence of the MPF.

In feasible terms, Constitutional Amendment number 15 of 1996 supports the possibility of municipal mergers, subject to consultation with the populations concerned.

Finally, it should be noted that federalism with a municipal emphasis given by the Federal Constitution of 1988 might be advantageous for many Brazilian municipalities, spread over a continental country. Its excessive fragmentation, in the metropolitan scope in particular, however, seems to be more detrimental than beneficial. We hope that the indicatives presented in this paper contribute to the accumulation of evidence for better management and governance of urban space and its economic implications for the Brazilian case.

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The Dynamical Organizations Theory: Openness, Synthesis, and Emergence

A Retrospective Case Study
Stories of Change

R. N. Knowles

rnknowles@aol.com

Abstract

Organizations are complex, adapting, self-organizing networks of people that change one conversation at a time. Open, recursive conversations among all the people provide energy to the system enabling everyone to learn and grow. New opportunities are considered and synthesized. Decisions emerge and are acted upon, building a more sustainable future for the people and their organization. This is the Dynamical Organizations Theory.

Keywords: dynamical organizations theory; self-organizing networks; adaptation; sustainable future

La Teoría de las Organizaciones Dinámicas: Apertura, Síntesis y Emergencia

Un Estudio de Caso Retrospectivo: Historias de Cambio

Resumen

Las organizaciones son redes complejas, adaptables y autoorganizadas de personas que cambian una conversación a la vez. Las conversaciones abiertas y recursivas entre todas las personas proporcionan energía al sistema para que todos puedan aprender y crecer. Nuevas oportunidades son consideradas y sintetizadas. Las decisiones surgen y se ponen en práctica, construyendo un futuro más sostenible para las personas y su organización. Esta es la Teoría de las Organizaciones Dinámicas.

Palabras clave: teoría de las organizaciones dinámicas, redes de autoorganización, adaptación, futuro sostenible

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动态组织理论：开放性、综合性与突现性 关于变化的回顾性案例分析故事

命题

组织是自我管理的复杂适应性人际网络。组织一次只改变一次沟通。所有人之间开放的递归沟通为组织提供了能量，使每个人都能学习和成长。新的机会得以考虑与综合。决策得以产生并付诸行动，从而为所有人及其组织建设一个更可持续的未来。这便是动态组织理论。

关键词：动力组织理论;自组织网络;适应;可持续未来

Introduction

This is a retrospective, 8-year case study of the Dynamical Organizations Theory. This study reveals how the work of all of us at the DuPont Belle, WV Plant accomplished the extraordinary changes that we made together. The stories of change are considered in light of Dynamical Organizations Theory which I gradually developed over many years of study, practical application, and reflection. All of these stories were reviewed and confirmed by a number of former Belle Plant people who shared this exciting time with me.

A Brief Overview of the Theory

Dynamical Organizations Theory: Openness, Synthesis, and Emergence

Significant, sustainable organizational change is achieved through ongoing, focused, disciplined, honest conversations among all the stakeholders about overcoming the issues and challenges facing them, opening up new possibilities, and acting on them. This requires courage, care, concern, and commitment by the leaders who fully share the organization's vision and mission, then invite and engage with the people to help to co-create their shared future,

- by honestly and openly talking about how to improve, modify, and overcome their issues and challenges,
- by synthesizing new possibilities and prospects, and
- by coalescing around an emergent pathway to a new culture and acting to build a new future.

The people and the organization are in a reciprocal relationship with the whole and the parts as they co-create their future (Bortoft, 1996).

