Reducing Uncertainty: A Formal Theory of *Organizations in Action*[1]

Jaap Kamps and László Pólos
University of Amsterdam

Scheduled for publication in:
American Journal of Sociology 104(6):1774–1810, May 1999.

[1]This research was in part supported by the Netherlands Organization for Scientific Research (NWO; grant #PGS 50-334 and #400-20-036) and the Hungarian National Science Foundation (OTKA; grant #I-2258). This article had many drafts: the first was published in 1991 as CCSOM Report 91-35 (Pólos, 1991). We wish to thank the *AJS* reviewers for their insightful comments and Jeroen Bruggeman, Michael Masuch, and Gábor Péli for comments on earlier drafts. All theorems in the article are proved by the automated theorem prover OTTER (Organized Techniques for Theorem-proving and Effective Research; McCune, 1994b); an electronic version of the formulas is available at ⟨`http://www.ccsom.uva.nl/thompson.html`⟩ or from the author. Direct correspondence to Jaap Kamps, Applied Logic Laboratory, Center for Computer Science in Organization and Management, Faculty of Social Sciences (PSCW), Universiteit van Amsterdam, Sarphatistraat 143, 1018 GD Amsterdam, the Netherlands, E-mail: ⟨`kamps@ccsom.uva.nl`⟩.

Abstract

This article presents a formal reconstruction of James D. Thompson's classic contribution to organization theory, *Organizations in Action*. The reconstruction explicates the underlying argumentation structure for Thompson's propositions—literally, theorems or problems to be demonstrated. This allows Thompson's propositions to be derived as theorems in a deductive theory. As it turns out, the formal theory is based on general assumptions using only few primitive concepts. In addition, this theory explains why Thompson's propositions do not hold for noncomplex or "atomic" organizations (a restriction on the domain of application). Furthermore, this study reveals that organizations attempt to reduce constraints in their environment—a heretofore unknown implication of the theory.

1 Introduction

Thompson's *Organizations in Action* was published more than three decades ago but is still one of the classics of organization theory. The book provides a unifying perspective on open- and closed-systems thinking in organization theory that has been recognized as an important contribution in its own right (Scott, 1998). The environment is a key source of uncertainty for an organization, and Thompson argued that much of organizational action can be explained by the need to reduce uncertainty. Consider a specific action such as "buffering" (e.g., building warehouses or storages), aiming to seal off the organization's technical or operational core from environmental uncertainty. The main lines of his arguments always are couched in explicitly formulated propositions but also are brought to life by examples such as the typologies of technologies (long-linked, mediating, or intensive), interdependencies (pooled, sequential, or reciprocal), and coordination (by standardization, by plan, or by mutual adjustment). His typologies have inspired much research in organizational design (Galbraith, 1977) and contingency theory (Mintzberg, 1979). However, despite the impressive number of citations, the book itself is not read much anymore—most students of organization science will only know the book through references.[1] Because of this, the typologies and examples of Thompson are getting more attention than his core ideas, which are captured in the propositions. The aim of this article is to bring Thompson's main ideas back into focus by presenting a logical formalization of his propositions. That is, we will formalize the propositions of *Organizations in Action* in first-order logic and reconstruct the underlying argumentation for them.

Thompson's *Organizations in Action* is a suitable candidate for a formalization attempt in organization and management theory. First, Thompson's theory is formulated using abstract concepts that transcend individual organizations and particular organization types (Zald, 1996). Second, the influential role of *Organizations in Action* ensures that the thinking of quite a number of contemporary scholars is based, at least in part, on ideas presented in this famous book. As a result, the basic assumptions of *Organizations in Action* are likely to turn out to be common assumptions of several organization theories.

In this article, we give an axiomatic reconstruction of the first chapters of *Organizations in Action*. Our main focus is on the second chapter of this book. Arguably, this is the most important chapter of the book since it provides a unifying perspective on rational, closed-systems strategies in an open-systems environment. The article is structured as follows: First, in §2, we will introduce the research methodology of logical formalization; then, in §3 we will apply this method to Thompson's *Organizations in Action*; and finally, in §4, we will review the formal theory of *Organizations in Action* and discuss issues related to our work.

2 Research Methodology: Logical Formalization

Most textbooks on social science research methodology contain chapters on the scientific or logical foundations of social research. Typically, these chapters are used indirectly to provide the background context for discussing social scientific inquiry (Singleton and Straits, 1999). Logical formalization is an attempt to address such issues directly, by rationally reconstructing scientific theories and representing them in formal logic. In recent years, there has been a

[1]The Social Sciences Citation Index lists 145 citations in 1995, 154 in 1996, and 135 in 1997 (Social Sciences Citation Index, 1995, 1996, 1997).

resurgence of interest in logical formalization as a methodology for theory building. The main efforts have been directed at Organizational ecology (Hannan and Freeman, 1977, 1989) including the theory of organizational inertia (Péli et al., 1994; Kamps and Masuch, 1997), life history strategies (Péli and Masuch, 1997), niche width (Bruggeman, 1997; Péli, 1997), and age dependence (Hannan, 1998). These case studies have shown the potential of logical formalization for reconstructing theories (Hannan, 1997).

Logical formalization uses the classical, axiomatic-deductive notion of a theory (Popper, 1959). The premises of a formal theory consist of general statements (universal laws or empirical generalizations, supplemented with definitions) of which the validity is known or assumed. The premises form the axioms or basis of the theory. We distinguish between a *definition*, which introduces a name for a meaningful concept that is expressible in terms of other concepts and an *assumption*, which contains a claim that is known or assumed to hold for the theory's (intended) domain of application.[2] The theorems of a formal theory are those statements that are logical consequences of the set of premises, that is, statements that are necessarily true whenever the premises are true. The theory consists of all the statements that are logical consequences of the set of premises (including the premises because they are trivial consequences of themselves). In any exposition of a theory, there are, apart from the premises, only a small number of salient consequences singled out. We use the following labels: a *theorem*, which is an interesting consequence of a theory because it is a surprising result, or a new testable implication of the theory; a *lemma*, which is a minor theorem—an intermediate result that is used to derive further theorems or lemmas but is of some interest in its own right; and a *corollary*, which is an immediate consequence of a theorem. Theoretical explanations and predictions correspond to deductions of theorems from the set of premises (Popper, 1959).

Formal logic provides a number of strict criteria for theories, such as consistency and soundness of argumentation, which are difficult (if not impossible) to impose on their discursive counterparts.[3] The *consistency* of the formal theory ensures that the theory is free of contradictions. Discursive theories seldom contain conspicuous contradictions, since they are easily obscured by the ambiguity of natural language. When formalizing a theory in logic, these contradictions will surface and can be resolved. The consistency of the theory can be tested by constructing a model (roughly comparable to a case or an example) of the theory. The argumentation for a proposition is *sound* if the proposition is a logical consequence of the premises (i.e., if the proposition is a theorem). If a proposition is not a consequence of the premises, then the argumentation is unsound: the proposition is not a prediction of the theory, and the theory does not explain the proposition's claim. If a proposition is a consequence of the premises, then we know that this prediction of the theory is sound, and premises support a sound argument that explains the proposition. That is, if we consider cases in which the premises hold, then the theorem must also hold (i.e., the theorem is a prediction). Conversely, if we consider cases where the theorem holds, then the premises give an explanation for why the theorem holds. There are also criteria for falsifiability (the existence of a state of affairs that falsifies a theorem or theory) and contingency (theorems

[2]These statements are also called laws or hypotheses depending on the range of evidence for them. We prefer to use the neutral term, assumptions, here.

[3]Tests for these criteria usually result in lengthy derivations. Fortunately, there are several computational tools available that can perform these tests automatically. Details on the use of automated theorem provers and other automated reasoning tools for formal theory building are discussed in (Kamps, 1998). In this article, all proofs are checked by the automated theorem prover OTTER (McCune, 1994b).

that are neither self-contradictory, nor self-contained). In addition, making the underlying argumentation structure of the theory explicit will, in turn, shed light on its explanatory and predictive power, parsimony, and coherence.[4]

3 Thompson's *Organizations in Action*

Organizations in Action provides a unifying framework for both the classical, closed-systems theories and the emerging open-systems theories of organizations. As Thompson writes, "A central purpose of this book is to identify a framework which might link at important points several of the now independent approaches to the understanding of complex organizations" (Thompson, 1967, p.viii).

This framework has survived the test of time remarkably well, that is, the material is part of mainstream organization theory and citations are frequent. In this article, we will mainly focus on the second chapter of *Organizations in Action*. Arguably, the second chapter is the most important one because it provides the crucial link between closed-systems and open-systems strategies. The second chapter starts with one of Thompson's famous typologies, a typology of technologies: *Long-linked technologies* are serial interdependent. Several actions have to be performed in sequence. The prototypical example is an assembly line; *Mediating technologies* are concerned with linking of interdependent customers. Typical examples are commercial banks, insurance firms, and employment agencies; and *Intensive technologies* are crucially dependent upon feedback on their actions. Typical examples are hospitals, construction industry, and military combat teams (Thompson, 1967, pp.15–18).

These three types of technology are increasingly susceptible to environmental influences and are therefore decreasingly faithful approximations of closed-systems strategies. The three variations in technology are introduced merely "to illustrate the propositions we wish to develop" (Thompson, 1967, p.15). These carefully formulated propositions will be the main focus of study in this article, since they capture Thompson's unifying framework. The propositions of the second chapter are listed in table 1.

There has been some debate on the theoretical status of Thompson's propositions. As the editors of a collection of his essays write:

> Unlike some sociologists, Thompson cannot be accused of being "wordy" and of using unnecessary jargon. He uses simple language and got to the point quickly. This is especially true for his major work, *Organizations in Action*. Indeed, the reader sometimes feels Thompson gets to the point too quickly; his parsimonious style sometimes leaves the reader behind. Also, although his work contains numerous propositions, all are not derived from a common set of explicit theoretical concepts and assumptions. In this sense Thompson was not a rigorous deductive theorist. Instead, he introduced concepts and formulated propositions appropriate to the organizational realities he was examining, with little effort to show that

[4]There are alternative ways to investigate the logical status of theories. Sastry (1997) uses simulation to investigate completeness, consistency, and parsimony of a model based on Tushman and Romanelli (1985). The logical formalization of theories and the examination of their models are complementary approaches. If the theory's propositions are proved as theorems like we did in this article, then we have shown that the claim holds for *all* models that satisfy the premises. Alternatively, for refuting predictions of a theory, as Sastry (1997) does, it is sufficient to show one particular model in which the premises of the theory hold, but the prediction does not. Constructing a single model is also sufficient to prove the consistency of the theory.

Table 1: PROPOSITIONS OF THOMPSON'S CHAPTER 2.

Label	Content
Proposition 2.1	Under norms of rationality, organizations seek to seal off their core technologies from environmental influences.
Proposition 2.2	Under norms of rationality, organizations seek to buffer environmental influences by surrounding their technical cores with input and output components.
Proposition 2.3	Under norms of rationality, organizations seek to smooth out input and output transactions.
Proposition 2.4	Under norms of rationality, organizations seek to anticipate and adapt to environmental changes which cannot be buffered or leveled.
Proposition 2.5	When buffering, leveling, and forecasting do not protect their technical cores from environmental fluctuations, organizations under norms of rationality resort to rationing.

Note: All propositions are from (Thompson, 1967, pp.14–24).

> different sets of propositions derived logically from still more general propositions, assumptions, and concepts. (Rushing and Zald, 1976, pp.ix–x)

However, we observed that Thompson's informal argumentation for the propositions suggests an underlying explanatory structure. Therefore, we decided to reconstruct this argumentation in formal logic and build a rigorous deductive theory of *Organizations in Action*. In the rest of this section, we will try to derive Thompson's propositions as theorems in a formal, deductive theory of *Organizations in Action*.

3.1 Complex Organizations

Before we can prove the propositions, we will have to introduce a number of general concepts from Thompson's chapter 1. We will only introduce those concepts from chapter 1 that are necessary for deriving the propositions in further sections. The main ingredient of all organization theories is, obviously, organizations. We use the predicate O for "organizations". For example, $\mathsf{O}(o)$ expresses that o is an organization. We also use a predicate SO for a "suborganization" of an organization. For example, $\mathsf{SO}(o_1, o_2)$ expresses that o_2 is a suborganization of (organization) o_1. A suborganization is a part of the organization (but not all arbitrary parts of an organization are suborganizations).

Organizations in Action is explicitly dealing with "complex organizations". Thompson states that complex organizations are ubiquitous in modern societies and gives several examples: manufacturing firms, hospitals, schools, armies, community agencies (Thompson, 1967, p.3). However, Thompson does not give a definition of complex organizations, nor does he dwell upon differences between complex and other, noncomplex organizations. We will define complex organizations by some of their characteristics, and will discuss in §3.3, below, what noncomplex organizations would look like and why, if they exist, they are exempted from Thompson's theory.

