The logic of organizational markets

Vermeulen, I.; Bruggeman, J.

The Logic of Organizational Markets: Thinking Through Resource Partitioning Theory

Ivar Vermeulen and Jeroen Bruggeman*

March 2000

Abstract

Resource partitioning theory claims that "Increasing concentration enhances the life chances of specialist organizations." We systematically think through this theory, specify implicit background assumptions, sharpen concepts, and rigorously check the theory's logic. As a result, we increase the theory's explanatory power, and claim—contrary to received opinion—that under certain general conditions, "resource partitioning" and the proliferation of specialists can take place *independently* of organizational mass and relative size effects, size localized competition, diversifying consumer tastes, increasing number of dimensions of the resource space, and changing niche widths. Our analysis makes furthermore clear that specialist and generalist strategies are asymmetric, and shows that not concentration enhances the life chances of specialists but economies of scale instead. Under the conditions explicated, we argue that if scale economies come to dominate, the number of organizations in the population increases, regardless of the incumbents' sizes.

Key words: theory reconstruction; resource partitioning; competition; market concentration; economies of scale; niche; specialization; organizational ecology; logical formalization; applied logic.

*We are grateful to Jaap Kamps, Michael Masuch, Patricia Thornton, and Jelka Hopster for their helpful comments on an earlier version, and to Glenn Carroll, Gábor Péli, Arjen van Witteloostuijn and Christophe Boone for discussions about resource partitioning.

1 Introduction

The value of a field of science is in the theories it produces. For a scientific theory to be valuable, it must be unambiguous and logical. Many social science texts that present theory are not clear, though (Sutton and Staw 1995), leaving the burden of disambiguating and tracing the theory's logic on the readers of these texts. For such texts, valuable ideas may not be fully comprehended and exploited. Relieving this burden is very difficult in the case of discursive theories (*i.e.,* presented in natural language), since natural language has no clearcut benchmarks to check or improve the theory's logic. As a consequence, theory development and scientific debate are unnecessarily impaired. To increase logical rigor and precision, and to raise the level of discussion to a new level, representing the core argument of a theory in formal logic is an approved method (Suppes 1968; Kyburg 1968; Péli et al. 1994; Hannan 1997; Kamps and Pólos 1999).

Logical formalization has recently been applied, among others, to various parts of organizational ecology. In terms of explanatory and predictive power, this is one of the most advanced sociological theories. Although in better shape than most other theories in the field, it turned out not to be logically perfect. Logical formalization can help to resolve ambiguities, explicate tacit assumptions, improve the theory's logic, increase parsimony, and infer new and unforeseen conclusions (Péli et al. 1994; Kamps and Masuch 1997; Péli and Masuch 1997; Bruggeman 1997b; Péli 1997; Hannan 1998). As part of this larger effort, we want to analyze and formalize the explanatory structure of resource partitioning theory (Carroll 1985).

Resource partitioning has become one of the most important parts of organizational ecology (Hannan and Carroll 1992; Carroll and Hannan 1995), and deals with the population dynamics of competing generalist and specialist organizations. Its main claim is that "Increasing concentration enhances the life chances of specialist organizations" (Carroll and Hannan 1995, p.p.217). Along with the proliferation of specialists, the theory claims there is less niche overlap and competition between specialists and generalists (*i.e.,* resource partitioning). This relatively new theory is particularly interesting because it stands in stark contrast with older views from industrial economics. The latter sees high concentration as a barrier to entry, especially for small organizations (Barney and Ouchi 1986, p.p.373, 374). Many empirical researchers have seen fit to test resource partitioning's claims, and they found corroborating evidence for resource partitioning in the car industry (Hannan et al. 1995), banking (Freeman and Lomi 1994; Lomi 1995), newspapers (Carroll 1985), the telephone industry (Barnett and Carroll 1987) beer brewery (Swaminathan and Carroll 1995), wine making (Swaminathan 1995), auditing (Boone, Bröcheler, and Carroll 2000), hi-tech industries (Mitchell 1995; Wade 1996), and the American feature film industry (Mezias and Mezias 1999). These findings are important, because higher entry rates of new firms (here, of specialists) are often associated with innovation, increased product choice, and industry renewal (Thornton 1999).

By passing resource partitioning "through the purgatory of proofs and refutations," as Lakatos (1976) phrased it, we want to get the listed advantages of logical formalization. Furthermore, we will attempt to show the redundancy of a number of assertions from organizational ecology, that a number of theorists believe to be necessary in the explanatory argument. In sum, we will try to generalize and increase the explanatory power of the theory at hand, and use logic as our tool.

Compared to logical formalization, computer simulation (Carley and Prietula 1994; Sastry 1997; Gilbert and Troitzsch 1999) and mathematics (Sørensen 1978; Coleman 1990) are relatively well known formal approaches, that also increase rigor and precision. These two approaches are well suited to keep track of a great deal of variables and their interactions, and simulation in particular makes possible to explore highly complex problems, both empirical and virtual (Axelrod 1997). For analyzing complex *theories* and their explanatory arguments, however, computer supported logical formalization is suited best. It is an approach complementary to the other two.

Logical formalization can stay relatively close to a source text, whereas mathematics and simulation often require to impose strong assumptions about metrics (Péli 1997; Hannan 1997). In the context of analyzing theories, logic can be seen as critical reflection on reasoning, with mathematical precision. If the conclusions of a theory are inferred logically, then in *all* models (*i.e.,* instances of the pertaining sentences) where the assumptions are true, the conclusions must also be true. The other two approaches, in contrast, can show that in *some* models, both assumptions and conclusions are true (Kamps and Pólos 1999). It goes without saying that along with analyzing existing theories, all three strands of formal techniques can help developing new theories.

In this paper, we formalize resource partitioning theory in 5 steps, with iterations if necessary. First, we extract the main claims and their supportive arguments from the text (Section 2.1). These claims and arguments taken together, we see as the *core theory*. Analyzing and sharpening key concepts in the core theory is our second step (Section 2.2). In the third step (Section 2.3), we focus on the structure of argument. We distinguish premises (*i.e.,* assumptions, definitions, or "background" assumptions) from conclusions, use the sharpened concepts from step 2, and informally axiomatize the core theory. Loopholes in the argument (*i.e.,* "hidden" background assumptions), we fill in the course of our analysis.

The first three steps are, for short, a rational reconstruction of the theory, preparing the ground for the formalization proper in step 4. In step 5, we check the two essential logical properties—soundness and consistency—computationally (Section 3). This is important because conclusions that intuitively appear to follow from premises may nevertheless be false, and intuitively implausible statements may turn out to be soundly derivable. Furthermore, a computer check may reveal additional loopholes and other flaws in the argument, that have been overlooked by authors, reviewers, editors, and formalizers. The results of the formalization are presented in Section 4, followed by a discussion in Section 5.