Basic Conditions

- Organizations are complex, adapting, self-organizing networks of people.
- Freely flowing of information is critical. Anything that inhibits the free flow of information reduces the people's ability and will to grow, learn, and become the best they can be. Dysfunctional behaviors like sexual harassment and bullying are hugely destructive because people pull back and stop sharing information. They are diminished, and great potential for both the individuals and the organization is lost.
- Self-organizing criticality (SOC), a fundamental process of change, was developed by Bak, Tang, and Wiesenfeld (1987) studying sand falling slowly onto a sand pile, building potential energy, self-organizing, and then reaching the point where a slip in the pile occurred releasing potential energy.
    - Most of the slips were small.
    - Less often, there were middle-sized slips.
    - Very infrequently, there were few big slips.
    - ou can't predict when the next grain of sand will cause a slip in the pile, nor how large the slip will be.
- Focused, disciplined conversations are like the grains of sand falling onto a sand pile.
- As people openly address their opportunities and challenges, the potential energy for change increases. Trust, interdependence, and confidence build, ideas are synthesized and change emerges.
- The leaders must develop a compelling vision and mission using a complexity tool like the Process Enneagram© (McCarter & White, 2013), engage in authentic, respectful conversations, constantly walking among the people, creating the space where it is safe to have open, honest conversations about things of importance. The changes build on themselves, everyone learns and grows, and the rate of change gradually increases. They co-create their future.
- No one knows when the next conversation will result in a release of potential energy and create a change.
- Most of the changes are small, some are middle-sized, and a few are quite big just as Bak et, al. (1987) observed in their Self-Organizing Criticality Theory.
- Small changes provide the opportunity for all the people to learn to work together in a new way. Little mistakes are easily corrected.

The Story

These stories of change and the creation of a new order occurred from April 1987 to February 1996 at the DuPont Belle, West Virginia Plant where I was the Plant Manager working with the Belle Plant Leadership Team (BPLT) and all the Belle people. We transformed this large chemical plant from one of the poorest performing into one of the best performing plants in the entire DuPont Company. Reflecting on these stories, studying John Bennett's Systematics, chaos, and complexity theory and consulting with and observing organizations extensively in many countries led me to developing the Dynamical Organizations Theory in 2017 (Knowles, 2017).

We saved the Belle Plant from being shut down by helping the people build respect, to solve compelling, complex problems together, to improve performance, and increase earnings. Extensive, sustainable change was an outcome of this work.

The Belle Plant Context

The DuPont Belle Plant was started in 1927 to produce organic chemicals from the plentiful, local sources of coal, water, and air. The people in West Virginia are a strong, reliable work force. For years, the Belle Plant was a high-quality supplier of a variety of organic chemicals like the chemical building blocks used to make nylon during the Second World War. It was one of the key plants in the growing DuPont Company.

My Arrival

However, when I arrived in April 1987, the Plant's performance had deteriorated to the point where the Plant's survival was in question. The entire work force of 1,300 people was frustrated, cynical, and stuck. Resistance to change was deeply rooted. The safety performance, a core DuPont value at this time, was dreadful. The Plant was losing money.

I was transferred from the DuPont Plant in Niagara Falls, NY, where I had been the Plant Manager, and, as an outsider, was not welcomed by anyone including the superintendents, supervisors, clerical, and hourly people. They had become so isolated that they thought they were doing just fine. Dysfunctional behaviors were rampant throughout all the levels and groups; trust levels were awful and productivity was low. In fighting to overcome this, my own behavior became very harsh and demanding. While there was a union representing the control laboratory people, most of the Plant was non-union. However, the strong union culture in West Virginia greatly influenced the way the people thought and worked so, for example, there were fixed craft lines and many difficult, restrictive work rules.

The process of transformation began immediately. I met with all 1,300 people in the first six weeks, either individually or in small groups, day and night, to introduce myself and talk about our shared future of becoming one of DuPont's top performers again.

I focused on re-establishing the safety standards, building honesty, respect, and trust. I helped the people to see that everyone had to significantly improve their own performance. Eliminating dysfunctional behaviors and improving the safety performance were key pieces of this work. I walked the

Plant for hours every day talking with and listening to the people at all levels and all shifts; we operated 24/7.

At first, getting to know the people was awkward, but as I kept at this, the personal interactions got easier. I had to show the people that I was genuinely interested in their success. Over time, my management approach opened up and became more approachable; trust built; effectiveness; and the total plant performance improved. In the first couple of years, the flow of information opened up creating an environment where it was safe to talk and share, enabling information to flow more freely throughout the organization, up, down, and across all levels and silos. People could share their ideas and insights without fear of criticism or being put down. As the energy built, many good things began to happen.

Here are some of the things I did:

- I walked around the plant, greeting and talking with people about how they were individually doing, how the plant was doing on our safety and environmental performance and sharing the latest business news. I insisted on achieving high standards, so the Plant could compete in the global markets, survive, and prosper.

- Sometimes, I would walk around just looking at the good things people were doing. Other times, when I could, I would sit down with the people in their work area and have a cup of coffee. I spent a lot of time listening, but did not make decisions there with them since that would undermine the line organization.