We will use CO for complex organizations. For example, $\mathsf{CO}(o)$ says that o is a complex organization. Thompson gives some structural characteristics of complex organization. He adopts the suggestion of Parsons (1960) that organizations exhibit three distinct levels of responsibility and control: technical, managerial, and institutional. According to Thompson, "every formal organization contains a suborganization whose "problems" are focused around effective performance of the technical function" (Thompson, 1967, p.10). We introduce the predicate TC for the technical or operational core of an organization. For example, $\mathsf{TC}(o, tc)$ says that tc is the technical core of o. We will define complex organizations as exactly those organizations that have a technological suborganization:

Definition 1 *Complex organizations.*
$\forall x\, [\mathsf{CO}(x) \;\leftrightarrow\; \mathsf{O}(x) \wedge \exists y\, [\mathsf{SO}(x,y) \wedge \mathsf{TC}(x,y)]]$
(Read: x is a complex organization if and only if x is an organization and there exists a y such that y is a suborganization of x and y is the technical core of x.)

Thompson uses the notion of a technical core (the transformational or production process) in a general sense that applies to all three types of technologies: long-linked, mediating, and intensive technology (pp.15–18). The core technologies of assembly lines are the processing of material and supervision of these operations. In case of mediating technologies like commercial banks, the core activities are the linking of depositors and borrowers. And in case of intensive technologies like hospitals, core activities are the performance of some specific combination of various skills depending, on the patient's state.

Definition 1 still allows complex organizations to have more than one technical core, although Thompson consistently uses the definite article "the" when referring to an organization's core technologies (p.10). We will explicitly assume that the technical core of an organization can be uniquely determined—complex organizations can only have one technical core.

Assumption 1 *The technical core is unique.*
$\forall x, y, z\, [\mathsf{TC}(x,y) \wedge \mathsf{TC}(x,z) \;\rightarrow\; y = z]$
(Read: if both y and z are the technical core of x, then y is equal to z.)

Assumption 1 ensures that we can talk about *the* technical core of a complex organization. This technical core is the technical suborganization of definition 1, as becomes clear from the following lemma:[5]

Lemma 1 *The technical core of a complex organizations is a suborganization.*
$\forall x, y\, [\mathsf{CO}(x) \wedge \mathsf{TC}(x,y) \;\rightarrow\; \mathsf{SO}(x,y)]$
(Read: if x is a complex organization with core technologies y, then y is a suborganization of x.)

Proof: (Using definition 1 and assumption 1.) By Def. 1, a complex organization has a technical core that is a suborganization. By Ass. 1, an organization can have only one technical core. Therefore, the technical core of a complex organization is a suborganization.

$$
\begin{array}{rcl}
 & \mathsf{CO}(o_1) \wedge \mathsf{TC}(o_1, tc_1) & \text{(by assumption)} \\
\Rightarrow & (\exists tc_2)\ \mathsf{SO}(o_1, tc_2) \wedge \mathsf{TC}(o_1, tc_2) & \text{(by Def. 1)} \\
\Rightarrow & tc_1 = tc_2 & \text{(by Ass. 1)} \\
\Rightarrow & \mathsf{SO}(o_1, tc_1) &
\end{array}
$$

[5]All derived statements are proved using the automated theorem prover OTTER (McCune, 1994b). We will give here only the outline of those proofs: the first lines of the proofs are by assumption, and the meta-implication symbol, $\Rightarrow$, indicates steps in the proof. Most steps involve *modus ponens*: if ϕ holds and ϕ implies ψ, then ψ holds as well.

Lemma 1 is a technicality that will be used in some of the other proofs. It allows us to talk about the technical core of a complex organization by ensuring that the technical core is the specific suborganization of definition 1.

The performance of their core technologies is crucial for organizations. According to Thompson (p.11), "it would therefore be advantageous for an organization subject to criteria of rationality to remove as much uncertainty as possible from its *technical core*." We call this "rational evaluation" and capture this by a predicate, REVA. For example, $\mathsf{REVA}(o, tc)$ expresses that o evaluates tc in terms of technical rationality. As stated above, we assume that core technologies are rationally evaluated:

Assumption 2 *The technical core is rationally evaluated.*
$\forall x, y\, [\mathsf{TC}(x, y) \;\rightarrow\; \mathsf{REVA}(x, y)]$
(Read: if y is the technical core of x, then x will rationally evaluate y.)

Furthermore, if an organization rationally evaluates a particular suborganization, then it will attempt to reduce uncertainty for that suborganization. We introduce a predicate, UC, for uncertainty of a (sub)organization. For example, $\mathsf{UC}(o, u)$ says that o has uncertainty u. We further introduce a predicate, RED, for the reduction. For example, $\mathsf{RED}(o, u, tc)$ expresses that o attempts to reduce u for tc. We can now formulate the assumption that organizations attempt to reduce the uncertainty for suborganizations that are rationally evaluated:

Assumption 3 *Organizations attempt to reduce uncertainty for rationally evaluated suborganizations.*
$\forall x, y, z\, [\mathsf{SO}(x, y) \wedge \mathsf{REVA}(x, y) \wedge \mathsf{UC}(y, z) \;\rightarrow\; \mathsf{RED}(x, z, y)]$
(Read: if y is a suborganization of x, and x rationally evaluates y, and z is the uncertainty of y, then x attempts to reduce uncertainty z for y.)

Using assumptions 2 and 3, we can now derive the following lemma for complex organizations:

Lemma 2 *Complex organizations attempt to reduce uncertainty for their technical cores.*
$\forall x, y, z\, [\mathsf{CO}(x) \wedge \mathsf{TC}(x, y) \wedge \mathsf{UC}(y, z) \;\rightarrow\; \mathsf{RED}(x, z, y)]$
(Read: if x is a complex organization with core technologies y, and z is the uncertainty of y, then x attempts to reduce the uncertainty z for y.)

Proof: (Using lemma 1, and assumptions 2, and 3.) By Lem. 1, the technical core is a suborganization, and by Ass. 2, it is rationally evaluated by the organization. Therefore, by Ass. 3, the organization attempts to reduce uncertainty for the technical core.

$$
\begin{array}{lcl}
 & \mathsf{CO}(o_1) \wedge \mathsf{TC}(o_1, tc_1) \wedge \mathsf{UC}(tc_1, u_1) & \text{(by assumption)} \\
\Rightarrow & \mathsf{SO}(o_1, tc_1) & \text{(by Lem. 1)} \\
\Rightarrow & \mathsf{REVA}(o_1, tc_1) & \text{(by Ass. 2)} \\
\Rightarrow & \mathsf{RED}(o_1, u_1, tc_1) & \text{(by Ass. 3)}
\end{array}
$$

Lemma 2 will be an important part of the argumentation in the rest of this article, because "coping with uncertainty [appears] as the essence of the administrative process" (p.159).

In this section, we introduced the setting for Thompson's proposition by introducing predicates for organizations, O; suborganizations, SO; and core technologies, TC. This led to the defined notion of complex organizations, CO (Def. 1). We assumed that organizations have

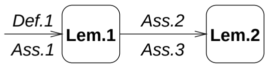

Figure 1: *Reducing uncertainty (structure of the theory 1).*

only one technological suborganization (Ass. 1). We derived that the technical core of a complex organization is a suborganization (Lem. 1; see Fig. 1). We furthermore introduced predicates for uncertainty, UC; for rational evaluation, REVA; and for reduction, RED. We assumed that the performance of their core technologies is crucial for organizations (Ass. 2), and that an organization will attempt to remove as much uncertainty as possible from suborganizations whose performance is rationally evaluated (Ass. 3). We derived that complex organizations attempt to reduce uncertainty for their technical cores (Lem. 2).

3.2 Sealing Off

In this section, we will now try to prove Thompson's first proposition: "organizations seek to seal off their core technologies from environmental influences" (p.19). Before we can give a formal version of this proposition, we have to introduce some more predicates. According to Thompson, organizations are subject to environmental influences. These environmental influences consist of both environmental fluctuations and constraints. Environmental fluctuations are dynamic, they reflect the change of market conditions (such as seasonal demand). Environmental constraints are static restrictions on the organization (such as new legislation). We introduce two predicates, FL and CS, for fluctuations and constraints, respectively. For example, $\mathsf{FL}(tc, f, o)$ says that tc is exposed to a fluctuation f from o, and $\mathsf{CS}(tc, c, o)$ expresses that tc is exposed to a constraint c from o. We define environmental influences, ENVI, to be the general term used for both fluctuations and constraints. For example, $\mathsf{ENVI}(tc, i, o)$ says that tc is exposed to environmental influence i from o.

Definition 2 *Environmental influence.*
$\forall x, y, z\ [\mathsf{ENVI}(x, y, z)\ \leftrightarrow\ \mathsf{FL}(x, y, z) \vee \mathsf{CS}(x, y, z)]$
(Read: x is exposed to an influence y from z if and only if x is exposed to a fluctuation y from z or x is exposed to a constraint y from z.)

Thompson argues that "technologies and environments are major sources of uncertainty for organizations" (p.13). To express that environments cause uncertainty, we use a predicate, C, for causality. For example, $\mathsf{C}(i, u)$ expresses that i causes u.[6] Environmental influences cause uncertainty in the organization:

Assumption 4 *Environmental influences cause uncertainty.*
$\forall x, y, z\ [\mathsf{ENVI}(x, y, z)\ \rightarrow\ \exists v\ [\mathsf{UC}(x, v) \wedge \mathsf{C}(y, v)]]$
(Read: if x is exposed to an environmental influence y from z, then there exists a v such that v is the uncertainty of x, and influence y causes uncertainty v.)

Thompson's use of the term "sealing off" (p.19) corresponds closely to the reduction of uncertainty that is due to an environmental influence. An organization seals a suborganization

[6] Causality is a complex notion with intricate properties. In this article, we do not use any formal property of causality, although we would (at least) consider causality to be transitive (if x causes y and y causes, in turn, z then x causes z: $\forall x, y, z\ [\mathsf{C}(x, y) \wedge \mathsf{C}(y, z)\ \rightarrow\ \mathsf{C}(x, z)]$).

off from an environmental influence if it attempts to reduce the uncertainty caused by this influence. We define a predicate, SEFF, in precisely this way. For example, $\mathsf{SEFF}(o, i, tc)$ expresses that o seals off tc from influence i.

Definition 3 *Sealing off.*
$\forall x, y, z\ [\mathsf{SEFF}(x, y, z)\ \leftrightarrow\ \mathsf{SO}(x, z) \wedge \exists v, w\ [\mathsf{ENVI}(z, y, v) \wedge \mathsf{UC}(z, w) \wedge \mathsf{C}(y, w) \wedge \mathsf{RED}(x, w, z)]]$
(Read: x seals z off from y if and only if z is a suborganization of x, and there exists v and w such that z is exposed to an influence y from v, and y causes uncertainty w of z, and x attempts to reduce w for z.)

We can now prove the following theorem:

Theorem 1 *Complex organizations seal off their core technologies from environmental influences.*
$\forall x, y, z, v\ [\mathsf{CO}(x) \wedge \mathsf{TC}(x, y) \wedge \mathsf{ENVI}(y, z, v)\ \rightarrow\ \mathsf{SEFF}(x, z, y)]$
(Read: if x is a complex organization, and y is the technical core of x, and y is exposed to an influence z from v, then x seals y off from z.)

Proof: (Using lemmas 1 and 2, definition 3, and assumption 4.) By Lem. 1, the technical core is a suborganization. By Ass. 4, an environmental influence causes uncertainty for the technical core. By Lem. 2, complex organizations attempt to reduce this uncertainty for their technical core. Therefore, by Def. 3, the organization is sealing its technical suborganization off from the environmental influence.

$$\begin{array}{lcl} & \mathsf{CO}(o_1) \wedge \mathsf{TC}(o_1, tc_1) \wedge \mathsf{ENVI}(tc_1, e_1, o_2) & \text{(by assumption)} \\ \Rightarrow & \mathsf{SO}(o_1, tc_1) & \text{(by Lem. 1)} \\ \Rightarrow & (\exists u_1)\ \mathsf{UC}(tc_1, u_1) \wedge \mathsf{C}(e_1, u_1) & \text{(by Ass. 4)} \\ \Rightarrow & \mathsf{RED}(o_1, u_1, tc_1) & \text{(by Lem. 2)} \\ \Rightarrow & \mathsf{SEFF}(o_1, e_1, tc_1) & \text{(by Def. 3)} \end{array}$$

This theorem is a formal version of Thompson's proposition 2.1: "Under norms of rationality, organizations seek to seal off their core technologies from environmental influences" (p.19). The phrase "Under norms of rationality" is not explicitly mentioned in the antecedent of theorem 1. These "norms of rationality" seem to underly all propositions, and are reflected in the "rational evaluation" of assumptions 2 and 3, which, by lemma 2, play a role in the argument. The phrase "seek to ..." is captured by the intentional interpretation of the RED predicate: attempt to reduce. Since sealing off is defined in terms of the reduce predicate, it inherits the intentional interpretation.