2 Rational reconstruction

Resource partitioning is about competing subpopulations of specialists and generalists, and asks "under what conditions will the specialist form be viable and why?" (Carroll and Hannan 1995, p.p.215). Before we go into the source text, we explicate some conceptual background from organizational ecology (Hannan and Freeman 1977; Hannan and Carroll 1992), that is important in resource partitioning theory.

Organizations tap resources from their environment, and the set of resources they tap is called their realized niche. The set of resources an organization could potentially tap in the absence of competitors, given its technology, goals, and market strategy, is its fundamental niche. Populational niches need not concern us at the moment. Two organizations compete if and only if their fundamental niches "overlap," and overlap means set intersection. Competition thus increases with niche overlap (Hannan and Freeman 1989).

In organizational ecology, organizations are seen as inert, which means most of them cannot adapt flexible to their environment (Hannan and Freeman 1984). If they are founded in a particular population (a collection of organizations with overlapping niches and similar form), they are likely to stay in that population for the rest of their lives. Generalists do not become specialists or vice versa. Whereas organizational structures are inert, niches may expand, shrink or drift, due to changes in the environment, organizational change (although rare), or both.

2.1 Core theory

Resource partitioning theory was published in 1985 by Glenn Carroll, but our main source is a more recent and slightly expanded treatment in a textbook (Carroll and Hannan 1995, p.p.215-221). This text has 92 sentences, of which seven qualify as core theory. The remainder 85 sentences rephrase (parts of) the core theory, give examples, describe concepts, pose the research question, establish connections to other chapters of the textbook, or are additional assumptions. Of these remainder assumptions, we will try to show they are redundant.

Thus our core theory (see Table 1) is a set of quotations from Carroll and Hannan (1995, p.p.216-217), in their order of appearance in the text. Notice that in the text they appear *next* to each other.

1. Early in these markets, when the arena is crowded, most firms vie for the largest possible resource base.
2. Competition forces each to specialize to some extent to differentiate itself, although the overall strategy adopted by most firms is generalist in nature.
3. As scale economies come to dominate, only a few generalists survive and they move toward the center of the market.
4. This lessened crowding of generalists and their move to the center opens up small pockets of resources on the periphery of the market, and it is here that specialist forms usually appear and thrive.
5. In fact, the market at this point has been partitioned into generalist and specialist resources.
6. The key predictive variable in the model is the overall level of *market concentration*. [Italics in the original.]
7. When the market is not highly concentrated, specialist organizational forms will not do as well as they do when it is highly concentrated.

Table 1: Core theory

Questions

With respect to the core theory, one could ask if it can explain resource partitioning and the proliferation of specialists. Moreover, there exist six additional assertions in organizational ecology, of which it is generally believed that at least some are necessary in the explanation of (part of) the outcome. First, some have argued that large organizations exert stronger competitive pressure on small organizations than the other way around, because the former have greater market power. It has been proven mathematically that this assertion added to the core theory accounts for the outcome (Bruggeman 1997a). Second, large organizations consume larger resources than small organizations. Some argue that if a large generalist dies and the volume of the resource base does not decrease, resources are freed and resource pockets are opened for several small specialists to enter. In fact, this is an almost literal reading of core sentence 4, and this reading would certainly help to explain the proliferation of specialists. Third, organizational ecology has a model of size localized competition (Hannan et al. 1990), wherein organizations of similar size compete more strongly than organizations of very dissimilar sizes. This model can account for the outflow of middle sized organizations (here, small generalists) and the subsequent inflow of small specialists.

From a parsimony point of view, either assertion would require to increase the "weight" of the core theory by an assumption about the effect of organizational size, plus the conceptual ambiguity surrounding this notion. Moreover, it would suggest that resource partitioning occurs only in domains where such an additional assumption holds.

Fourth, empirical evidence suggests that at some point, consumers develop a greater variety of tastes, leading to a larger market periphery, *i.e.,* a larger resource base for specialists where they can flourish (Carroll and Hannan 1995, p.219). In this case, explaining the proliferation of specialists is rather trivial. Fifth, Péli and Nooteboom (1999) made an analogy between niche positioning and the problem of sphere packing from physics. They claim, on the basis of an intricate mathematical model that is not in their paper, that the resource space for specialists grows if the number of dimensions of the resource space increases. And sixth, the source text (p.p.218-9) argues that the niche width of the few surviving generalists increases, although it is not clear from the text how this effect influences the outcome.

We ask for each of these six assertions if it is necessary for the explanatory argument. Our aim is to establish a parsimonious set of premises on the basis of the source text, and closely related information from organizational ecology if necessary. If we succeed, the insight gained is that additional causes, phrased in the above assertions, are not necessary for the outcome to occur. Such insight can lead to re-interpretations of previous research and a new understanding of the process of resource partitioning.

2.2 Key concepts

In the second step, we analyze the important concepts occurring in sentences of the core theory, and their relations, if any.

Resource base, market, and arena

A key notion is that of resource base. The resource base of a (sub)population is the set of all resources from which the organizations in the (sub)population tap. This set is also called the niche of the (sub)population (Hannan and Freeman 1989). A resource base can be partitioned into a center and a periphery. In the center, resources are relatively abundant compared to the periphery where resources are more scarce. Center and periphery are not spatial concepts, although in some cases they may take a spatial meaning, for instance for newspapers with regionally different readers.

In core sentence 1 the notion "arena" is used as a synonym for resource base; in sentence 3, 4, and 5 the synonym "market" is used. In sentence 1, 6, and 7, however, market is used as an equivalent of population. For clarity, we will abstain from arena and market as synonyms for resource base, also because in most organizational theories, market denotes a collection of resources *and* organizations.

Generalists and specialists

Generalists and specialists are defined in terms of "niche width," and have wide and narrow niches respectively (Freeman and Hannan 1983; Carroll and Hannan 1995, p.p.215). Each organizational population considered in resource partitioning theory contains a generalist subpopulation and a specialist subpopulation, and organizations are either generalist or specialist. In core sentence 1, generalists are said to "vie for the largest possible resource base." The strategy of these generalists is to include as many resources as possible in their organizational niche. Having a wide niche and aiming at the center of the resource base both contribute to the generalist strategy.

In core sentence 2, organizations specialize "to differentiate themselves." Here, the strategy of specializing is to avoid competitive pressures by reducing the crowding (see below for a definition) of the niche. Having a narrow niche and aiming at the periphery of the resource base are ways to live up to the specialist strategy. Incorporating many resources and avoiding competitive pressures are asymmetric strategies. A consequence of the generalist-versus-specialist strategies is that generalists' niches are usually more crowded than specialists'.