- Together, we continued to look for better ways to do things. Sometimes, I talked with just one person and other times I talked with groups.

- As ideas began to emerge, I encouraged the people to follow up, talk with their teammates and others who could help. I would offer to run interference for them if they wanted that sort of help. I encouraged them to talk with whoever they thought could contribute to making things better and build on their ideas.

- I always picked up any trash. Sometimes, I shoveled snow with them.

- I would ask for their input on how they thought I was doing, and would talk about that. This feedback often helped me to do a better job.

- Sometimes, there were strong differences, but we focused on the issues and did not make it personal. When I did not know the answers to their questions, I would tell them I didn't know and promise to get back with them when I found the answer; I always got back to them.

I was dedicated and persistent in walking around the plant engaging with everyone. This required courage, care, concern, and commitment; some days were pretty rough. It took courage because I never knew just what would happen and how critical the people would be. It took caring because I had to show the people I cared by taking the time to sit with them, listen, and to ask how I could be of help. It took concern because I had to show the people that I really cared about rebuilding the strength of the Plant. It took commitment because I dedicated hours and hours to walking around, listening, and learning. After the first 2 years when I realized the importance of these continuous, focused conversations, I dedicated myself to doing this for about 5 hours a day, and kept at it for 5 years. I kept a daily log of his time in the field to maintain the discipline for myself. (Yes, I worked long hours.)

Many, many changes occurred as we learned and grew together. The Plant became one of the best performing plants in the DuPont Company. The Leadership Team and I kept a constant focus on talking together with the people about improving all aspects of our performance including the safety performance, eliminating dysfunctional behaviors, opening up the flow of information, building on our skills and knowledge and creating a better future, listening, learning, and asking for their help.

For example, we on the Leadership Team decided that we needed to take a stand about improving the climate for change, so we developed a set of guiding principles about how we, on the Leadership Team, wanted to treat everyone. These are the Belle Treatment of People Principles shown here (Knowles, 2002, Foreward, LVIII).

The Belle Treatment of People Principles:

1. People want interesting work—work that makes good use of their abilities. Boring jobs de-motivate and alienate.

2. They want opportunity for learning and growth and opportunity to apply the skills.

3. They can be trained (that is, they are able and willing) to do several different jobs.

4. They want equal opportunity to advance and try different work.

5. They want responsibility in their work, some degree of decision making.

6. They “want in” on decisions that affect them.

7. People expect management to lead, not abdicate. People look to management to make its contribution in those critical areas where employees do not have the requisite orientation, knowledge, or resources.

8. They expect a leadership team to be consistent and predictable.

9. People want to be part of a winning team.

10. People want to know what’s going on at Belle, in the department, and in the Company.

11. People want to be informed about the business and get early feedback

on the performance of their part of the operation.

12. They want fair pay and knowledge about how the pay system works.

13. They have a need to relate to others on the job.

14. They want rational rules and a minimum of regimentation. People want a say in the rules.

15. They want to be treated like people —people have ego needs.

We distributed these around the Plant and asked people to hold us accountable for living up to them. At first, people did not believe that we really wanted to do this, but after talking about them for about two months, they began to challenge us when we did not live up to them. We continually improved with their help. We used these consciously when we were discussing performance or discipline problems. As people challenged us, they began to accept these Treatment of People Principles for themselves and more significant changes happened.

A significant learning for us on the Leadership Team was experiencing the power of taking a stand, putting ourselves into the system and becoming a part of it. These Treatment of People Principles became the solid base on which we could stand when everything else was changing. While we couldn't control much that was happening to us and the business, we could control how we treated each other.

Another stand that I took this was about improving our safety (occupational safety, occupational health, and process safety) and environmental performance. My mantra was "I did not have a right to make my living at a place where it was okay for someone to get hurt or mess up the environment; we also had to improve our earnings so let's do all these things as best we can."

Constantly talking and listening together, helping each other, developing ideas, solving problems together led to a shift where the people began to become "leaderful," a term I had heard from Karen Ann Zion in a conference in 1993. Being leaderful meant that anyone who saw a need for some improvement could begin the process on their own initiative without waiting for their supervisor to tell them to do something.