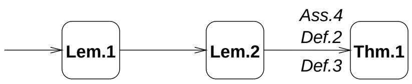

Figure 2: *Sealing off (structure of the theory 2).*

We introduced predicates for environmental fluctuations, FL, and environmental constraints, CS. This led to the defined notion of environmental influence, ENVI (Def. 2). We introduced a predicate for causes, C. We assumed that environmental influences cause uncertainty (Ass. 4). We defined a predicate for sealing off, SEFF (Def. 3), and learned that complex organizations are sealing off their core technologies from environmental influences (Thm. 1; see Fig. 2).

3.3 Beyond Thompson: Atomic Organizations

Thompson does not discuss why he restricts his theory to complex organizations. In this section, we will step away from Thompson's book and try to answer questions like: What would noncomplex organizations look like? Do they exist in the real world? If so, why are they excluded from Thompson's theory? How do they fare in the real world?

We will simply define noncomplex organizations as organizations that are not complex organizations. We baptize such organizations as *atomic organizations* and define a predicate ATO for them: $\mathsf{ATO}(o)$ says that o is an atomic organization.

Definition 4 *Atomic organizations.*
$\forall x\, [\mathsf{ATO}(x) \;\leftrightarrow\; \mathsf{O}(x) \wedge \neg \mathsf{CO}(x)]$
(Read: x is an atomic organization if and only if x is an organization and x is not a complex organization.)

Note that we define ATO in terms of another defined predicate, CO. This is only allowed if it does not lead to circularity. In other words, we must be able to trace back the underlying primitive concepts. This can be done by unfolding the definition of complex organizations (definition 1):

Lemma 3 *Atomic organizations are organizations that have no suborganization as technical core.*
$\forall x\, [\mathsf{ATO}(x) \;\leftrightarrow\; \mathsf{O}(x) \wedge \neg \exists y\, [\mathsf{SO}(x, y) \wedge \mathsf{TC}(x, y)]]$
(Read: x is an atomic organization if and only if x is an organization, and there is no y such that y is a suborganization of x and y is the technical core of x.)

Proof: (Using definitions 1 and 4.) By Def. 4 atomic organizations are organizations that are not complex organizations. Using Def. 1, they are organizations that are either no organizations (which would be a contradiction), or do not have a technical suborganization.

$$
\begin{array}{lcl}
 & \mathsf{ATO}(o_1) & \text{(by assumption)} \\
\Leftrightarrow & \mathsf{O}(o_1) \wedge \neg \mathsf{CO}(o_1) & \text{(by Def. 4)} \\
\Leftrightarrow & \mathsf{O}(o_1) \wedge \neg[\mathsf{O}(o_1) \wedge \exists y\, [\mathsf{SO}(o_1, y) \wedge \mathsf{TC}(o_1, y)]] & \text{(by Def. 1)} \\
\Leftrightarrow & \mathsf{O}(o_1) \wedge [\neg \mathsf{O}(o_1) \vee \neg \exists y\, [\mathsf{SO}(o_1, y) \wedge \mathsf{TC}(o_1, y)]] & \\
\Leftrightarrow & \mathsf{O}(o_1) \wedge \neg \exists y\, [\mathsf{SO}(o_1, y) \wedge \mathsf{TC}(o_1, y)] &
\end{array}
$$

Lemma 3 gives an abstract characterization of atomic organizations: atomic organizations do not have their core technologies grouped in a special suborganization—there is no clear separation between their core technologies and other activities. We can use this characterization to try to identify organization that would be atomic in the sense of Def. 4. There are some examples of organizations that correspond to this abstract characterization. Examples of atomic organizations are small organizations, especially organizations such as family firms that have only very few employees. These small organizations do not have a clear separation between technological and other activities; for example, they are managed by their owners, who are also involved in the technical operations. Although small-sized organizations have not received much attention in the literature, the majority of organizations has only a very limited number of employees, and small organizations occupy a substantial part of the market (Granovetter, 1984). As Granovetter (1984, p.333) notes, "the study of organizations is often taken to be synonymous with the study of "complex organizations"" and "much of what has been done in some otherwise splendid work on the sociology of economic life and complex organizations has proceeded as if the entire waterfront has been covered, when in fact work has concentrated in one important receding pool." Together with small organizations, another example of atomic organizations is new organizations. New enterprise startups usually do not have a fully crystallized management structure; technical and management activities are all performed by the entrepreneur. New organizations involve new roles, which have to be learned (at the cost of inefficiency) (Stinchcombe, 1965). Obviously, new and small organizations show considerable overlap.

Lemma 3, stating that atomic organizations do not have a technological suborganization, still leaves us two possibilities in discussing the technical core of atomic organizations. The first option is to assume that the technical core of atomic organizations does not exist at all.[7] This option has as a result that all statements that involve the technical core do not apply to atomic organizations. The second option is to argue that all organizations, including atomic ones, have certain technologies that constitute the core of their activities. Therefore, it makes sense to talk about the core technologies of any organization. If, as in the case of atomic organizations, these technological activities are not grouped together in a suborganization, we treat the entire organization as its own technical core.

Since Thompson does not discuss noncomplex organizations, we can only speculate on which option to choose. We will pursue the second option because it allows us to further investigate characteristics of atomic organizations. We can implement this option by assuming that if the technical core of an organization is not a suborganization, then it is identical with the organization itself:

Assumption 5 *If the technical core of an organization is not a suborganization, then we treat the whole organization as its technical core.*
$\forall x, y\, [\mathsf{O}(x) \wedge \mathsf{TC}(x,y) \wedge \neg \mathsf{SO}(x,y) \;\rightarrow\; x = y]$
(Read: if x is an organization, and y is the technical core of x, and y is not a suborganization of x, then x and y are identical.)

Assumption 5 gives us indeed the result of the second option:

Lemma 4 *Atomic organizations are identical with their technical core.*
$\forall x, y\, [\mathsf{ATO}(x) \wedge \mathsf{TC}(x,y) \;\rightarrow\; x = y]$
(Read: if x is an atomic organization, and y is the technical core of x, then x and y are identical.)

Proof: (Using lemma 3 and assumption 5.) By Lem. 3, atomic organizations do not have a technical core that is a suborganization, that is, it is either not a suborganization or not a technical core (which would be a contradiction). Therefore, the technical core of an atomic organization is not a suborganization, and by Ass. 5, it follows that the technical core is identical with the atomic organization.

$$\begin{array}{rll} & \mathsf{ATO}(o_1) \wedge \mathsf{TC}(o_1, tc_1) & \text{(by assumption)} \\ \Rightarrow & \mathsf{O}(o_1) \wedge \neg\exists y\, [\mathsf{SO}(o_1,y) \wedge \mathsf{TC}(o_1,y)] & \text{(By Lem. 3)} \end{array}$$

[7] Formally, $\forall x\, [\mathsf{ATO}(x) \;\rightarrow\; \neg\exists y\, [\mathsf{TC}(x,y)]]$.

$$\begin{array}{lcr}
\Rightarrow & \forall y\ [\neg\mathsf{SO}(o_1, y) \vee \neg\mathsf{TC}(o_1, y)] & \\
\Rightarrow & \neg\mathsf{SO}(o_1, tc_1) \vee \neg\mathsf{TC}(o_1, tc_1) & \\
\Rightarrow & \neg\mathsf{SO}(o_1, tc_1) & \\
\Rightarrow & o_1 = tc_1 & \text{(By Ass. 5)}
\end{array}$$

Lemma 4 is the companion of lemma 1, which stated that the technical core of a complex organization is a suborganization. Lemma 4 reiterates that atomic organizations cannot differentiate between their core technologies and other activities: there is no distinction between levels of technical and managerial responsibilities and control.

Now that we have identified the technical core of atomic organizations, we can try to discuss issues relating to its uncertainty. Unfortunately, assumption 4 puts hardly any restriction on uncertainties caused by the environment. Thompson recognized that an organization may be subject to a number of different uncertainties, for example, technological uncertainty and the uncertainty due to influences (Thompson, 1967, p.1). As a result, we cannot represent the uncertainty as a function of the organization because a single organization may be exposed to different influences that cause different uncertainties for it. However, we would want to require something weaker, namely that a single environmental influence will only cause a single uncertainty:

Assumption 6 *A single influence causes a single uncertainty.*
$\forall x, y, z, v, w\ [\mathsf{ENVI}(x, y, z) \wedge \mathsf{UC}(x, v) \wedge \mathsf{C}(y, v) \wedge \mathsf{UC}(x, w) \wedge \mathsf{C}(y, w) \ \rightarrow\ v = w]$
(Read: if x is exposed to an influence y from z, and y causes uncertainty v of x, and y also causes uncertainty w of x, then uncertainty v is equal to uncertainty w.)

This assumption is a restriction on assumption 4, which stated that that an influence will cause uncertainty. This restriction is consistent with Thompson's text. Using assumption 6 we can derive a theorem about atomic organizations:

Theorem 2 *The technical core of an atomic organization faces the same environmental uncertainty as the organization.*
$\forall x, y, z, v, w\ [\mathsf{ATO}(x) \wedge \mathsf{TC}(x, y) \wedge \mathsf{ENVI}(x, v, z) \wedge \mathsf{UC}(x, w) \wedge \mathsf{C}(v, w) \ \rightarrow\ \exists u\ [\mathsf{UC}(y, u) \wedge \mathsf{C}(v, u) \wedge u = w]]$
(Read: if x is an atomic organization with core technologies y, and if x is exposed to an influence v from z, and v causes uncertainty w of x, then there exist uncertainty u of the technical core y, caused by v, and the uncertainty u is equal to the uncertainty w.)

Proof: (Using lemma 4 and assumptions 4 and 6.) By Lem. 4 atomic organizations are identical with their technical cores. Therefore, the technical core faces the same environmental influence as the organization. By Ass. 4, this causes uncertainty of the technical core. Then by Ass. 6, the uncertainty of the technical core is the same as the uncertainty of the organization.

$$\begin{array}{lcr}
 & \mathsf{ATO}(o_1) \wedge \mathsf{TC}(o_1, tc_1) \wedge \mathsf{ENVI}(o_1, e_1, o_2) \wedge \mathsf{UC}(o_1, u_1) \wedge \mathsf{C}(e_1, u_1) & \text{(by assumption)} \\
\Rightarrow & o_1 = tc_1 & \text{(by Lem. 4)} \\
\Rightarrow & \mathsf{ENVI}(tc_1, e_1, o_2) & \\
\Rightarrow & (\exists u_2)\ \mathsf{UC}(tc_1, u_2) \wedge \mathsf{C}(e_1, u_2) & \text{(by Ass. 4)} \\
\Rightarrow & u_2 = u_1 & \text{(by Ass. 6)}
\end{array}$$

Theorem 1 stated that complex organizations seal off their core technologies from environmental influences. Theorem 2, in contrast, states that atomic organizations and their core technologies face the same uncertainty—noncomplex organizations cannot reduce the uncertainty for their technical core.[8] Theorem 2 may help explain the massive failure rates of small organizations (U.S. Small Business Administration, 1985), and of new enterprises—the liability of newness (Freeman et al., 1983; Brüderl et al., 1992; Hannan, 1998). In the case of atomic organizations, an environmental influence causes the same uncertainty on the organizational level as it will on the technical core. As a result, atomic organizations cannot reduce uncertainty for their core technologies. Unlike complex organizations, they have no separate managerial level that can mediate between the technical core and the environment. All the environmental influences that atomic organizations face are faced at equal strength by their core technical activities. As argued before (Perrow, 1986), small organizations are trivial organizations, but nevertheless they do occur in great numbers.

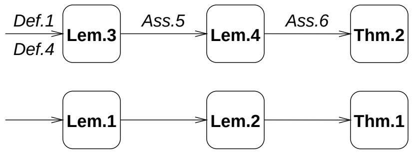

Figure 3: *Atomic organizations (structure of the theory 3).*

In this section, we investigated the possibility of noncomplex organizations. We defined a predicate, ATO, for atomic or noncomplex organizations (Def. 4). Unfolding the definitions of complex (Def. 1) and atomic organizations (Def. 4) characterizes noncomplex organizations as those having no technical suborganization (Lem. 3; see Fig. 3). We assumed that if the technical core of an organization is not a suborganization, then we treat the entire organization as the technical core (Ass. 5). We derived that this is the case for noncomplex organizations (Lem. 4). We assumed that one environmental influence can only cause one type of uncertainty for an organization (Ass. 6), and derived that atomic organizations cannot reduce the uncertainty caused by environmental influences (Thm. 2). This indicates that Thompson's restriction to complex organizations is not an arbitrary one: his propositions do not hold for noncomplex organizations.