The phrase "Generalists move toward the center of the resource base" is a figure of speech which means that the niches of generalist organizations increasingly include abundant resources. Notice that for resource partitioning theory, it does not matter if resources, *e.g.,* consumer tastes, change while generalist organizations do not, or if generalist organizations change their position with respect to the resource base.

Economies of scale

The text is clear on this concept: "An economy of scale exists when the per-unit cost of producing a product or service declines with the number of units produced." Scale economies are a main determinant for the growth of large firms that enjoy these economies.

Crowding

The notion of crowding is not defined in the source text, but its meaning is essential in the explanatory argument. There exists one definition in organizational ecology (Podolny et al. 1996) and we will use it. Crowding is defined as the degree to which organizations tap from the same resources. If many organizations aim at a relatively limited number of resources, organizational niches are crowded. If organizations differentiate themselves and aim at different resources, crowding is low. Podolny et al. (1996, p.666) focus on individual organizations in their study, and define, inspired by McPherson (1983), a crowding measure of an organizational niche as the sum of its niche overlaps by other organizations.

symbols: $A(i)$	:	crowding of the niche of organization i
n	:	number of organizations in a population
$a(ij)$	:	extent to which the fundamental niche of organization i is overlapped by that of organization j

Def 1. Niche crowding (Podolny et al.)

$$A(i) = \sum_{j=1, j\neq i}^{n} a(ij)$$

Niche overlap defined as set intersection is a mathematical and clearly defined notion that abstracts away from niche dimensions. If another organization has full niche overlap with the focal organization (*i.e.,* the set intersection equals the niche of the focal organization), then $a(ij)$ is assigned the value 1. If there is no niche overlap (*i.e.,* the set intersection is empty), then $a(ij) = 0$. So, the value of the term $a(ij)$ ranges between zero and one.

Since resource partitioning is about (sub)populations, the theory must have a definition of crowding at the (sub)population level, which can be simply constructed on the basis of Podolny's definition. The crowding of a populational resource base, is the crowding of the niches of all organizations in the population.

symbols:	cr	:	crowding of the populational resource base
	$\overline{A}$	:	mean crowding of organizational niches

Def 2a. Populational crowding

$$cr = \sum_{i=1}^{n} A(i) = n\,\overline{A}$$

In analogy to the definition of populational crowding, the crowding measure of the generalist subpopulation is the sum of the crowding of all generalist niches, by generalists or by specialists (that may to some extent tap the same resources as generalists). The same argument applies to the specialist subpopulation. Definition 2b and 2c give measures for generalist and specialist crowding, respectively.

symbols:					
cr_g	:	crowding of the generalist resource base	cr_s	:	crowding of the specialist resource base
n_g	:	number of generalist organizations	n_s	:	number of specialist organizations
$\overline{A}_g$	:	mean crowding of generalist niches	$\overline{A}_s$	:	mean crowding of specialist niches

Def 2b. Generalist crowding

$$cr_g = n_g\overline{A}_g$$

Def 2c. Specialist crowding

$$cr_s = n_s\overline{A}_s$$

Because in resource partitioning theory, all organizations are either generalist or specialist, the sum of generalist and specialist crowding is equal to the populational crowding, $cr = cr_g + cr_s$.

Competition

Competition is undefined in the source text, but is well defined in Hannan and Carroll's textbooks. Like crowding (Def.1), competition increases with niche overlap and with the number of organizations; populational competition is the aggregate of competitive ties in the population (Hannan and Carroll 1992), like crowding here. In the explanatory argument of resource partitioning, crowding is therefore equivalent to competition.

Concentration

Concentration denotes, informally speaking, the degree to which the resources in a market are tapped or controlled by a small number of firms of the population in that market. Usually, concentration is defined as the ratio of the aggregate size of the (3 or 4) largest firms to that of all firms in the population (Shepherd 1987). Carroll's original paper has (1) "economic concentration" (Carroll 1985, p.1262), which presumably denotes the above definition from economics, and (2) "resource concentration" (p.1275) that probably coincides with the preceding meaning, because large organizations take large resources from the resource base and small organizations small resources. The source text is more ambiguous, and has (3) "ownership concentration" (Carroll and Hannan 1995, p.184), along with a table in which (4) concentration is the number of organizations operating in the same market (Carroll and Hannan 1995, Table 9-1, p.185), and there is (5) concentration of specialists and of generalists independently (Carroll and Hannan 1995, p.p.192, 216). Perhaps generalist concentration could mean the same as (6) concentration of the "general interest mass market" (Carroll 1985, p.1276), because generalists are mostly there. We suspend deciding upon this matter and discuss concentration later, after investigating its role in the argument.

Resource partitioning

The concept of resource partitioning denotes a decrease of the extent to which generalists and specialists tap from the same resources (Carroll and Hannan 1995, p.217), *i.e.,* decreasing niche overlap of specialists and generalists[1]. In our interpretation, the opening up of small pockets of resources in the periphery (sentence 4) is a figure of speech and not meant literally. Again, it

[1]The notion of resource partitioning suggests a partitioning of resources in a mathematical sense, as a subdivision of a set into subsets, such that each element of the set is in one of these subsets, and in no more than one. These mathematical properties hold for the resource base, which is partitioned into a center and a periphery, but not for the niches of the specialist and generalist subpopulations, which do overlap to some extent.

is not important if specialists and generalists move away from each other or resources get partitioned between specialists and generalists. The effect of both is decreasing niche overlap of generalists and specialists, which in our view is the important point.

Resource partitioning processes start "early in these markets" (sentence 1). We will refer to this point in time as the *starting point* of resource partitioning processes. Since the source text does not describe an end point of the process, we will not have it in our formal representation either. These considerations complete our analysis of concepts.

2.3 Informal axiomatization

We will now focus on the structure of the argument. Our goal is to informally axiomatize the core theory, by representing it as a set of relatively short statements with a clear logical structure. Synonymous concepts are mapped onto one notion, using the above analyses.

For each resulting sentence, its role in the argument is tagged. These roles can be premise, or conclusion. A major conclusion is called a *theorem* (abbreviated **Thm**), an intermediate conclusion a *lemma* (**L**). In addition to these sentences, background assumptions will be added if necessary. A premise can be an assumption (**A**) a background assumption (**BA**), or a definition (**Def**).

Core sentences 1 and 2

The first two core sentences provide information about the conditions that hold "early in these markets," that is, at the starting point of resource partitioning. At that time, "most firms vie for the largest possible resource base" and "the overall strategy adopted by most firms is clearly generalist in nature." We will not use this boundary condition and show that the outcome of the process can occur for any initial ratio of generalist and specialist firms.