As people helped to solve problems and make improvements, more change happened. People do not resist change when they are creating change. Initially, most of the improvements and changes were small, like in Bak et al.'s 1987 sand pile studies, and could be easily missed. But as I walked around the Plant, talking and listening I did not miss many of these small changes. I constantly reinforced the safety, environmental improvement messages, and the Belle Treatment of People Principles. As people became more and more confident in trusting me, the organization became more leaderful. Sometimes, we made mistakes, but we supported each other and learned from them. We kept moving forward by constantly trying to live up to our safety, environmental, and Treatment of People Principles. People felt more and more confident about making decisions related to improving their own work. Our core messages created a container, a strange attractor that I call the BOWL (Knowles, 2002), in which people could operate with a high degree of freedom in doing and improving their work. Interest, excitement, and energy built as we all learned. We all derived new meaning in or recursive conversations; this is the Hermaneutic process in action.

Here are some of the changes that were made by the people. None of these changes were very significant in and of themselves. However, the accumulation and buildup of these all together resulted in the Belle Plant's strong improvements and sustainable transformation.

Some Changes

Stories of small changes:

Many of these changes were made in the first 2–3 years that I was at the Plant.

- Morning, production status meetings were moved from the main office conference room to the Shift Supervisors office and became stand-up meetings.
- Two one-hour business review meetings were held each week in shops and control rooms.
- The manager's and general superintendents' offices were moved from a big office building outside the main gate into the Plant to be closer to the people.
- Preferred parking was for Safety Stars only. These were people who had worked injury-free for at least 25 years.
- Bullying was greatly reduced. Some people were terminated. As we shined the light-of-day on bullying behavior, a lot of it stopped.
- When I would occasionally forget my safety glasses, I was sent back to get them by an operator.
- Eddie Long, a mechanic, kicked 4–5 contractors off the plant who were not working safely. He did this on his own.
- Employee-led safety teams strengthened the Central Safety Committee.
- Everyone had email accounts.
- Current safety, environmental, and business information was put onto the login screens every day.
- I had an open-door policy, but not a swinging door policy; people had to work through their supervisors first.
- The Leadership Team held a self-reflections session for 30 minutes at the start of every weekly staff meeting, talking about our performance, and giving ourselves a score on our performance. We used a statistical process control chart on the wall to keep a public record of our performance. This helped us to improve our own performance.
- Everyone insisted on achieving and sustaining high standards in the work.

- We held each other accountable for living up to our responsibilities.
- I walked the coal conveyor and climbed distillation columns, so I could learn about where the people actually worked.
- Keeping Process Safety Management and training up to date was critical and was emphasized this in each Central Safety Committee meeting.
- The safety shoe team was led by an operator.
- Employees volunteered and were loaned to substitute teach for a day or two to help the Kanawha County School Board free up teachers for computer training. This was the Chamber of Commerce Project Teach.
- Teams began to loan special equipment like a pickup truck to other groups in times of need.
- An employee-led program was created to eliminate smoking on the plant.
- An operator, on his own, shut down the amines process to fix a small leak at the top of a distillation column.
- I created a Community Advisory Panel and actively met with them each month.
- Martha Mullins, the science teacher at the Belle Middle School, and three students visited the Plant with Ken Ward, the reporter for the Charleston, Gazette, to learn about how ammonia was handled and processed. This was done to demonstrate my willingness to share information with the media and the public.
- Many open houses were held.
- I tried to learn how to weld and, while failing to weld anything, I showed the welders my respect for their craft.
- I learned to play Appalachian dance tunes on the hammered dulcimer showing my appreciation for this part of their culture.
- Visitors to the Plant were usually escorted by hourly people.

Stories of Middle-Sized Changes

- Demurrage costs (fees that we paid vendors when we did not return their tank trucks quickly enough) were cut from $800,000/year to $100,000/year by a team of operators in just six months.
- Becky Dixon, an operator, invited radio talk show hosts into the plant to show them the good things the people were doing to improve the Plant's environmental performance. She initiated, organized, and led the entire visit which was a great success. With her guidance, I did my part.
- Site-wide, multi-level teams were formed to work on special projects like environmental stewardship.