3.4 Buffering and Anticipating

After the *intermezzo* of the §3.3, we will continue with our formalization of Thompson's arguments. In this section, we try to prove a formal version of Thompson's second proposition: "organizations seek to buffer environmental influences" (Thompson, 1967, p.20), and his fourth proposition: "organization seek to anticipate and adapt to environmental changes" (p.21).

Theorem 1 in §3.2 stated that complex organizations attempt to seal off their core technologies from environmental influences. This suggests that complex organizations have some sort of control over influences directed at their (technical) suborganizations. We introduce a

[8]Theorem 2 states that the uncertainties on the organizational level and on the technological level are really identical. It would not be rational of an atomic organization to attempt to reduce the uncertainties within the organization because such an attempt must fail.

predicate, HC, for "having control." For example, $\mathsf{HC}(o, i)$ says that o has control over i. We assume that organizations have some control over environmental influences directed at their suborganizations:

Assumption 7 *Organizations have control over environmental influences on their suborganizations.*
$\forall x, y, z, v\ [\mathsf{O}(x) \wedge \mathsf{SO}(x, y) \wedge \mathsf{ENVI}(y, z, v)\ \rightarrow\ \mathsf{HC}(x, z)]$
(Read: if x is an organization, and y is a suborganization of x, and y is exposed to an influence z from v, then x has control over z.)

The idea is that organizations mediate between the environment and suborganizations like the technical core (Thompson, 1967, p.11). Note an organization does not necessarily have *complete* control over such an environmental influence; it just means that the organization can undertake some actions that will reduce the influence (but which may not eliminate it completely). In the rest of this section, we will discuss some concrete actions for reducing uncertainty.

Next, we assume that if organizations attempt to reduce something (such as uncertainty), and they have some control over one of its causes, then they will also attempt to reduce this cause:

Assumption 8 *If an organization attempts to reduce something, and has control over a cause of it, the organization will attempt to reduce the cause.*
$\forall x, y, z, v\ [\mathsf{RED}(x, y, z) \wedge \mathsf{C}(v, y) \wedge \mathsf{HC}(x, v)\ \rightarrow\ \mathsf{RED}(x, v, z)]$
(Read: if x attempts to reduce y for z, and v causes y, and x has control over v, then x attempts to reduce v for z.)

This assumption presupposes the organizational rationality that a reduction of the cause will result in a reduction of the effect. As Thompson writes, "Instrumental action is rooted on the one hand in desired outcomes and on the other hand in beliefs about cause/effect relationships" (p.14). We can now derive the following theorem:

Theorem 3 *Complex organizations attempt to reduce environmental influences for their core technologies.*
$\forall x, y, z, v\ [\mathsf{CO}(x) \wedge \mathsf{TC}(x, y) \wedge \mathsf{ENVI}(y, z, v)\ \rightarrow\ \mathsf{RED}(x, z, y)]$
(Read: if x is a complex organization, and y is the technical core of x, and y is exposed to an influence z from v, then x attempts to reduce z for y.)

Proof: (Using lemmas 1 and 2, definition 1, and assumptions 4, 7, and 8.) By Def. 1, complex organizations are organizations, and by Lem. 1 the technical core is a suborganization. By Ass. 4, an environmental influence causes uncertainty for the technical core. By Lem. 2, complex organizations attempt to reduce uncertainty for their technical core. Thus, by Ass. 7, organizations have control over the influences on their suborganizations. Therefore, by Ass. 8, organizations attempt to reduce this environmental influence for their technical core.

$$
\begin{array}{cll}
 & \mathsf{CO}(o_1) \wedge \mathsf{TC}(o_1, tc_1) \wedge \mathsf{ENVI}(tc_1, e_1, o_2) & \text{(by assumption)} \\
\Rightarrow & \mathsf{O}(o_1) & \text{(by Def. 1)} \\
\Rightarrow & \mathsf{SO}(o_1, tc_1) & \text{(by Lem. 1)} \\
\Rightarrow & (\exists u_1)\ \mathsf{UC}(tc_1, u_1) \wedge \mathsf{C}(e_1, u_1) & \text{(by Ass. 4)}
\end{array}
$$

$$
\begin{array}{lcl}
\Rightarrow & \mathsf{RED}(o_1, u_1, tc_1) & \text{(by Lem. 2)} \\
\Rightarrow & \mathsf{HC}(o_1, e_1) & \text{(by Ass. 7)} \\
\Rightarrow & \mathsf{RED}(o_1, e_1, tc_1) & \text{(by Ass. 8)}
\end{array}
$$

The impact of this theorem becomes more clear in its specific predictions for the two types of environmental influences: fluctuations and constraints. The reduction of environmental fluctuations by an organization is called "buffering" in Thompson: "buffering absorbs environmental fluctuations" (p.21). We define a predicate, BUF, for buffering. For example, $\mathsf{BUF}(o, f, tc)$ says that o is buffering fluctuation f for tc.

Definition 5 *Buffering.*
$\forall x, y, z\ [\mathsf{BUF}(x, y, z) \ \leftrightarrow\ \mathsf{SO}(x, z) \wedge \mathsf{FL}(z, y, x) \wedge \mathsf{RED}(x, y, z)]$
(Read: x buffers y for z if and only if z is a suborganization of x, and z is exposed to a fluctuation y from x, and x attempts to reduce y for z.)

Typical examples of buffering are the stockpiling of materials and supplies, and the maintaining of warehouse inventories (p.20). We now have the following corollary:

Corollary 1 (of theorem 3) *Complex organizations buffer environmental fluctuations for their core technologies.*
$\forall x, y, z\ [\mathsf{CO}(x) \wedge \mathsf{TC}(x, y) \wedge \mathsf{FL}(y, z, x) \ \rightarrow\ \mathsf{BUF}(x, z, y)]$
(Read: if x is a complex organization, and y is the technical core of x, and y is exposed to a fluctuation z from x, then x buffers z for y.)

Proof: Using theorem 3, lemma 1, and definitions 2, and 5.

$$
\begin{array}{lcl}
 & \mathsf{CO}(o_1) \wedge \mathsf{TC}(o_1, tc_1) \wedge \mathsf{FL}(tc_1, e_1, o_1) & \text{(by assumption)} \\
\Rightarrow & \mathsf{SO}(o_1, tc_1) & \text{(by Lem. 1)} \\
\Rightarrow & \mathsf{ENVI}(tc_1, e_1, o_1) & \text{(by Def. 2)} \\
\Rightarrow & \mathsf{RED}(o_1, e_1, tc_1) & \text{(by Thm. 3)} \\
\Rightarrow & \mathsf{BUF}(o_1, e_1, tc_1) & \text{(by Def. 5)}
\end{array}
$$

This corollary is a formal version of Thompson's proposition 2.2: "Under norms of rationality, organizations seek to buffer environmental influences by surrounding their technical cores with input and output components" (p.20).

The theorem also makes a specific prediction in case of environmental constraints. The reduction of environmental constraints by an organization is called "anticipating and adapting" or "forecasting" in Thompson: "To the extent that environmental fluctuations can be anticipated, however, they can be treated as **constraints** on the technical core" (p.22). We define a predicate, ANA, for anticipating and adapting. For example, $\mathsf{ANA}(o, c, tc)$ says that o is anticipating and adapting to constraint c for tc.

Definition 6 *Anticipating and adapting.*
$\forall x, y, z\ [\mathsf{ANA}(x, y, z) \ \leftrightarrow\ \mathsf{SO}(x, z) \wedge \mathsf{CS}(z, y, x) \wedge \mathsf{RED}(x, y, z)]$
(Read: x anticipates and adapts to y for z if and only if z is a suborganization of x, and z is exposed to a constraint y from x, and x attempts to reduce y for z.)

Anticipation and adaptation typically involves the reallocation of resources according to the forecasted market demand or supply constraints. This gives rise to another corollary:

Corollary 2 (of theorem 3) *Complex organizations anticipate and adapt to an environmental constraint for their core technologies.*
$\forall x, y, z\ [\mathsf{CO}(x) \wedge \mathsf{TC}(x, y) \wedge \mathsf{CS}(y, z, x)\ \rightarrow\ \mathsf{ANA}(x, z, y)]$
(Read: if x is a complex organization, and y is the technical core of x, and y is exposed to a constraint z from x, then x anticipates and adapts to z for y.)

Proof: Using theorem 3, lemma 1, and definitions 2, and 6.

$$
\begin{array}{lcl}
 & \mathsf{CO}(o_1) \wedge \mathsf{TC}(o_1, tc_1) \wedge \mathsf{CS}(tc_1, e_1, o_1) & \text{(by assumption)} \\
\Rightarrow & \mathsf{SO}(o_1, tc_1) & \text{(by Lem. 1)} \\
\Rightarrow & \mathsf{ENVI}(tc_1, e_1, o_1) & \text{(by Def. 2)} \\
\Rightarrow & \mathsf{RED}(o_1, e_1, tc_1) & \text{(by Thm. 3)} \\
\Rightarrow & \mathsf{ANA}(o_1, e_1, tc_1) & \text{(by Def. 6)}
\end{array}
$$

This corollary is a formal version of Thompson's proposition 2.4: "Under norms of rationality, organizations seek to anticipate and adapt to environmental changes which cannot be buffered or leveled" (p.21).

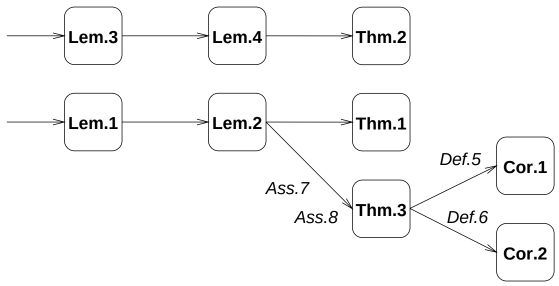

Figure 4: *Buffering and anticipating (structure of the theory 4).*

We have introduced a predicate for "having control," HC, and assumed that organizations have (some) control over environmental influences on their suborganizations (Ass. 7). We further assumed that if organizations have control over the cause of something they want to reduce, they will attempt to reduce this cause (Ass. 8), and we derived that complex organizations attempt to reduce environmental influences for their technical cores (Thm. 3; see Fig. 4). We defined buffering as the reduction of fluctuations, BUF (Def. 5), defined anticipating and adapting as the reduction of constraints, ANA (Def. 6), and derived that complex organizations will buffer environmental fluctuations (Cor. 1) and anticipate and adapt to environmental constraints (Cor. 2).

3.5 Smoothing or Leveling

In this section, we attempt to derive a formal version of Thompson's third proposition: "organizations seek to smooth out input and output transactions" (p.21). According to Thompson, organizations also attempt to reduce fluctuations in the environment (p.21). Apparently, organization have some control over specific elements of their environment. We define a predicate,

CEE, for controlled elements in the environment. For example, $\mathsf{CEE}(o_1, o_2)$ says that o_2 is an element in the environment of o_1 over which o_1 has some control:[9]

Definition 7 *Controlled environmental elements.*
$\forall x, y\ [\mathsf{CEE}(x, y)\ \leftrightarrow\ \mathsf{O}(x) \wedge \forall z\ [\mathsf{ENVI}(x, z, y)\ \rightarrow\ \mathsf{HC}(x, z)]]$
(Read: y is an element in x's controlled environment if and only if x is an organization, and for all z such that x is exposed to an influence z from y it is the case that x has control over z.)

This definition, again, does not imply that organizations have unilateral control over other elements in their environment, the amount of control may be limited. Using this definition, we can now derive:

Theorem 4 *Complex organizations attempt to reduce environmental influences in their controlled environment for their technical core.*
$\forall x, y, z, v, w\ [\mathsf{CO}(x) \wedge \mathsf{TC}(x, y) \wedge \mathsf{ENVI}(y, z, x) \wedge \mathsf{CEE}(x, v) \wedge \mathsf{ENVI}(x, w, v) \wedge \mathsf{C}(w, z)\ \rightarrow\ \mathsf{RED}(x, w, y)]$
(Read: if x is a complex organization, and y is the technical core of x, and y is exposed to an influence z from x, and v is in the controlled environment of x, and x is exposed to an influence w from v, and w causes z, then x attempts to reduce w for y.)