Furthermore, "competition forces each to specialize in some extent." A straightforward reading of this phrase would be that, after the starting point, when competition is high, organizations actively limit the crowding of their niches to avoid increasing competitive pressures. But if one assumes that literally *each* organization has this strategy, a single organization that has not would falsify the assumption. An interpretation that is more in line with the Darwinian perspective of organizational ecology is that due to high competitive forces, organizations with relatively lower niche crowding are favored by selection over organizations with higher niche crowding (and for other properties similar). This assumption is about average rather than individual organizations.

A 1 After the starting point, the mean crowding of generalist niches will not increase.

A 2 After the starting point, the mean crowding of specialist niches will not increase.

Sentence 1 states that at the starting point, "the arena is crowded." The high levels of crowding, implying high levels of competition, suggest that at the starting point of resource partitioning, the environment must be near or at its carrying capacity for the population. We verified this conjecture with the author, who confirmed that the process of resource partitioning, as well as the decline of generalists and the proliferation of specialist organizations usually starts, roughly, shortly after the growth of a population has come to a halt (Carroll, personal communication).

Core sentence 3

The third core sentence mentions three events. First, "scale economies come to dominate," second "only a few generalists survive" and third "they move toward the center of the market." Since economies of scale increase mortality rates in organizational populations (p.216), we rephrase the first part of the sentence in the following manner.

A 3 If scale economies come to dominate, the number of generalist organizations decreases.

The second part of the sentence says that the niches of the remaining generalist organizations move toward the center of the resource base:

A 4 If the number of generalist organizations decreases, the niches of the remaining generalists move toward the center of the resource base.

Core sentences 4 and 5

Sentence 4 says that "This lessened crowding of generalists and their move to the center opens up small niche pockets on the periphery of the resource base," and furthermore that "it is here that specialists often appear and thrive." The cause for this lessened crowding of generalists is indicated by core sentence 3: the decreasing number of generalist organizations, due to the dominance of scale economies. From Definition 2, however, it follows that not only the number of generalist organizations, but also the mean crowding of generalist niches determines the level of generalist crowding. Assumption 1 states that after the starting point of resource partitioning, the mean crowding of generalist niches will not increase. This allows us to propose the first part of core sentence 4 as an intermediate result,

L 1 If, after the starting point, scale economies come to dominate, generalist crowding decreases.

If generalists move toward the center, their niche overlap with specialist organizations in the periphery presumably decreases. This decrease, then, will result in a lower mean crowding of specialist niches. Lower mean crowding enhances the life chances of specialist organizations and accounts for their proliferation. In other words, if we may assume that,

A 5 If generalist niches move toward the center of the resource base, the mean crowding of specialist niches decreases.

which, after all, is in line with the opening up of small pockets of resources on the periphery, we can derive the last part of core sentence 4,

L 2 If, after the starting point, generalist niches move toward the center of the resource base, and the crowding of specialists does not decrease, the number of specialists increases.

Core sentence 5 says that at this point (later than the starting point) the resource base has become partitioned into generalist and specialist resources. Since we interpreted resource partitioning as decreasing niche overlap of specialists and generalists, we rephrase core sentence 5 accordingly.

A 6 If generalist niches move toward the center of the resource base, the mean overlap of generalist and specialist niches decreases.

Let us briefly return to the starting point and ask ourselves what happens to populational crowding afterwards. Density dependence theory (Hannan and Carroll 1992) explains that at the carrying capacity (so at all times after the starting point of resource partitioning), perturbations of populational competition (hence crowding) are dampened, and competition returns to an equilibrium state. An increase of competition causes organizational outflow, which in turn reduces competition. Conversely, a decrease of competition allows for organizational inflow, due to which competition will increase. Since the same argument holds for crowding, we specify this in a background assumption.

BA 1 After the starting point, populational crowding is (approximately) stationary.

From density dependence theory, it seems to follow that after the carrying capacity has been reached, the number of organization neither declines nor resurges. When unpacking the crowding measure (Def 2), one notices that the number of organizations and their niche overlaps can vary independently. This independence makes possible to sidesteps a possible contradiction with density dependence, that does not have niche overlap as a parameter in its models. So, when density dependence has it that at the carrying capacity, populational competition stays at the same level, the number of organizations may decrease or increase if at the same time their mean niche overlap increases or decreases, respectively.

In core sentence 4, the proliferation of specialist organizations is suggested to be a consequence of both the lessened crowding of generalists and their move to the center. Lemma 2 claims, however, that generalists' move to the center is a sufficient condition for increasing numbers of specialists. We claim that also the lessened crowding of generalists is a sufficient condition for specialist proliferation. Since after the starting point, populational crowding remains stationary (BA 1), and populational crowding is the summation of generalist and specialist crowding (Def 2), we can derive that,

L 3 If, after the starting point, generalist crowding decreases, specialist crowding increases.

Because after the starting point, the mean crowding of specialist niches does not increase (A 1), it must be the case that the number of specialist organizations increases.

L 4 If, after the starting point, generalist crowding decreases, the number of specialists increases.

Core sentence 4 states that the "lessened crowding of generalist and their move to the center" entail specialist proliferation. We have just argued that both events *independently* can cause the proliferation of specialists. Because specialist numbers can increase without generalists moving to the center, this increase can also be expected in populations in stable environments and with highly inert organizations that do not move.

Core Sentences 6 and 7

Sentence 6 says that "the key predictive variable in the model is the overall level of *market concentration*." Finally, sentence 7 says that "When the market is not highly concentrated, specialist organizational forms will not do as well as when it is highly concentrated.” These summarizing sentences address the research question and therefore are theorem candidates.

From the text (p.216) it seems that scale economies cause concentration to increase, although it is not said explicitly. But even if our reading between the lines is correct, it is certainly not said in the source text that the “predictive variable” concentration causes any of the other events described. Therefore we can not use sentence 6 in the explanation, but claim that not concentration but economies of scale cause resource partitioning and the proliferation of specialists. To substantiate our claim, we have to prove the following theorems,

Thm 1 If economies of scale come to dominate, niche overlap between generalists and specialists decreases.

Thm 2 If, after the starting point, economies of scale come to dominate, the number of specialist organizations increases.

If we succeed to prove the two theorems, then we have shown that concentration, as well as the six additional assertions (see Section 2.1), are not necessary in the explanation of resource partitioning processes. We have now completed our rational reconstruction of the text, and have prepared a set of statements to be formalized.