- Site training for teams was done by site hourly people.
- Steve Wilson, an insulator and Asbestos Team Chairman, on his own initiative, called to the EPA to learn more about how to handle asbestos.
- The Plant moved to teams and became involved with the Association for Quality and Participation. The Plant obtained the only (AQP) Site Chapter.
- National recognition was received from AQP for a Site Team of the Year.
- I strongly supported the Fire Brigades, the Belle Activities Committee, the annual Plant picnic, and the 25 Year Club.
- I constantly supported the shift supervisors and their emergency response and fire-fighting teams.
- The Shift Supervisors Team was moved to report directly to the me which opened the flow of information, coordination, and effectiveness.
- Safety audits and plant visits were conducted with Claire Knowles, my wife from Niagara Falls, NY, when she was visiting on week-ends.
- The Belle Plant Treatment of People Principles were established.
- Quality control lab tests were moved to the production operators from the control lab. technicians.
- People filled out their own time cards—openly available for all to see.
- The main exit valve on the refrigerated, 110-foot-tall, ammonia storage tank was changed from 24 inches to 10 inches to reduce the likelihood of a major spill. This was accomplished without warming and completely emptying the tank. This saved us a lot of money and time.

Stories of Large Changes

- The Belle Vision (People, Safety, Environment, Quality, Cost, Customer) was developed.
- I discovered that I was the biggest barrier to the Plant's success and had to change my own behavior from my domineering, harsh approach to becoming a better listener and start to partner with the people. As small part of this work, I changed my seat at the Leadership Team meetings from the head of the table to sitting by the wall, stepping into the meeting as I needed to resolve an issue. This was a difficult shift for me, but had a very positive impact on the leadership Team's performance and influenced the entire Plant.
- Worst-Case Scenarios were successfully shared with the Greater Charleston, WV, community of 300,000 people in our national, ground-breaking, 2-year project called Safety Street. Community leaders like Mildred Holt, a teacher, and Nikki Smith (Orcutt), a student,

helped the communications effort. This gave us a big boost in our relationships with the community.

- First-line supervisors were removed from shifts.
- The Plant converted to merit shop (the lowest cost, qualified bidder) for construction projects.
- Conversions from pneumatic to electronic controls were successfully made on 16 different production processes without running parallel. This cut the costs and time for the conversions in half.
- Mandatory random drug testing was begun. Belle was the first chemical plant in DuPont to do this.

More Changes

I decided to look at how the changes impacted the Plant's progress by using the Sustainability Ratios (Knowles, 2002). The BPTL made a qualitative assessment about each change using the six sustainability ratios. In these ratios, the numerator indicates improved sustainability and the denominator indicates the sustainability has been weakened. In Figure 1, the sustainability ratios are displayed around a particular change decision.

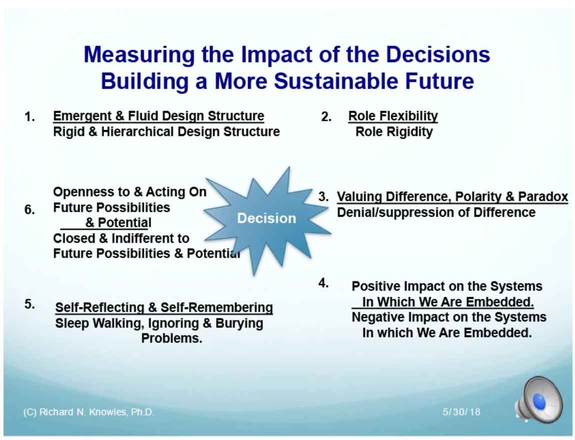

Figure 1. Measuring the impact of the decision building a more sustainable future.

We talked about each change and made a subjective judgment about how the change impacted our three areas of focus.

- Organizational Effectiveness (OE) related to how people were working together.
- Functional Effectiveness (FE) related to how we were growing our skills and using them.
- Business Effectiveness (BE) related to how the business was impacted.

These ratios are meaningful, leading indicators about making quality of decisions to build better organizational resilience and sustainability.