Proof: (Using theorem 3, definition 7, and assumption 8.) By Thm. 3, complex organizations reduce environmental influences for their technical core. If this environmental influence is caused by another environmental influence on an element of the controlled environment of the organization, then, by Def. 7, the organization has some control over the second influence. Therefore, by Ass. 8 the organization will attempt to reduce the second influence for the organization.

$$
\begin{array}{lcl}
 & \mathsf{CO}(o_1) \wedge \mathsf{TC}(o_1, tc_1) \wedge \mathsf{ENVI}(tc_1, e_1, o_1) \wedge \mathsf{CEE}(o_1, o_2) & \\
 & \wedge \mathsf{ENVI}(o_1, e_2, o_2) \wedge \mathsf{C}(e_2, e_1) & \text{(by assumption)} \\
\Rightarrow & \mathsf{RED}(o_1, e_1, tc_1) & \text{(by Thm. 3)} \\
\Rightarrow & \mathsf{HC}(o_1, e_2) & \text{(by Def. 7)} \\
\Rightarrow & \mathsf{RED}(o_1, e_2, tc_1) & \text{(by Ass. 8)}
\end{array}
$$

We will investigate the impact of this theorem by considering the specific predictions it makes for environmental fluctuations. Thompson uses the term "smoothing" for the reduction of fluctuations in the environment: "smoothing or leveling involves attempts to reduce fluctuations in the environment" (p.21). We define a predicate, SM, for smoothing. For example, $\mathsf{SM}(o, f, tc)$ says that o smoothes f for tc:

Definition 8 *Smoothing.*
$\forall x, y, z\ [\mathsf{SM}(x, y, z)\ \leftrightarrow\ \mathsf{SO}(x, z) \wedge \exists v\ [\mathsf{FL}(x, y, v) \wedge \mathsf{RED}(x, y, z)]]$
(Read: x smoothes y for z if and only if z is a suborganization of x, and there exists a v such that x is exposed to a fluctuation y from v, and x attempts to reduce y for z.)

A typical example of smoothing is price mechanisms: by charging premiums during peak periods and inducements during slow periods (p.21). Note the difference between buffering and smoothing: buffering concerns the reduction of fluctuations within an organization,

[9] We wish to thank the reviewer who pointed out a deficiency in an earlier version of this definition.

whereas smoothing concerns the reduction of fluctuation in the environment. We now have the following corollary:

Corollary 3 (of theorem 4) *Complex organizations smooth environmental fluctuations in their controlled environment for their technical core.*
$\forall x, y, z, v, w\ [\mathsf{CO}(x) \wedge \mathsf{TC}(x, y) \wedge \mathsf{FL}(y, z, x) \wedge \mathsf{CEE}(x, v) \wedge \mathsf{FL}(x, w, v) \wedge \mathsf{C}(w, z) \ \rightarrow\ \mathsf{SM}(x, w, y)]$
(Read: if x is a complex organization, and y is the technical core of x, and y is exposed to a fluctuation z from x, and v is in the controlled environment of x, and x is exposed to a fluctuation w from v, and w causes z, then x smoothes w for y.)

Proof: Using theorem 4, lemma 1 and definitions 2 and 8.

$$\begin{array}{llr}
 & \mathsf{CO}(o_1) \wedge \mathsf{TC}(o_1, tc_1) \wedge \mathsf{FL}(tc_1, e_1, o_1) \wedge \mathsf{CEE}(o_1, o_2) & \\
 & \quad \wedge \mathsf{FL}(o_1, e_2, o_2) \wedge \mathsf{C}(e_2, e_1) & \text{(by assumption)} \\
\Rightarrow & \mathsf{ENVI}(tc_1, e_1, o_1) \wedge \mathsf{ENVI}(o_1, e_2, o_2) & \text{(by Def. 2)} \\
\Rightarrow & \mathsf{RED}(o_1, e_2, tc_1) & \text{(by Thm. 4)} \\
\Rightarrow & \mathsf{SO}(o_1, tc_1) & \text{(by Lem. 1)} \\
\Rightarrow & \mathsf{SM}(o_1, e_2, tc_1) & \text{(by Def. 8)}
\end{array}$$

This corollary is a formal version of proposition 2.3 in Thompson: “Under norms of rationality, organizations seek to smooth out input and output transactions” (p.21).

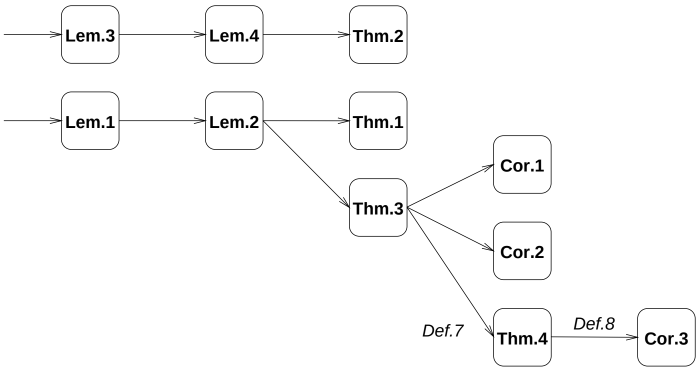

Figure 5: *Smoothing (structure of the theory 5).*

In the above section, we have defined predicates for “controlled environmental element,” CEE (Def. 7), and for smoothing, SM (Def. 8). We derived that complex organizations attempt to reduce environmental influences in their controlled environment (Thm. 4; see Fig. 5). In particular, we derived that complex organizations attempt to smooth out fluctuations in their controlled environment (Cor. 3).

3.6 Beyond Thompson: Negotiating

After proving a corollary on the reduction of fluctuations in the environment (Cor. 3), we come across an interesting question: What about the reduction of constraints in the environment? Thompson discusses propositions for both the reduction of fluctuations and the reduction of constraints in the organization but only discusses one proposition for the reduction of fluctuations in the environment (see Table 2). Can complex organizations, analogous to the

Table 2: REDUCTION OF CONSTRAINTS IN THE ENVIRONMENT?

	In the Organization	In the Environment
Fluctuations	Buffering (Cor. 1)	Smoothing (Cor. 3)
Constraints	Anticipating and adapting (Cor. 2)	...

reduction of fluctuations, also reduce constraints in the environment? The general theorem about the reduction of influences in the environment, theorem 4, suggests that this is the case. Since there is no corresponding proposition in Thompson, we will define a new concept that treats the reduction of constraints in the environment. This term is related to the anticipation and adaptation of definition 6. The difference is that in case of anticipating and adapting the reduction of constraints takes place within the organization, whereas here the reduction of constraints takes place in the environment. For want of a better term, we call the reduction of constraints in the environment "negotiating" and define a predicate, NEG, for it. For example, $\mathsf{NEG}(o, c, tc)$ says that o negotiates c for tc:

Definition 9 *Negotiating.*
$\forall x, y, z\ [\mathsf{NEG}(x, y, z) \ \leftrightarrow\ \mathsf{SO}(x, z) \wedge \exists v\ [\mathsf{CS}(x, y, v) \wedge \mathsf{RED}(x, y, z)]]$
(Read: x negotiates y for z if and only if z is a suborganization of x, and there exists a v such that x is exposed to a constraint y from v, and x attempts to reduce y for z.)

The definition of negotiating does not restrict the domain of the theory, it only defines NEG as shorthand for the reduction of constraints in the environment, allowing us to formulate statements more concisely.

The corollaries about buffering, smoothing, and anticipating and adapting are claims of Thompson (propositions 2.2, 2.3, and 2.4 respectively). A corollary about negotiating is not mentioned in Thompson but would complete the four logical possibilities to reduce fluctuations and constraints within organizations and within the environment (see Table 2). Using the same set of assumptions used to derive versions of the other propositions, we can derive the following corollary:

Corollary 4 (of theorem 4) *Complex organizations negotiate environmental constraints in their controlled environment for their technical core.*
$\forall x, y, z, v, w\ [\mathsf{CO}(x) \wedge \mathsf{TC}(x, y) \wedge \mathsf{CS}(y, z, x) \wedge \mathsf{CEE}(x, v) \wedge \mathsf{CS}(x, w, v) \wedge \mathsf{C}(w, z) \ \rightarrow\ \mathsf{NEG}(x, w, y)]$
(Read: if x is a complex organization, and y is the technical core of x, and y is exposed to a constraint z from x, and v is in the controlled environment of x, and x is exposed to a constraint w from v, and w causes z, then x negotiates w for y.)

Proof: Using theorem 4, lemma 1 and definitions 2 and 9.

$$
\begin{array}{llr}
 & \mathsf{CO}(o_1) \wedge \mathsf{TC}(o_1, tc_1) \wedge \mathsf{CS}(tc_1, e_1, o_1) \wedge \mathsf{CEE}(o_1, o_2) & \\
 & \quad \wedge \mathsf{CS}(o_1, e_2, o_2) \wedge \mathsf{C}(e_2, e_1) & \text{(by assumption)} \\
\Rightarrow & \mathsf{ENVI}(tc_1, e_1, o_1) \wedge \mathsf{ENVI}(o_1, e_2, o_2) & \text{(by Def. 2)} \\
\Rightarrow & \mathsf{RED}(o_1, e_2, tc_1) & \text{(by Thm. 4)}
\end{array}
$$

$$\Rightarrow \quad \mathsf{SO}(o_1, tc_1) \quad \text{(by Lem. 1)}$$
$$\Rightarrow \quad \mathsf{NEG}(o_1, e_2, tc_1) \quad \text{(by Def. 9)}$$

Although there is no corresponding proposition in Thompson (1967), this corollary follows from exactly the same assumptions that we used to derive the other theorems. Negotiation is a hitherto unknown implication of the theory: the theory predicts that organizations negotiate constraints in their environment.

The discovery of a new prediction of the theory gives us a new possibility for the empirical testing of the theory. If the empirical evidence supports the prediction of the theory, our confidence in the theory is strengthened. If, on the other hand, the prediction is not conform to the empirical evidence, we have falsified the theory. That is, we have at least falsified our formal reconstruction of it. We will discuss the new prediction in the light of some recent findings reported in the literature.

Can we be more specific about what "negotiating" in the sense of corollary 4 means? Negotiating is defined as attempts to reduce constraints in the environment. As a result, the reduction of constraints in the environment has an effect for all organizations that are subject to this constraint. All these organizations share the benefits of the reduction and therefore have a collective interest in reducing the constraint in the environment. For the prototypical example of a constraint, new legislation, this would mean that organizations will attempt to reduce the effects of legislation. We actually find support for such a claim in recent empirical findings on legalization (Edelman, 1992; Sutton et al., 1994; Sutton and Dobbin, 1996). These studies investigate the introduction of equal employment opportunity and affirmative action (EEO/AA) laws. Their main finding is that organizations can collectively mediate the impact of these laws. "Such laws set in motion a process of definition during which organizations test and collectively construct the form and boundaries of compliance in a way that meets legal demands yet preserves managerial interests" (Edelman, 1992, p.1532). This presents a clear case in which organizations successfully reduce environmental uncertainty by what we termed negotiating. Although negotiating is an implicit consequence of Thompson, it is not an unknown topic in organization theory. Finding this new prediction increases our confidence in Thompson's theory and in our formal interpretation of it.

Note that negotiating is defined as the action of individual organizations. However, consider what happens if more than one organization is facing the same environmental constraint. In that case, corollary 4 predicts that all these organizations will attempt to reduce this constraint in the environment.[10] The NEG predicate captures the rationality of individual organizations to engage in a (collective) attempt to reduce a constraint in the environment. Of course, whether such an attempt is successful may very well depend on the proportion of organizations participating in these attempts.

In this section, we defined NEG, a predicate for negotiating (Def. 9). Negotiating is not mentioned in Thompson but can be defined in analogy with smoothing (Def. 8). A corollary on negotiation (Cor. 4; see Fig. 6) can be derived from the same set of assumptions used for deriving the other theorems. This concludes our formal theory of *Organizations in Action.*

[10] For example, we can derive for the case of two organizations subject to the same constraint:
$\forall x_1, x_2, y_1, y_2, z_1, z_2, v, w\ [\mathsf{CO}(x_1) \land \mathsf{TC}(x_1, y_1) \land \mathsf{CS}(y_1, z_1, x_1) \land \mathsf{CEE}(x_1, v) \land \mathsf{CS}(x_1, w, v) \land \mathsf{C}(w, z_1) \land \mathsf{CO}(x_2) \land \mathsf{TC}(x_2, y_2) \land \mathsf{CS}(y_2, z_2, x_2) \land \mathsf{CEE}(x_2, v) \land \mathsf{CS}(x_2, w, v) \land \mathsf{C}(w, z_2) \ \rightarrow\ \mathsf{NEG}(x_1, w, y_1) \land \mathsf{NEG}(x_2, w, y_2)]$
by two applications of corollary 4, and so on.