3 Formalization

The set of statements is the point of departure for our logical formalization. To represent the statements formally (see Appendix), we use standard first-order logic (introductory: Gamut 1991; Barwise and Etchemendy 1990; an overview: Hodges 1983; advanced: van Dalen 1994). First-order logic has explicit rules for constructing well-formed expressions in the language; strict rules of inference by which new expressions can be derived from existing ones; and, formal semantics by which the researcher can “see” in an exact manner what the world according to a theory looks like.

We evaluate our formal representation according to logical criteria. The formal theory should be, first, consistent and second, sound. The reason for working in this order is that according to the principle *ex falso sequitur quodlibet* (from falsehood everything follows), an inconsistent theory is automatically “sound” but not in a way any scientist would want it to be. Only those theorems should be derivable that follow from a consistent set of premises.

Consistency

If a theory is inconsistent, *i.e.,* if it says that both ϕ and not-ϕ are true, it can not describe any possible state of affairs in the world, and can not have a model in a technical sense too (Chang and Keisler 1990). Since we want resource partitioning theory to be consistent, we have to show that it has a model in which all sentences are true. To produce a formal model of the theory, we use an automated model generator, MACE[2], that runs on the set of formal premises.

MACE produced a model of our formal representation, and we can be sure that the formal representation is consistent.

Soundness

We test the derivability of theorems and lemmas using an automated theorem prover, OTTER (Wos et al. 1991). The theorem prover is given a set of (non-contradictory) premises and the negation of the statement to be proven. If the theorem prover finds a contradiction, then the negated statement is false. *Ergo*: the statement is true.

The theorem prover confirmed that each of the lemmas and theorems is derivable from the premises, so our representation of resource partitioning theory is sound.

4 Results

On the basis of the logical formalization, we can now explain resource partitioning and the proliferation of specialists, in a sound, consistent, and surprisingly parsimonious way. In the explanation, we have not used any of the six additional assertions (see Section 2.1). They are redundant, which means that resource partitioning and the proliferation of specialists can take place without relative size effects on competition; relative size effects on the availability of resources (*i.e.,* small pockets in the resource base for specialists); size localized competition; a larger periphery due to diversifying consumer tastes; a higher number of dimensions of the resource space; and, changing niche widths of surviving generalists.

According to the source text, at the starting point, most firms pursue a generalist strategy ("vie for the largest possible resource base"). We have not used this information in any derivation, which shows that the ratio of

[2]Both automated model generator MACE and automated theorem prover OTTER that we use can be down-loaded from `http://www-unix.mcs.anl.gov/AR/otter/`

specialists and generalists at the start does not matter for the outcome. Furthermore, we have shown that niche widths, partly characterizing specialists and generalists, are not necessary for the explanation either. Our results thus point out a far more general class of settings where the process of resource partitioning can be expected to occur.

Lemma 1–3 have demonstrated that lessened crowding of generalists is a sufficient condition for the increasing number of specialists, and generalists' move to the center is not necessary for the outcome to occur. The latter implies that also in stable environments and with highly inert thus non-moving generalists, specialists can proliferate. Last but not least, concentration, presented as the "key predictive variable" in the source text, plays no explanatory role. As a consequence, the two theorems answering the question "under what conditions will the specialist form be viable and why?" emphasize the role of economies of scale rather than concentration for resource partitioning (Thm 1) and the proliferation of specialists (Thm 2).

Going beyond the source text, one may ask if these two outcomes in their turn influence the density of the population. In several empirical studies, on automobile manufacturers (Carroll and Hannan 1995, p.206) and breweries (Swaminathan and Carroll 1995, p.224) among others, the number of organizations has been found to increase unexpectedly, after a period of stability or decline. On the basis of our logical formalization, we can derive a theorem that might explain the increasing number of organizations. Due to the generalist and specialist strategies in resource partitioning theory, the mean crowding of generalist niches is higher than that of specialist niches. Furthermore, from the starting point onwards, the mean crowding of both generalist and specialist niches does not increase (A 1 and A 2). Since populational crowding is stationary (BA 1), it not only follows that the number of specialists increases (Thm 2), but also that the number of in-flowing specialists is larger than the number of out-flowing generalists. This means that the number of organizations in the population increases.

To end our formalization effort with this new result, we formally derive it as Theorem 3. We first assume explicitly that,

A 7 At the starting point, the mean crowding of generalist niches is higher than the mean crowding of specialist niches.

Subsequently, we derive a new lemma, starting from Definition 2, that says that,

L 5 If the crowding of the resource base is stationary (BA 1), and the mean crowding of both generalist and specialist niches does not increase (A 1,2), and the mean crowding of generalist niches is initially higher than that of specialist niches (A 7), then the inflow of specialists is higher than the outflow of generalists.

The automated model generator confirmed that the set of premises, with Assumption 7 added, is consistent. Moreover, the theorem prover derived Theorem 3, saying that,

Thm 3 If, after the starting point scale economies come to dominate, specialist inflow is higher than generalist outflow.

This theorem is surprising because it is normally believed that for increasing density to occur, it is necessary that specialists are smaller than generalists and can thrive on less resources, or else that diversifying consumer tastes lead to a larger market periphery or to a higher dimensionality of the resource space. We have just proven that none of these assertions is necessary.

5 Discussion

In the long long ago, scientists took their time to study each textbook extensively. In our information-overloaded society, hardly anyone has the time for such extensive study, but still everyone expects to learn a great deal from textbooks and scientific journals. Ambiguous or sloppy discourse with many unnecessary assumptions impedes comprehension, and it is therefore important to have clear, parsimonious and logical theories with high explanatory power. With such theories, more facts can be understood on the basis of fewer information to start with. We believe that the reconstructed, and rigorously checked, theory of resource partitioning theory meets this modern demand.

A number of assertions from organizational ecology, as well as some assumptions from the core theory turned out to be redundant for explaining resource partitioning (Thm 1) and the proliferation of specialists (Thm 2), as we argued in the previous section. We have *proven* these two theorems, not just argued for them by example, metaphor, empirical generalization, or other questionable ways of reasoning that frequently pass for theory in social science (Sutton and Staw 1995). This means that the theorems and the redundancy of the listed assertions are true beyond reasonable doubt, provided that the assumptions are true, no matter how counter-intuitive the results may seem.

Logical support is far stronger than empirical support can ever be. The only empirical contribution that is on equal level is *counter* evidence against a theoretical statement (Popper 1959). In the case of resource partitioning, the published empirical results are affirmative, but confirmation does not add new explanatory information, and does not prove that the explanations are sound.