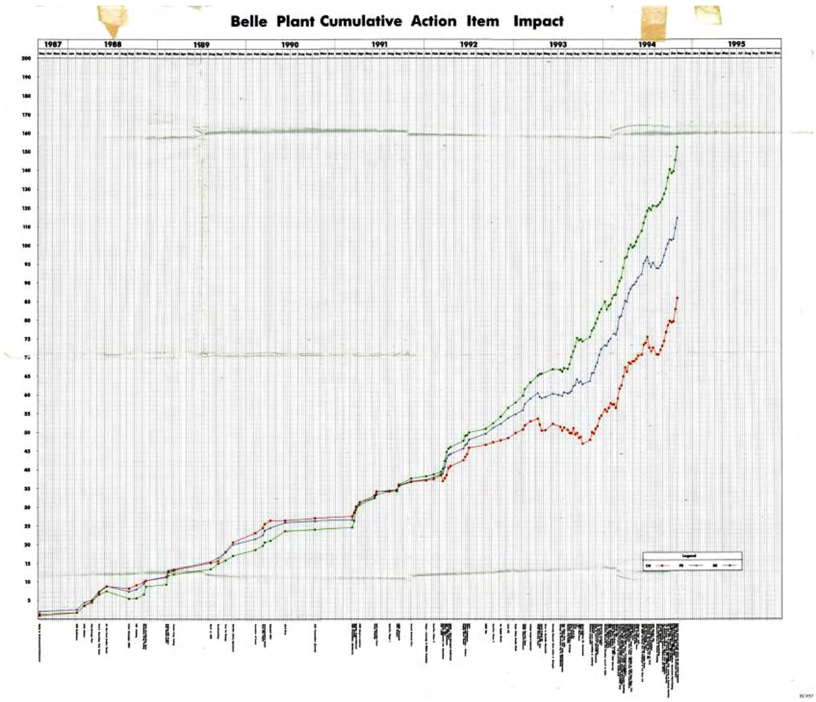

Figure 2. Belle Plant cumulative action item impact.

Progress was seen from the very beginning with most of the improvements developing first in the areas of OE and BE. It was expected that these improvements would happen ahead of the BE which is seen in the figure. The BE curve crossed over the other two in 1991. In 1992, the DuPont Company took away some of the health benefits causing a negative impact on our OE performance. We could see the OE curve drop, so we did some things to improve the OE and the curve turned upward again.

Each vertical line at the bottom of the chart indicates a specific change. The frequency with which changes occurred was slow at the beginning, but as we learned the frequency of changes increased. For the purposes of this paper, the specific changes listed here along the bottom of the chart are not important. But, the number of changes (126) and the increasing frequency of the changes are important: 1987 (1 Change) April–September, 1988 (9 Changes), 1989 (7 Changes), 1990 (6 Changes), 1991 (10 Changes), 1992 (16 Changes), 1993 (27 Changes), 1994 (50 Changes)

Figure 3 shows the progress using quantitative data in reducing and sustaining the OSHA Total Recordable Injury Frequency Rate, the time between Lost Work Day Injuries, and the changes in earnings, productivity, and emissions. Below the chart, the major things that were happening are listed. In the first phase, we did essentially all the things that Kotter (1996) talks about in his book, *Leading Change*, which was

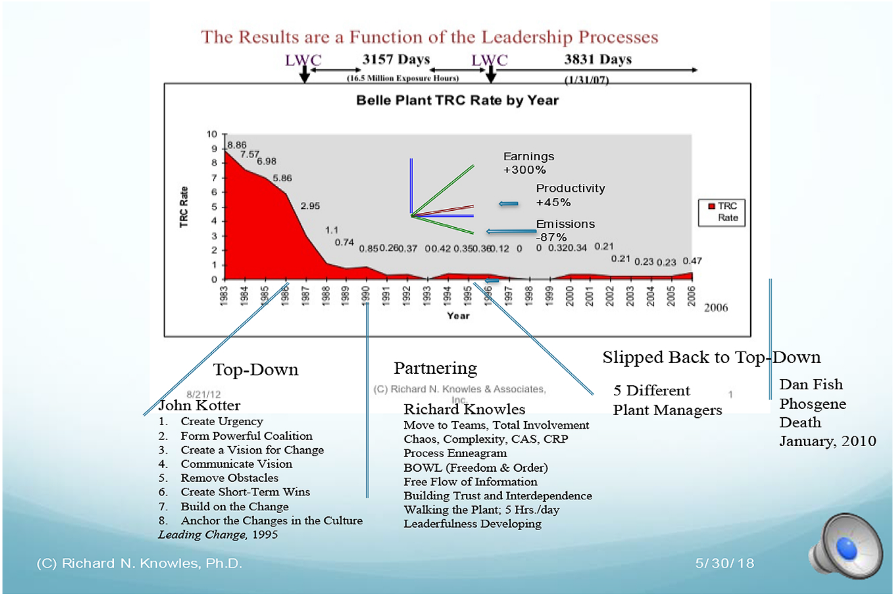

Figure 3. The results are a function of the leadership processes.

published in 1996. These items were listed here as examples of the sorts of things we did, although we did all this in 1987–1989.