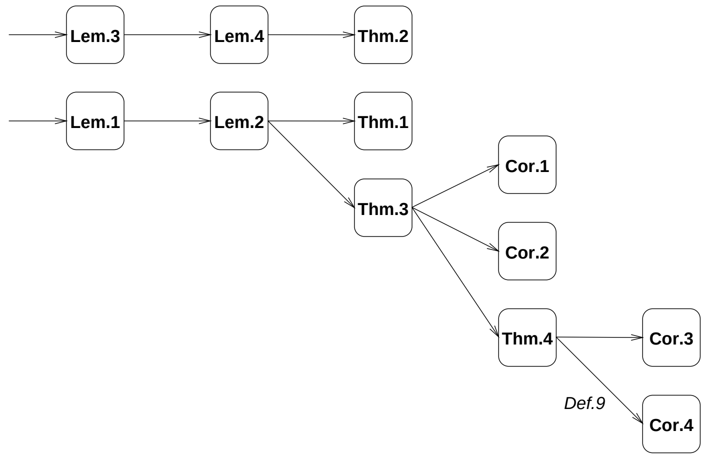

Figure 6: *Negotiating (structure of the theory 6).*

We derived formal versions of four of the five propositions in chapter 2 from general axioms of organization theory.

4 Discussion and Conclusions

We review the formal theory of *Organizations in Action* by the criteria introduced in §2: consistency, soundness, parsimony, coherence, and explanatory and predictive power

Consistency and soundness The main benefit of formal theories is that they provide clarity, both about the theory's propositions and about its argumentation structure. We have disambiguated the theory's natural language formulation by coding it in a formal language. The formal theory contains explicit definitions of complex organizations, sealing off, buffering, anticipating and adapting, and smoothing. Apart from giving a formal and precise formulation of the propositions, we also managed to trace back the argumentation for these propositions by finding reasonable and sufficient underlying assumptions. The formal theory is consistent.[11] All lemma's, theorems, and corollaries in §3 are sound consequences of the premises. The proofs give sound explanations for the claims and show that the claims are unavoidable consequences of the premises.

Parsimony and coherence In the formal theory of *Organizations in Action*, we used the predicates listed in Table 3. The theory is parsimonious because it uses only ten primitive predicates or concepts. In a formal theory, there is a clear distinction between primitive concepts and concepts that are defined in terms of the primitive concepts. A defined concept can be eliminated from the theory by replacing the concept with the expression it stands for. Note that we may only use defined concepts in the definition of other concepts if this does

[11] A formal theory is consistent if it has a model. There are computer programs currently available that generate models of a formal theory. Formally, such a model is an interpretation function that assigns objects of the domain to the constants, functions, and predicates of the theory. We used Mace (Models And Counter-Examples; McCune, 1994a) to generate such a model (and thereby proved the consistency of the theory). Technical details are available upon request from the authors.

Table 3: NOTATION USED IN THE FORMAL THEORY.

Predicate	Meaning
Primitive:	
$\mathsf{O}(o)$	o is an organization
$\mathsf{SO}(o, so)$	so is a suborganization of o
$\mathsf{TC}(o, tc)$	tc is the technical core of o
$\mathsf{REVA}(o, tc)$	o rationally evaluates tc
$\mathsf{UC}(o, u)$	o has uncertainty u
$\mathsf{RED}(o, i, tc)$	o attempts to reduce i for tc
$\mathsf{FL}(tc, f, o)$	tc is exposed to a fluctuation f from o
$\mathsf{CS}(tc, c, o)$	tc is exposed to a constraint c from o
$\mathsf{C}(i, u)$	i causes u
$\mathsf{HC}(o, i)$	o has control over i
Defined:	
$\mathsf{CO}(o)$	o is a complex organization
$\mathsf{ENVI}(tc, i, o)$	tc is exposed to an influence i from o
$\mathsf{SEFF}(o, i, tc)$	o seals off tc from i
$\mathsf{ATO}(o)$	o is an atomic organization
$\mathsf{BUF}(o, f, tc)$	o buffers f for tc
$\mathsf{ANA}(o, c, tc)$	o anticipates and adapts to c for tc
$\mathsf{CEE}(o_1, o_2)$	o_2 is in o_1's controlled environment
$\mathsf{SM}(o, f, tc)$	o smoothes f for tc
$\mathsf{NEG}(o, c, tc)$	o negotiates c for tc

not lead to circularity.[12] The nine defined predicates do not affect the theory's parsimony because they can be substituted for by their definiens (and the same theorems would still be derivable). The ten primitive predicates are general notions of organization theory (see Table 3).

The assumptions characterize the application domain of the theory: the theory applies to all domains that satisfy the assumptions.[13] Our reconstruction revealed that Thompson's argumentation is largely based on fairly basic assumptions of organization theory. We used only eight assumptions and two of them (Ass. 5 and 6) are only used for our discussion of noncomplex organizations. The underlying assumptions are general assumptions about organizations. As a result, the formal theory of *Organizations in Action* is a general theory, and the axiomatic structure of the theory facilitates further extension.

The argumentation structure of the theory was shown in Figure 6 in §3.6. The theory consists of two parts: a part about noncomplex organizations (lemmas 3 and 4, and theorem 2) and a part about complex organizations (roughly comparable to Thompson's propositions). Both parts are related by definition 4, which defines the notion of atomic organizations as the complement of complex organizations. There are four possible actions that organizations can perform in order to seal off their technical cores from environmental influences (see Table 2 in §3.6). Furthermore, we showed that buffering (corollary 1) and anticipating and adapting (corollary 2) are corollaries of a more general theorem about the reduction of environmental influences in the organization (theorem 3). Similarly, smoothing (corollary 3) and negotiating

[12]It is impossible to define all the concepts of a theory: if all concepts were defined in terms of the other concepts, then some of the definitions have to be circular.

[13]The definitions are only important for determining the meaning of the defined predicates used in the assumptions (in our case only definition 2, the definition of environmental influences).

(corollary 4) are corollaries of a more general theorem about the reduction of influences in the environment (theorem 4). As a result, the (formal) theory of *Organizations in Action* is a coherent theory.

Explanatory and predictive power When comparing the theorems of our formal theory with the propositions in the original text, there are some notable differences. We did provide formal versions of Thompson's propositions 2.1, 2.2, 2.3, and 2.4. However, we did not give a formal version of proposition 2.5: "When buffering, leveling, and forecasting do not protect their technical cores from environmental fluctuations, organizations under norms of rationality resort to rationing" (Thompson, 1967, p.23). Thompson's propositions 2.1 through 2.4 concern only environmental uncertainty—they all treat the reduction of environmental influences. Proposition 2.5 about rationing, in contrast, treats the reduction of the *effects* of environmental influences. In chapter 2 of *Organizations in Action*, Thompson only tells *when* organizations resort to rationing: namely, when buffering, leveling (smoothing), and forecasting (anticipating and adapting) do not protect the technical core. However, he does not explain *why* organizations resort to rationing. This explanation requires more detailed knowledge about the technological dependencies and the uncertainty caused by these dependencies. That is, explaining *why* organizations resort to rationing requires material properly contained in the other chapters of *Organizations in Action* (notably chapter 5 on the interdependence of components). Without including the further chapters, we are unable to explain why organizations resort to rationing, since: "Rationing is an unhappy solution, for its use signifies that the technology is not operating at its maximum" (p.23).

The formal theory identifies a number of unknown consequences of Thompson's theory. Thompson (1967) does not discuss noncomplex or atomic organizations explicitly, although he formulates his propositions for complex organizations. Atomic organizations form an interesting special case because they are more vulnerable to environmental influences. We proved that atomic organizations face the same uncertainty as their technical cores (theorem 2). Consequently, atomic organizations cannot comply with one of the main principles of "organizational rationality" as advocated by Thompson. The explicit treatment of atomic organizations is important because it gives an explanation for the fact that organizations embed their core technologies in managerial activities. These managerial activities negotiate between the technical suborganization and those who use its products. Without them, the organization would be an atomic organization and therefore open and unprotected to any environmental influence. Having a managerial level allows complex organizations to seal off their core technologies from environmental influences (theorem 1 and proposition 2.1 in Thompson). We also proved that organizations can attempt to reduce environmental uncertainty by reducing constraints in the environment, which we termed negotiating (corollary 4). Negotiating is not mentioned in Thompson but completes the four logical possibilities to reduce fluctuations and constraints within the organization and in the environment. Negotiating is a hitherto unknown implication of Thompson's theory. In other words, the theory predicts that organizations attempt reduce constraints in their environment. This negotiating is not an unknown topic in organization theory: recent empirical findings on legalization (Edelman, 1992; Sutton et al., 1994; Sutton and Dobbin, 1996) describe how organizations can (collectively) negotiate the impact of constraints in the environment.

4.1 Related and further research

We started this article by arguing that, although Thompson's theory remains influential, it seems to have lost much of its cachet. Recent literature focuses on alternative theories for explaining the complex relation between organizations and their environment, such as new institutionalism (Powell and DiMaggio, 1991) and organizational ecology (Hannan and Freeman, 1989). The feeling that Thompson's theory still has much to offer to contemporary scholars inspired us to conduct the formal analysis reported in this article.

The formal theory of *Organizations in Action* presented in this article is an axiomatic theory in which the underlying assumptions are made explicit.[14] Discussing these underlying assumptions allows us to make comparisons with other theories in organization theory. We used eight assumptions. Assumption 1 postulates the uniqueness of the technical core. This captures some of the background knowledge that had to be made explicit in order to derive the theorems. The assumption is a technicality that makes the notion of technical core more clear. The first major premises, assumptions 2 and 3, capture some the rationality principles underlying Thompson's theory. Assumption 2 states that the performance of the technical core is rationally evaluated, and assumption 3 states that organizations attempt to reduce uncertainty for rationally evaluated suborganizations. It is the engine of the theory: all the explanations of the formal theory depend on it. As Thompson (1967, p.159) states: "Uncertainty appears as the fundamental problem for complex organizations, and coping with uncertainty, as the essence of the administrative process." These two assumptions capture the core of Thompson's argument and seem typical for rational adaptation theories, such as contingency theory (Lawrence and Lorsch, 1967) and resource-dependence theory (Pfeffer and Salancik, 1978). Of course, institutional and ecological theorists will not readily agree with them. The (new) institutional theory is explicitly based "on the rejection of rational-actor models" (DiMaggio and Powell, 1991, p.8) and organizational ecology is constructed as "an alternative to the dominant adaptation perspective" (Hannan and Freeman, 1977, p.929).

One of the key assumptions of an open-systems perspective on organizations is captured by assumption 4, which states that environmental influences cause uncertainty. Although much changed since Thompson's book appeared the sixties, this assumption seems as pertinent as ever. And even though one could argue that, on the one hand, environmental influences seem to generate less uncertainty due to current information technology and flexible work practices, one might just as well argue that, on the other hand, this is compensated for by the increased volatility of the environment. The next two assumptions, assumptions 5 and 6, are only used for the discussion of non-complex or atomic organizations. Assumption 5 postulates that we treat the whole organization as its technical core if it has no suborganizations. This

[14]Masuch and Huang (1996) give a different formalization of Thompson in a multi-agent, action logic. The objectives of their formalization are different from ours: our objective was to recover the underlying axioms on which Thompson's argumentation is based, whereas their primary objective is to experiment with a new formal logic that is specially designed for representing actions. They argue: "actions presuppose *attitudes* and engender *change*, and both are notoriously hard to express in the extentional context of standard logics, e.g., First Order Logic" (Masuch and Huang, 1996, p.72). This may be the case, in the sense that modeling of actual actions happening in an organizational domain may be overly elaborate or complicated in first order logic. However, modeling a theory *about* actions can very well be expressed in first order logic, as we showed in this article. This corresponds with the findings of Masuch and Huang (1996) since, as it turned out, they did not need to use either the multi-agent or the action features of their logic. Due to the different objectives, the formal theory of *Organizations in Action* presented in this article makes the underlying argumentation structure of Thompson explicit, whereas Masuch and Huang use a series of abstract goal definitions (characterizing particular rational agents) to explain the propositions.

assumption is not based on Thompson's text but expresses a convention that allowed us to discuss noncomplex or atomic organizations. Assumption 6 is a technicality that states that single influence causes a single uncertainty (a minor restriction on assumption 4). This assumption makes explicit the background knowledge that allows for the discussion of atomic organizations.

The next assumption, assumption 7, states that organizations have (some) control over influences directed at their suborganizations. This is one of the core assumptions of rational adaptation theories but will certainly be challenged by institutional and especially ecological theorists. However, these different views may be less orthogonal than they appear to be at first glance. Assumption 7 by no means implies that organizations can control their environments. First, the amount of control that organizations have may be very limited. Second, even if organizations have control, in principle, over influences, their capability to effectively use this control may depend on their capability to predict such influences. Third, even if an organization can foresee an influence, it may lack the ability to react decisively, due to complex internal decision procedures, rendering their control useless.

Finally, assumption 8 states another rationality principle underlying the theory: if an organization attempts to reduce something, and has some control over the cause of it, the organization will attempt to reduce the cause. As Thompson (1967, p.14) writes "Instrumental action is rooted on the one hand in desired outcomes and on the other hand in beliefs about cause/effect relationships." This assumption is an important part of the explanation for theorems 3 and 4 and the corollaries about buffering, smoothing, and anticipating and adapting (as well as negotiating). Assumption 8 is a general principle of rationality that seems generally acceptable. Of course, ecologists will deemphasize the organization's capability to entertain beliefs about cause/effect relationships or, even more so, question the capacity to have control over causes. However, institutionalists and ecologists would agree that in the (according to them, improbable) event that the antecedent is satisfied, the consequent should hold as well.