Along with logical rigor, one could ask if our results are robust. For sure, they strongly depend on the (generalized) definition of crowding from organizational ecology. To prove the theorems, this definition, or another one wherein crowding depends on the number of organizations and on niche overlap, is necessary. The results also depend on the existence of a carrying capacity, that imposes a (flexible) upper bound on crowding. If crowding levels are too high, organizations disband or their niche overlap decreases until crowding has landed on its equilibrium level. Furthermore, if generalist niches would be *less* crowded than specialist niches (contrary to A 7), then Theorem 3 would not longer hold.

The main difference between Theorem 1 and 2 on the one hand and the source text on the other hand, is the explanatory role of economies of scale versus concentration, respectively. One could ask how important this difference is. If, on the one hand, economies of scale come to dominate, some organizations, with the highest economies of scale, grow (much) larger than the other organizations in the population, middle-sized generalists disband, and (small) specialists proliferate. Then the level of concentration increases accordingly. If, on the other hand, concentration increases, this increase might be indicative for economies of scale. If this argument is true, concentration is a proxy for economies of scale, and can be used in empirical studies. The claim that concentration is "the key predictive variable" (sentence 6) though, is not supported by the remainder of the source text. Moreover, recent empirical findings in the higher education publishing industry, are at odds with the positive correrelation of concentration and economies of scale. Thornton (1999) found concentration to increase while economies of scale, and the number of foundings, decreased. Her findings seem to be inconsistent with sentences 6 and 7 from the core theory, but are consistent with our reading and formal representation.

In our formal representation, we have economies of scale at the far end of the explanation, and one may of course put a question mark right there. In some branches, like retail, it might be the case that mergers or fusions, not treated in the current text, cause economies of scale. At the same time, anticipated economies of scale may trigger fusions and mergers, complicating the causal picture. On top of these, fusions and mergers will also increase organizational outflow directly, as well as concentration. Compared to this picture, the current formal theory is a somewhat simplified, although correct, representation of more complicated social phenomena.

According to the text, specialists attempt to have low competitive pressure, hence low niche overlap from other organizations. One could ask What if specialists' efforts to differentiate themselves are counteracted by generalists (or other specialists), or remain without success because of scarce peripheral resources? According to our core model (as captured by Def 2), the number of specialists would then not increase. This outcome is in line with industrial economics, which does not assume strategy differences between small (*i.e.*, specialist) and large (*i.e.*, generalist) organizations. Resource partitioning does assume a strategy difference, and our model shows that this difference accounts for the dissension between ecologists and economists.

One could also ask a more elementary question. What if specialists attempt to have no niche overlap at all? Without niche overlap, they would not have any competitive pressure, which would, according to organizational ecology at least, be a splendid condition for survival. Baum and Mezias (1992) and Baum and Haveman (1997) have studied the Manhattan hotel industry and argued that proximity is good for survival, because an agglomeration of hotels apparently attracts far more customers than each hotel individually would. From their studies one can infer that niche overlap is beneficial to a certain extent.

To generalize organizational ecology and to unify different strands of research, one could establish a conceptualization wherein niche overlap and the number of organizations together determine the dynamics of (sub)populations. Niche overlap acts as an "attracting" force on organizations (more resources) and at the same time as a "repelling" force (stronger competition). In such a general theory, also the effect of organizational mass should be taken into account. Barron (1999) argues convincingly that mass effects explain the decline of populational density after a maximum, a "stylized fact" that we can not explain in our current model. Our formalization of resource partitioning can be expanded with assumptions that capture such findings and considerations. The logical framework, possibly complemented by mathematical modeling or computer simulation, can provide the rigor and precision necessary for strong theory.

Thus a formal representation of a theory is not a rigid end station, but a step toward new understanding. It is superior to its natural language counterpart for thoroughly examining alternative assumptions, and provides a stepping stone for further developments of the theory. But formal theory is no panacea. Other than formal ways of thinking remain indispensable, as well as empirical research and statistical inferencing.

In the case of resource partitioning, it took us about two years to resolve conceptual ambiguities, to fill loopholes in the argument, and to make a consistent, sound, and relatively simple reconstruction of the source text. We felt like medieval hermeneuticians, equipped with high-tech automated theorem provers. Now we leave it to the reader to decide if it was worth the effort.

Appendix: Logical Representation

First-Order Logic has symbols for constants, functions and relations, that we introduce in Table 2. In addition to these symbols, logic has two quantifiers, $\forall$ (for all) and $\exists$ (there exists), and five logical connectives, $\wedge$ (and), $\vee$ (or), $\rightarrow$ (if..., then ...), $\leftrightarrow$ (if and only if) and $\neg$ (not).

symbols (in order of appearance):

$SP(t)$	: time t is the starting point
$x > y$	: x is larger than y
$\overline{A}_g(t)$	: mean crowding of generalist niches at t (function)
$\overline{A}_s(t)$	: mean crowding of specialist niches at t (function)
$SE(t_1, t_2)$	: scale economies dominate from times t_1 to t_2
$n_g(t)$	: number of generalists at time t (function)
$GMC(t_1, t_2)$	: generalist niches move to the center of the resource base from t_1 to t_2
$\overline{a}_{gs}(t)$	: mean niche overlap between generalists and specialists at t (function)
$cr(t)$	: crowding of the resource base at t (function)
$x \simeq y$	: x is neither (significantly) larger than y, nor (significantly) smaller than y
$cr_g(t)$	: crowding of the generalist resource base at t (function)
$cr_s(t)$	: crowding of the specialist resource base at t (function)
$n_s(t)$	: number of specialists in at t (function)
$x - y$	: x minus y (function)

Table 2: Symbols used in the logical formalization.

Premisses

A 1 $\forall t_1, t_2 \ [\,[SP(t_1) \ \wedge \ (t_2 > t_1)] \ \rightarrow \ \neg(\overline{A}_g(t_2) > \overline{A}_g(t_1))\,]$

Read: If t_1 is the starting point, and t_2 is later than t_1, then the mean crowding of generalist niches will not be higher at t_2 than at t_1.

A 2 $\forall t_1, t_2 \ [\,[SP(t_1) \ \wedge (t_2 > t_1)] \ \rightarrow \ \neg(\overline{A}_s(t_2) > \overline{A}_s(t_1))\,]$

Read: If t_1 is the starting point, and t_2 is later than t_1, then the mean crowding of specialist niches will not be higher at t_2 than at t_1.

A 3 $\forall t_1, t_2\ [SE(t_1, t_2) \ \rightarrow \ [(n_g(t_1) > n_g(t_2)) \ \wedge \ (t_2 > t_1)]\,]$

Read: If scale economies dominate from t_1 to t_2, then the number of generalists at t_1 is higher than at t_2, where t_2 is later than t_1.