- A core competency was the ability to safely use and make highly hazardous chemicals.
- Our Total Recordable Injury Case Rate (TRIR) dropped by 98%.
- The people sustained this level of safety performance for at a TRIR of about 0.3 or less for 17 years, 12 after I had left the Plant in February 1995.
- A carpenter suffered a Lost Work Day Case (LWC) injury when he cut his finger off in a bandsaw accident in April 1987 right after I came to Belle. Then we went 8.6 years before an operator suffered an LWC when he was burned in an accidental steam release. Then the Plant went 10.5 years until a phosgene release caused a fatality in 2010.
- Emissions went down by 88% from 1988 to 1995.
- Environmental upsets were reduced to almost zero.
- Productivity went up by 45%.
- Earnings up by 300%.
- The change-over cycle time between production campaigns in an operation where various different products were made in the same equipment and required thorough cleanup was cut from 7 weeks to 1 week.
- A permit for new landfill for non-hazardous wastes was obtained without the need for a formal public

hearing because trust had built with the community and the West Virginia Department of Environmental Conservation.

- We created a drug-free workplace.

The pay-off was terrific. When comparing the qualitative performance changes shown in Figure 2 with quantitative performance numbers shown in Figure 3, it can be seen that as the BE curve strengthened in the 1991–1993 period, the quantitative data we had on earnings, reduction in injuries, productivity, and emissions significantly improved. This simple tool of using the sustainability ratios was a strong leading indicator for our total improvement in measuring the Plant's performance.

Years (22) of study, reflection, consulting, and personal growth and understanding

I left the Belle Plant in February 1995, The DuPont Company in September 1996 and moved into consulting around the world on leadership and safety. I continued to explore more deeply how organizations actually worked and changed. Over the years, I created the Dynamical Organizations Theory; Openness, Synthesis and Emergence. The ideas and experiences were constantly explored, processes studied and tested, papers (30) and books (2) written, meetings and conferences (48) attended where debates and dialogue deepened.

Freely flowing information and focused conversations on important issues that faced the organization provided the energy for the organization to develop and change. The Process Enneagram© (Knowles, 2002), a powerful complexity tool, helped us to focus and keep track of the conversations. The BOWL, the strange attractor, provided the structure to hold and sustain the organization far from equilibrium where the energy and creativity are greatest. McCarter and White (2013, p. 152) suggest that the Process Enneagram is the "missing link between complexity theory and practical application."

Anything that inhibits the free flow of information hurts the performance of the organization. Leaders must create a safe space for the people to openly share information so they can talk, listen, and learn together, and stamp out disrespectful behaviors like harassment and bullying because they inhibit the free flow of information, keep people apart, and build up like a snowball rolling downhill leading to bigger and bigger problems like injuries and incidents, and, even to suicides and murders. The Bureau of Labor Statistics reported that there were 807 fatal injuries caused by persons or animals (BLS, 2017, p. 2), with 458 homicides and 275 suicides (BLS, 2017, p. 6). These dysfunctional behaviors cost organizations a huge amount in both human suffering and wasted money.

Conclusions

In the years when I was the Plant Manager for the Belle Plant, the changes we made resulted in a sustainable transformation of the total performance (people and facilities).

The use of qualitative and quantitative metrics complimented each other with the qualitative metrics serving as a strong leading indicator of improvement. Building on the combined intuitive leadership experiences of the Belle years with the very diverse consulting years in many different countries and kinds of organizations, the Dynamical Organizations Theory emerged.

Purposeful, focused, continuous, honest, and open conversations and dialogue about issues that are important to the organization are central for the Dynamical Organizations Theory. The leaders need to develop clarity on the vision and mission, be fully engaged, take a stand, set the conditions for a culture of caring and respect for everyone and insist on the open, free flow of information. Then build the BOWL to hold it all. This requires courage, care, concern, and commitment. The Process Enneagram is a powerful, useful, proven complexity tool that enables this to happen.

This retrospective case study provides strong support for the proposition that change occurs one conversation at a time as well as for the validity of Dynamical Organizations Theory: Openness, Synthesis and Emergence.

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