The formal reconstruction revealed that Thompson's theory can be related to several alternative theories such as organizational ecology (Hannan and Freeman, 1989) and new institutionalism (Powell and DiMaggio, 1991). Although organizational ecology was originally presented as an alternative to rational adaptation theory, their position turns out to be more qualified. Organizational ecologists carefully distinguish between the individual intentions of organizations and the organizational outcomes. The part of *Organizations in Action* we analyzed in this article is treating organizational intentions (or desired outcomes in Thompson's parlance). Organizational ecologists do not necessarily reject Thompson's assumptions about the rational intentions of individual organizations but would argue that the relation between these intentions and organizational outcomes is weak—resulting in organizations being relatively inert and unable to change their structure to better match the environment (Hannan and Freeman, 1984). Also Thompson does not believe that intentions and organizational outcomes are in perfect relation, for example, when he argues that "the basic threat to organizational success lies in interdependence with an uncooperative environment" (Thompson, 1967, p.160). And ecologists, on the other hand, are "acknowledging that organizational changes of some kinds occur frequently and that organizations sometimes even manage to make radical changes in strategies and structures" (Hannan and Freeman, 1984, p.149). The views of organizational ecologists and Thompson are not in contradiction, as can be evaluated by comparing this article with the formalization of organizational ecology's inertia theory (Péli et al., 1994). Although not in contradiction, there is a noticeable difference in the degree in which organizations are believed to be able to successfully realize their intentions in organizational outcomes. Several authors have made proposals for reconciling adaptation and evolutionary selection perspectives (Tushman and Romanelli, 1985; Levinthal, 1991; Amburgey et al., 1993).

Institutionalists have been more radical in their rejection of the rational adaptation perspective and explicitly focus on "properties of supra-individual units of analysis that cannot be reduced to aggregations or direct consequences of individuals" attributes or motives" (DiMaggio and Powell, 1991, p.8). Rather surprisingly, the formal reconstruction revealed that Thompson's theory can be directly related to new institutionalism. We proved corollary 4, stating that organizations attempt to reduce constraints in the environment, which corresponds to findings reported in institutional theory (Edelman, 1992; Sutton et al., 1994; Sutton and Dobbin, 1996). The formal theory suggests that adaptation theories and institutional theories are not mutually inconsistent. Moreover, adaptation theories can offer explanations for phenomena that are usually conceived as requiring institutional argumentation. This affirms that adaptation theories may have been discarded too soon: they can even offer explanations beyond the domains with which they are traditionally associated.

Deriving the corollary on negotiating in the environment strengthens the connection of *Organizations in Action* with related adaptation theories such as the resource-dependence theory. Pfeffer and Salancik (1978, pp.154–157) analyze interorganizational behaviors from the perspective of uncertainty reduction. The fact that traditional adaptation theories and neoinstitutional theories can offer alternative explanations raises some interesting research questions on the limits of both approaches to organization theory. For example, Sutton and Dobbin (1996, p.794) observe two types of responses to legal uncertainty, which "sustain the neoinstitutional argument, but offer new support for efficiency and labor-control hypothesis." There seem to be no *a priori* reasons to reject adaptation-based explanations (nor to reject institutional explanations). Kraatz and Zajac (1996, p.812) explored the limits of neoinstitutional theory, and their "findings reveal surprisingly little support for neoinstitutional predictions." This leads them to conclude that "current research on organization-environment relations may underestimate the power of traditional adaptation-based explanations in organizational sociology" (p.812). Further research is needed to elucidate the relation between (rational) adaptation theories and (neo)institutional theories and to investigate how adaptation theories might be embedded in institutional theory and *vice versa*. The formalization of one dominant adaptation theory is only a small step toward clarifying the relation between adaptation theories and institutional theories.

One of our future research directions is to extend the material by incorporating further chapters of Thompson. Our main focus has been on the propositions in chapter 2. This chapter provides the crucial link between organizations that strive to use the rationality of closed-systems strategies in an open-systems environment by attempting to seal off their core technology from influences of the environment. Thompson (1967, p.1) argues that the two basic sources for uncertainty for organizations are *technologies* and *environments*. The part of Thompson we formalized in this article concerns uncertainty that is strictly caused by the environment. We intend to incorporate also those uncertainties that are caused by technologies or by a combination of technologies and environments. This would then allow for explaining why organizations have to resort to unhappy solutions like rationing (the missing proposition 2.5). The axiomatic structure of the theory facilitates such further extension.

Building a deductive theory of *Organizations in Action* explicated the underlying assumptions of the framework that Thompson proposes. Making the underlying assumptions explicit implies that they too can become the subject of discussion and criticism. Although we made particular efforts to motivate these assumptions by the text itself, we do not claim that we have always chosen the single best solution. However, by being explicit about our assumptions, any debate about the theory and its assumptions can be unambiguously pointed down. This allows for a constructive mode of theory building in which alternatives can be generated, evaluated on their merits, and well-argued choices can be made.

References

Amburgey, T. L., D. Kelly, and W. P. Barnett (1993). Resetting the clock: The dynamics of organizational change and failure. *Administrative Science Quarterly 38*, 51–73.

Brüderl, J., P. Preisendörfer, and R. Ziegler (1992). Survival chances of newly founded business organizations. *American Sociological Review 57*, 227–242.

Bruggeman, J. (1997). Niche width theory reappraised. *Journal of Mathematical Sociology 22*(2), 201–220.

DiMaggio, P. J. and W. W. Powell (1991). Introduction. See Powell and DiMaggio (1991), Chapter 1, pp. 1–38.

Edelman, L. B. (1992). Legal ambiguity and symbolic structures: Organizational mediation of civil rights law. *American Journal of Sociology 97*, 1531–1576.

Freeman, J., G. R. Carroll, and M. T. Hannan (1983). The liability of newness: Age dependence in organizational death rates. *American Sociological Review 48*, 692–710.

Galbraith, J. R. (1977). *Organization Design.* Addison-Wesley, Reading MA.

Granovetter, M. (1984). Small is bountiful: Labor markets and establishment size. *American Sociological Review 49*, 323–334.

Hannan, M. T. (1997). Comment: On logical formalization of theories from organizational ecology. See Raftery (1997), pp. 145–150.

Hannan, M. T. (1998). Rethinking age dependence in organizational mortality: Logical formalizations. *American Journal of Sociology 104*, 126–164.

Hannan, M. T. and J. Freeman (1977). The population ecology of organizations. *American Journal of Sociology 82*, 929–964.

Hannan, M. T. and J. Freeman (1984). Structural inertia and organizational change. *American Sociological Review 49*, 149–164.

Hannan, M. T. and J. Freeman (1989). *Organizational Ecology.* Harvard University Press, Cambridge MA.

Kamps, J. (1998). Formal theory building using automated reasoning tools. In A. G. Cohn, L. K. Schubert, and S. C. Shapiro (Eds.), *Principles of Knowledge Representation and Reasoning: Proceedings of the Sixth International Conference (KR'98)*, pp. 478–487. Morgan Kaufmann Publishers, San Francisco CA.

Kamps, J. and M. Masuch (1997). Partial deductive closure: Logical simulation and management science. *Management Science 43*(9), 1229–1245.

Kraatz, M. S. and E. J. Zajac (1996). Exploring the limits of the new institutionalism: The causes and consequences of illegitimate organizational change. *American Sociological Review 61*, 812–836.

Lawrence, P. R. and J. W. Lorsch (1967). *Organization and Environment.* Harvard University Press, Cambridge MA.

Levinthal, D. A. (1991). Organizational adaptation and environmental selection—interrelated processes of change. *Organization Science 2*, 140–145.

Masuch, M. and Z. Huang (1996). A case study in logical deconstruction: Formalizing J.D. Thompson's *organizations in action* in a multi-agent action logic. *Computational and Mathematical Organization Theory 2*(2), 71–114.

McCune, W. (1994a). A Davis-Putnam program and its application to finite first-order model search: Quasigroup existence problems. Technical report, Argonne National Laboratory, Argonne IL. DRAFT.

McCune, W. (1994b). Otter: Reference manual and guide. Technical Report ANL-94/6, Argonne National Laboratory, Argonne IL.

Mintzberg, H. (1979). *The Structuring of Organizations.* Prentice-Hall, Englewood Cliffs NJ.

Parsons, T. (1960). *Structure and Process in Modern Societies.* The Free Press, Glenncoe IL.

Péli, G. (1997). The niche hiker's guide to population ecology: A logical reconstruction of organizational ecology's niche theory. See Raftery (1997), pp. 1–46.

Péli, G., J. Bruggeman, M. Masuch, and B. Ó Nualláin (1994). A logical approach to formalizing organizational ecology. *American Sociological Review 59*, 571–593.

Péli, G. and M. Masuch (1997). The logic of propagation strategies: Axiomatizing a fragment of organizational ecology in first-order logic. *Organization Science 8*, 310–331.

Perrow, C. (1986). *Complex Organizations: A Critical Essay* (Third ed.). McGraw-Hill, New York.

Pfeffer, J. and G. R. Salancik (1978). *The External Control of Organizations: A Resource Dependence Perspective.* Harper & Row Publishers, New York NY.

Pólos, L. (1991). Organizations on holiday: Formalizing Thompson's organizations in action. Technical Report 91-35, Center for Computer Science in Organization and Management, University of Amsterdam.

Popper, K. R. (1959). *The Logic of Scientific Discovery.* Hutchinson, London.

Powell, W. W. and P. J. DiMaggio (Eds.) (1991). *The New Institutionalism in Organizational Analysis.* University of Chicago Press, Chicago IL.

Raftery, A. E. (Ed.) (1997). *Sociological Methodology 1997.* Blackwell, Oxford UK.

Rushing, W. A. and M. N. Zald (Eds.) (1976). *Organizations and Beyond: Selected Essays of James D. Thompson*. D.C. Heath, Lexington MA.

Sastry, M. A. (1997). Problems and paradoxes in a model of punctuated organizational change. *Administrative Science Quarterly 42*, 237–275.

Scott, W. R. (1998). *Organizations: Rational, Natural, and Open Systems* (Fourth ed.). Prentice-Hall, Englewood Cliffs NJ.

Singleton, Jr., R. A. and B. C. Straits (1999). *Approaches to Social Research* (Third ed.). Oxford University Press, New York, Oxford.

Social Sciences Citation Index (1995). Social sciences citation index: an international interdisciplinary index to the literature of the social sciences. Institute for Scientific Information, Philadelphia PA.

Social Sciences Citation Index (1996). Social sciences citation index: an international interdisciplinary index to the literature of the social sciences. Institute for Scientific Information, Philadelphia PA.

Social Sciences Citation Index (1997). Social sciences citation index: an international interdisciplinary index to the literature of the social sciences. Institute for Scientific Information, Philadelphia PA.

Stinchcombe, A. L. (1965). Social structure and organizations. In J. G. March (Ed.), *Handbook of Organizations*, pp. 152–193. Rand McNally, Chicago IL.

Sutton, J. R. and F. Dobbin (1996). The two faces of governance: Responses to legal uncertainty in U.S. firms, 1955 to 1985. *American Sociological Review 61*, 794–811.

Sutton, J. R., F. Dobbin, J. W. Meyer, and W. R. Scott (1994). The legalization of the workplace. *American Journal of Sociology 99*, 944–971.

Thompson, J. D. (1967). *Organizations in Action: Social Science Bases of Administrative Theory*. McGraw-Hill, New York.

Tushman, M. L. and E. Romanelli (1985). Organizational evolution: A metamorphosis model of convergence and reorientation. *Research in Organizational Behavior 7*, 171–222.

U.S. Small Business Administration (1985). The state of small business: A report of the president. United States Government Printing Office, Washington DC.

Zald, M. N. (1996). More fragmentation? unfinished business in linking the social sciences and the humanities. *Administrative Science Quarterly 41*, 251–261.

A A formal theory of *Organizations in Action*

A.1 Definitions

Definition 1 Complex organizations.

$\forall x\,[\mathsf{CO}(x) \;\leftrightarrow\; \mathsf{O}(x) \wedge \exists y\,[\mathsf{SO}(x,y) \wedge \mathsf{TC}(x,y)]]$

(Read: x is a complex organization if and only if x is an organization and there exists a y such that y is a suborganization of x, and y is the technical core of x.)

Definition 2 Environmental influence.

$\forall x,y,z\,[\mathsf{ENVI}(x,y,z) \;\leftrightarrow\; \mathsf{FL}(x,y,z) \vee \mathsf{CS}(x,y,z)]$

(Read: x is exposed to an influence y from z if and only if x is exposed to a fluctuation y from z, or x is exposed to a constraint y from z.)