A 4 $\forall t_1, t_2 \; [\, [(n_g(t_1) > n_g(t_2)) \;\wedge\; (t_2 > t_1)] \;\rightarrow\; GMC(t_1, t_2) \,]$

Read: If the number of generalists is higher at t_1 than at t_2, and t_2 is later than t_1, then the generalist niches move toward the center of the resource base from t_1 to t_2.

A 5 $\forall t_1, t_2 \;\; [GMC(t_1, t_2) \;\rightarrow\; (\overline{A}_s(t_1) > \overline{A}_s(t_2))]$

Read: If generalist niches move toward the center of the resource base from t_1 to t_2, then the mean overlap between generalist and specialist niches at t_1 is larger than at t_2.

A 6 $\forall t_1, t_2 \;\; [GMC(t_1, t_2) \;\rightarrow\; (\overline{a}_{gs}(t_1) > \overline{a}_{gs}(t_2))]$

Read: If generalist niches move toward the center of the resource base from t_1 to t_2, then the mean niche overlap between generalists and specialists at t_1 is larger than at t_2.

A 7 $\forall t_1 \qquad [SP(t_1) \;\rightarrow\; (\overline{A}_g(t_1) > \overline{A}_s(t_1))]$

Read: If t_1 is the starting point, the mean crowding of generalist niches at t_1 is higher than the mean crowding of specialist niches at t_1.

BA 1 $\forall t_1, t_2 \;\; [\, [SP(t_1) \;\wedge\; (t_2 > t_1)] \;\rightarrow\; (cr(t_1) \simeq cr(t_2)) \,]$

Read: If t_1 is the starting point, and t_2 is later than t_1, then the crowding of the resource base generalist will be similar at t_1 and t_2.

We add an additional background assumption (**BA 2**), stating that a starting point of a resource partitioning process in a given population occurs only once. In other words, if a starting point has been reached, it will not be reached again. This is common sense background knowledge for humans, but not for computers.

BA 2: $\forall t_1 t_2 \;\; [\, [SP(t_1) \;\wedge\; (t_2 > t_1)] \;\rightarrow\; \neg SP(t_2)]$

Read: If t_1 is the starting point, and t_2 is later than t_1, then t_2 is not the starting point.

To be able to derive the lemmas and theorems, we also need to represent Definition 2 in first-order logic. Rather that translating the equalities straight away, we need for our derivations certain inequalities that trivially follow from this definition. For instance in the equality $cr_g = n_g\overline{A}_g$, if $\overline{A}_g$ does not increase and n_g decreases, then it is obvious that cr_g must also decrease. This inequality we call Corollary 1. In a similar way we get Corollary 2a, 2b and 3.

Cor 1 $\forall t_1, t_2\ \ [\,[\neg(\overline{A}_g(t_2) > \overline{A}_g(t_1))\ \wedge\ (n_g(t_1) > n_g(t_2))]\ \rightarrow\ (cr_g(t_1) > cr_g(t_2))\,]$

Read: If the mean crowding of generalist niches is not higher at t_2 than at t_1, and the number of generalists is higher at t_1 than at t_2, then the generalist resource base is more crowded at t_1 than at t_2.

Cor 2a $\forall t_1, t_2\ \ [\,[(cr_s(t_2) > cr_s(t_1))\ \wedge\ \neg(\overline{A}_s(t_2) > \overline{A}_s(t_1))]\ \rightarrow\ (n_s(t_2) > n_s(t_1))\,]$

Read: If the specialist resource base is more crowded at t_2 than at t_1, and the mean crowding of specialist niches is not higher at t_2 than at t_1, then the number of specialists is higher at t_2 than at t_1.

Cor 2b $\forall t_1, t_2\ \ [\,[\neg(cr_s(t_1) > cr_s(t_2))\ \wedge\ (\overline{A}_s(t_1) > \overline{A}_s(t_2))]\ \rightarrow\ (n_s(t_2) > n_s(t_1))\,]$

Read: If the specialist resource base is not more crowded at t_1 than at t_2, and the mean crowding of specialist niches is higher at t_1 than at t_2, then the number of specialists is higher at t_2 than at t_1.

Cor 3 $\forall t_1, t_2\ \ [\,[(cr(t_1) \simeq cr(t_2))\ \wedge\ (cr_g(t_1) > cr_g(t_2))]\ \rightarrow\ (cr_s(t_2) > cr_s(t_1))\,]$

Read: If the crowding of the resource base is similar at t_1 and t_2, and the generalist resource base is more crowded at t_1 than at t_2, then the specialist resource base is more crowded at t_2 than at t_1.

Lemmas

L 1 $\forall t_1, t_2\ \ [\,[SP(t_1)\ \wedge\ SE(t_1, t_2)]\ \rightarrow\ (cr_g(t_1) > cr_g(t_2))\,]$

Read: If t_1 is the starting point, and scale economies dominate from t_1 to t_2, then the generalist resource base is more crowded at t_1 than at t_2.

L 2 $\forall t_1, t_2\ \ [\,[SP(t_1)\ \wedge\ GMC(t_1, t_2)\ \wedge\ \neg(cr_s(t_1) > cr_s(t_2))]\ \rightarrow$

$(n_s(t_2) > n_s(t_1))$]

Read: If t_1 is the starting point, generalist niches move toward the center of the resource base from t_1 to t_2, and the crowding of the specialist resource base is not higher at t_1 than at t_2, then the number of specialists is higher at t_2 than at t_1.

L 3 $\forall t_1, t_2 \;\; [\,[SP(t_1) \;\wedge\; (cr_g(t_1) > cr_g(t_2)) \;\wedge\; (t_2 > t_1)] \;\rightarrow\; (cr_s(t_2) > cr_s(t_1))\,]$

Read: If t_1 is the starting point, the generalist resource base is more crowded at t_1 than at t_2, and t_2 is later than t_1, then the specialist resource base is more crowded at t_2 than at t_1.

L 4 $\forall t_1, t_2 \;\; [\,[SP(t_1) \;\wedge\; (cr_g(t_1) > cr_g(t_2)) \;\wedge\; (t_2 > t_1)] \;\rightarrow\; (n_s(t_2) > n_s(t_1))\,]$

Read: If t_1 is the starting point, the generalist resource base is more crowded at t_1 than at t_2, and t_2 is later than t_1, then the number of specialists is higher at t_2 than at t_1.