Definition 3 Sealing off.

$\forall x,y,z\,[\mathsf{SEFF}(x,y,z) \;\leftrightarrow\; \mathsf{SO}(x,z) \wedge \exists v,w\,[\mathsf{ENVI}(z,y,v) \wedge \mathsf{UC}(z,w) \wedge \mathsf{C}(y,w) \wedge \mathsf{RED}(x,w,z)]]$

(Read: x seals z off from y if and only if z is a suborganization of x, and there exists v and w such that z is exposed to an influence y from v, and y causes uncertainty w of z, and x attempts to reduce w for z.)

Definition 4 Atomic organizations.

$\forall x\,[\mathsf{ATO}(x) \;\leftrightarrow\; \mathsf{O}(x) \wedge \neg\mathsf{CO}(x)]$

(Read: x is an atomic organization if and only if x is an organization and x is not a complex organization.)

Definition 5 Buffering.

$\forall x,y,z\,[\mathsf{BUF}(x,y,z) \;\leftrightarrow\; \mathsf{SO}(x,z) \wedge \mathsf{FL}(z,y,x) \wedge \mathsf{RED}(x,y,z)]$

(Read: x buffers y for z if and only if z is a suborganization of x, and z is exposed to a fluctuation y from x, and x attempts to reduce y for z.)

Definition 6 Anticipating and adapting.

$\forall x,y,z\,[\mathsf{ANA}(x,y,z) \;\leftrightarrow\; \mathsf{SO}(x,z) \wedge \mathsf{CS}(z,y,x) \wedge \mathsf{RED}(x,y,z)]$

(Read: x anticipates and adapts to y for z if and only if z is a suborganization of x, and z is exposed to a constraint y from x, and x attempts to reduce y for z.)

Definition 7 Controlled environmental elements.

$\forall x,y\,[\mathsf{CEE}(x,y) \;\leftrightarrow\; \mathsf{O}(x) \wedge \forall z\,[\mathsf{ENVI}(x,z,y) \;\rightarrow\; \mathsf{HC}(x,z)]]$

(Read: y is an element in x's controlled environment if and only if x is an organization, and for all z such that x is exposed to an influence z from y it is the case that x has control over z.)

Definition 8 Smoothing.

$\forall x,y,z\,[\mathsf{SM}(x,y,z) \;\leftrightarrow\; \mathsf{SO}(x,z) \wedge \exists v\,[\mathsf{FL}(x,y,v) \wedge \mathsf{RED}(x,y,z)]]$

(Read: x smoothes y for z if and only if z is a suborganization of x, and there exists a v such that x is exposed to a fluctuation y from v, and x attempts to reduce y for z.)

Definition 9 Negotiating.

$\forall x,y,z\,[\mathsf{NEG}(x,y,z) \;\leftrightarrow\; \mathsf{SO}(x,z) \wedge \exists v\,[\mathsf{CS}(x,y,v) \wedge \mathsf{RED}(x,y,z)]]$

(Read: x negotiates y for z if and only if z is a suborganization of x, and there exists a v such that x is exposed to a constraint y from v, and x attempts to reduce y for z.)

A.2 Assumptions

Assumption 1 The technical core is unique.

$\forall x,y,z\,[\mathsf{TC}(x,y) \wedge \mathsf{TC}(x,z) \;\rightarrow\; y = z]$

(Read: if both y and z are the technical core of x, then y is equal to z.)

Assumption 2 The technical core is rationally evaluated.

$\forall x,y\,[\mathsf{TC}(x,y) \;\rightarrow\; \mathsf{REVA}(x,y)]$

(Read: if y is the technical core of x, then x will rationally evaluate y.)

Assumption 3 Organizations attempt to reduce uncertainty for rationally evaluated suborganizations.

$\forall x, y, z\ [\mathsf{SO}(x, y) \wedge \mathsf{REVA}(x, y) \wedge \mathsf{UC}(y, z)\ \rightarrow\ \mathsf{RED}(x, z, y)]$

(Read: if y is a suborganization of x, and x rationally evaluates y, and z is the uncertainty of y, then x attempts to reduce uncertainty z for y.)

Assumption 4 Environmental influences cause uncertainty.

$\forall x, y, z\ [\mathsf{ENVI}(x, y, z)\ \rightarrow\ \exists v\ [\mathsf{UC}(x, v) \wedge \mathsf{C}(y, v)]]$

(Read: if x is exposed to an environmental influence y from z, then there exists a v such that v is the uncertainty of x, and influence y causes uncertainty v.)

Assumption 5 If the technical core of an organization is not a suborganization, then we treat the whole organization as its technical core.

$\forall x, y\ [\mathsf{O}(x) \wedge \mathsf{TC}(x, y) \wedge \neg\mathsf{SO}(x, y)\ \rightarrow\ x = y]$

(Read: if x is an organization, and y is the technical core of x, and y is not a suborganization of x, then x and y are identical.)

Assumption 6 A single influence causes a single uncertainty.

$\forall x, y, z, v, w\ [\mathsf{ENVI}(x, y, z) \wedge \mathsf{UC}(x, v) \wedge \mathsf{C}(y, v) \wedge \mathsf{UC}(x, w) \wedge \mathsf{C}(y, w)\ \rightarrow\ v = w]$

(Read: if x is exposed to an influence y from z, and y causes uncertainty v of x, and y also causes uncertainty w of x, then uncertainty v is equal to uncertainty w.)

Assumption 7 Organizations have control over environmental influences on their suborganizations.

$\forall x, y, z, v\ [\mathsf{O}(x) \wedge \mathsf{SO}(x, y) \wedge \mathsf{ENVI}(y, z, v)\ \rightarrow\ \mathsf{HC}(x, z)]$

(Read: if x is an organization, and y is a suborganization of x, and y is exposed to an influence z from v, then x has control over z.)

Assumption 8 If an organization attempts to reduce something, and has control over a cause of it, the organization will attempt to reduce the cause.

$\forall x, y, z, v\ [\mathsf{RED}(x, y, z) \wedge \mathsf{C}(v, y) \wedge \mathsf{HC}(x, v)\ \rightarrow\ \mathsf{RED}(x, v, z)]$

(Read: if x attempts to reduce y for z, and v causes y, and x has control over v, then x attempts to reduce v for z.)

A.3 Theorems

Lemma 1 The technical core of a complex organizations is a suborganization.

$\forall x, y\ [\mathsf{CO}(x) \wedge \mathsf{TC}(x, y)\ \rightarrow\ \mathsf{SO}(x, y)]$

(Read: if x is a complex organization with core technologies y, then y is a suborganization of x.)

Lemma 2 Complex organizations attempt to reduce uncertainty for their technical cores.

$\forall x, y, z\ [\mathsf{CO}(x) \wedge \mathsf{TC}(x, y) \wedge \mathsf{UC}(y, z)\ \rightarrow\ \mathsf{RED}(x, z, y)]$

(Read: if x is a complex organization with core technologies y, and z is the uncertainty of y, then x attempts to reduce the uncertainty z for y.)

Theorem 1 Complex organizations seal off their core technologies from environmental influences.

$\forall x, y, z, v\ [\mathsf{CO}(x) \wedge \mathsf{TC}(x, y) \wedge \mathsf{ENVI}(y, z, v)\ \rightarrow\ \mathsf{SEFF}(x, z, y)]$

(Read: if x is a complex organization, and y is the technical core of x, and y is exposed to an influence z from v, then x seals y off from z.)

Lemma 3 Atomic organizations are organizations that have no suborganization as technical core.

$\forall x\ [\mathsf{ATO}(x)\ \leftrightarrow\ \mathsf{O}(x) \wedge \neg\exists y\ [\mathsf{SO}(x, y) \wedge \mathsf{TC}(x, y)]]$

(Read: x is an atomic organization if and only if x is an organization, and there is no y such that y is a suborganization of x, and y is the technical core of x.)

Lemma 4 Atomic organizations are identical with their technical core.

$\forall x, y\ [\mathsf{ATO}(x) \wedge \mathsf{TC}(x, y)\ \rightarrow\ x = y]$

(Read: if x is an atomic organization and y is the technical core of x, then x and y are identical.)

Theorem 2 The technical core of an atomic organization faces the same environmental uncertainty as the organization.

$\forall x, y, z, v, w\ [\mathsf{ATO}(x) \wedge \mathsf{TC}(x, y) \wedge \mathsf{ENVI}(x, v, z) \wedge \mathsf{UC}(x, w) \wedge \mathsf{C}(v, w)\ \rightarrow\ \exists u\ [\mathsf{UC}(y, u) \wedge \mathsf{C}(v, u) \wedge u = w]]$

(Read: if x is an atomic organization with core technologies y, and if x is exposed to an influence v from z, and v causes uncertainty w of x, then there exist uncertainty u of the technical core y, caused by v, and the uncertainty u is equal to the uncertainty w.)

Theorem 3 Complex organizations attempt to reduce environmental influences for their core technologies.

$\forall x, y, z, v\ [\mathsf{CO}(x) \wedge \mathsf{TC}(x, y) \wedge \mathsf{ENVI}(y, z, v)\ \rightarrow\ \mathsf{RED}(x, z, y)]$

(Read: if x is a complex organization, and y is the technical core of x, and y is exposed to an influence z from v, then x attempts to reduce z for y.)

Corollary 1 Complex organizations buffer environmental fluctuations for their core technologies.

$\forall x, y, z\ [\mathsf{CO}(x) \wedge \mathsf{TC}(x, y) \wedge \mathsf{FL}(y, z, x)\ \rightarrow\ \mathsf{BUF}(x, z, y)]$

(Read: if x is a complex organization, and y is the technical core of x, and y is exposed to a fluctuation z from x, then x buffers z for y.)

Corollary 2 Complex organizations anticipate and adapt to an environmental constraint for their core technologies.

$\forall x, y, z\ [\mathsf{CO}(x) \wedge \mathsf{TC}(x, y) \wedge \mathsf{CS}(y, z, x)\ \rightarrow\ \mathsf{ANA}(x, z, y)]$

(Read: if x is a complex organization, and y is the technical core of x, and y is exposed to a constraint z from x, then x anticipates and adapts to z for y.)

Theorem 4 Complex organizations attempt to reduce environmental influences in their controlled environment for their technical core.

$\forall x, y, z, v, w\ [\mathsf{CO}(x) \wedge \mathsf{TC}(x, y) \wedge \mathsf{ENVI}(y, z, x) \wedge \mathsf{CEE}(x, v) \wedge \mathsf{ENVI}(x, w, v) \wedge \mathsf{C}(w, z)\ \rightarrow\ \mathsf{RED}(x, w, y)]$

(Read: if x is a complex organization, and y is the technical core of x, and y is exposed to an influence z from x, and v is in the controlled environment of x, and x is exposed to an influence w from v, and w causes z, then x attempts to reduce w for y.)

Corollary 3 Complex organizations smooth environmental fluctuations in their controlled environment for their technical core.

$\forall x, y, z, v, w\ [\mathsf{CO}(x) \wedge \mathsf{TC}(x, y) \wedge \mathsf{FL}(y, z, x) \wedge \mathsf{CEE}(x, v) \wedge \mathsf{FL}(x, w, v) \wedge \mathsf{C}(w, z)\ \rightarrow\ \mathsf{SM}(x, w, y)]$

(Read: if x is a complex organization, and y is the technical core of x, and y is exposed to a fluctuation z from x, and v is in the controlled environment of x, and x is exposed to a fluctuation w from v, and w causes z, then x smoothes w for y.)

Corollary 4 Complex organizations negotiate environmental constraints in their controlled environment for their technical core.

$\forall x, y, z, v, w\ [\mathsf{CO}(x) \wedge \mathsf{TC}(x, y) \wedge \mathsf{CS}(y, z, x) \wedge \mathsf{CEE}(x, v) \wedge \mathsf{CS}(x, w, v) \wedge \mathsf{C}(w, z)\ \rightarrow\ \mathsf{NEG}(x, w, y)]$

(Read: if x is a complex organization, and y is the technical core of x, and y is exposed to a constraint z from x, and v is in the controlled environment of x, and x is exposed to a constraint w from v, and w causes z, then x negotiates w for y.)

A.4 Additional background assumptions (not used in the text)

- Proper suborganizations: $\forall x, y\ [\mathsf{SO}(x, y)\ \rightarrow\ \mathsf{O}(x) \wedge \neg \mathsf{O}(y)]$.
- Irreflexive influences: $\forall x, y\ [\neg \mathsf{ENVI}(x, y, x)]$.
- Irreflexive causes: $\forall x\ [\neg \mathsf{C}(x, x)]$.
- Transitive causes: $\forall x, y, z\ [\mathsf{C}(x, y) \wedge \mathsf{C}(y, z)\ \rightarrow\ \mathsf{C}(x, z)]$.