L 5 $\forall t_1, t_2 \;\; [\,[(cr(t_1) \simeq cr(t_2)) \;\wedge\; \neg(\overline{A}_g(t_2) > \overline{A}_g(t_1)) \;\wedge\; \neg(\overline{A}_s(t_2) > \overline{A}_s(t_1))$
$\wedge\; (\overline{A}_g(t_1) > \overline{A}_s(t_1))] \;\rightarrow\; ((n_s(t_2) - n_s(t_1)) > (n_g(t_1) - n_g(t_2))\,]$

Read: If the crowding of the resource base is similar at t_1 and t_2, the mean crowding of generalist niches is not higher at t_2 than at t_1, the mean crowding of specialist niches is not higher at t_2 than at t_1, and the mean crowding of generalist niches at t_1 is higher than the mean crowding of specialist niches at t_1, then the number of specialists at t_2 minus the number of specialists at t_1 is higher than the number of generalists at t_1 minus the number of generalists at t_2.

Theorems

Thm 1 $\forall t_1, t_2 \;\; [SE(t_1, t_2) \;\rightarrow\; (\overline{a}_{gs}(t_1) > \overline{a}_{gs}(t_2))]$

Read: If scale economies dominate from t_1 to t_2, then the mean niche overlap between generalists and specialists is larger at t_1 than at t_2.

Thm 2 $\forall t_1, t_2 \;\; [\,[SP(t_1) \;\wedge\; SE(t_1, t_2)] \;\rightarrow\; (n_s(t_2) > n_s(t_1))\,]$

Read: If t_1 is the starting point, and scale economies dominate from t_1 to t_2, then the number of specialists is larger at t_1 than at t_2.

Thm 3 $\forall t_1, t_2 \ \ [\,[SP(t_1) \ \wedge \ SE(t_1, t_2)] \ \rightarrow$
$[(n_g(t_1) > n_g(t_2)) \ \wedge \ ((n_s(t_2) - n_s(t_1)) > (n_g(t_1) - n_g(t_2)))]\,]$

Read: If t_1 is the starting point, and scale economies dominate from t_1 to t_2, then the number of generalists is higher at t_1 than at t_2, and the number of specialists at t_2 minus the number of specialists at t_1 is higher than the number of generalists at t_1 minus the number of generalists at t_2.

References

Axelrod, R. (1997). *The Complexity of Cooperation*. Princeton, N.J. Princeton University Press.

Barnett, W. and G. Carroll (1987). Competition and mutualism among early telephone companies. *Administrative Science Quarterly 30*, 400–421.

Barney, J. B. and W. G. Ouchi (1986). *Organizational Economics*. San Francisco. Jossey-Bass.

Barron, D. N. (1999). The structuring of organizational populations. *American Sociological Review 64*, 421–445.

Barwise, J. and J. Etchemendy (1990). *The Language of First-Order Logic*. Menlo Park. CSLI.

Baum, J. A. C. and H. A. Haveman (1997). Love thy neighbor? differentiation and agglomeration in the manhattan hotel industry, 1898–1990. *Administrative Science Quarterly 42*, 304–338.

Baum, J. A. C. and S. J. Mezias (1992). Localized competition and organizational failure in the manhattan hotel industry, 1898–1990. *Administrative Science Quarterly 37*, 580–604.

Boone, C., V. Bröcheler, and G. R. Carroll (2000). Custom service: Application and test of resource partitioning among dutch auditing firms from 1880 to 1982. *Organization Studies, forthcoming*.

Bruggeman, J. (1997a). *Formalizing Organizational Ecology*. Ph. D. thesis, Amsterdam, ILLC DS-1996-4.

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

Carley, K. and M. Prietula (Eds.) (1994). *Computational Organization Theory*. Hillsdale, N.J. Erlbaum.

Carroll, G. R. (1985). Concentration and specialization: Dynamics of niche width in populations of organizations. *American Journal of Sociology 90*, 1262–1283.

Carroll, G. R. and M. T. Hannan (Eds.) (1995). *Organizations in Industry*. Oxford. Oxford University Press.

Chang, C. and H. J. Keisler (1990). *Model Theory* (3rd ed.). Amsterdam. North-Holland.

Coleman, J. S. (1990). *Foundations of Social Theory*. Cambridge, MA. Harvard University Press.

Dalen, D. v. (1994). *Logic and Structure* (3rd ed.). Berlin. Springer-Verlag.

Freeman, J. and M. T. Hannan (1983). Niche width and the dynamics of organizational populations. *American Journal of Sociology 88*, 1116–1145.

Freeman, J. and A. Lomi (1994). Resource partitioning and foundings of banking cooperatives in Italy. In J. A. Baum and J. V. Singh (Eds.), *Evolutionary Dynamics of Organizations*, pp. 269–293. New York. Oxford U.P.

Gamut, L. (1991). *Logic, Language and Meaning*. Chicago. Chicago U.P.

Gilbert, N. and K. G. Troitzsch (1999). *Simulation for the Social Scientist*. Open University Press.

Hannan, M., J. Ranger-Moore, and J. Banaszak-Holl (1990). Competition and the evolution of organizational size distributions. In J. V. Singh (Ed.), *Organizational Evolution: New Directions*, pp. 246–268. Newbury Park. Sage.

Hannan, M. T. (1997). On logical formalization of theories from organizational ecology. In A. E. Raftery (Ed.), *Sociological Methodology*, pp. 145–149. Oxford. Blackwell.

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

Hannan, M. T. and G. R. Carroll (1992). *Dynamics of Organizational Populations*. New York. Oxford University Press.

Hannan, M. T., G. R. Carroll, E. A. Dundon, and J. C. Torres (1995). Organizational evolution in a multinational context: Entries of automobile manufacturers in Belgium, Britain, France, Germany, and Italy. *American Sociological Review 60*, 509–528.

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*. Cambridge, MA. Harvard University Press.

Hodges, W. (1983). Elementary predicate logic. In D. Gabbay and F. Guenthner (Eds.), *Handbook of Philosophical Logic*, Volume 1. Dordrecht. Reidel.

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

Kamps, J. and L. Pólos (1999). Reducing uncertainty: A formal theory of *organizations in action. American Journal of Sociology 104*, 1776–1812.

Kyburg, Jr., H. E. (1968). *Philosophy of Science: A Formal Approach*. New York. Macmillan.

Lakatos, I. (1976). *Proofs and Refutations*. Cambridge. Cambridge U.P.

Lomi, A. (1995). The population and community ecology of organizational founding: Italian cooperative banks. *European Sociological Review 11*, 75–98.

McPherson, M. (1983). An ecology of affiliation. *American Sociological Review 48*, 519–532.

Mezias, J. M. and S. J. Mezias (1999). Resource partitioning, the founding of specialist firms, and innovation: The american feature film industry, 1912-1929. *Organization Science forthcoming*.

Mitchell, W. (1995). Medical diagnostic imaging manufacturers. In G. R. Carroll and M. T. Hannan (Eds.), *Organizations in Industry*. Oxford. Oxford University Press.

Péli, G. (1997). The niche hiker's guide to population ecology: A logical reconstruction of organizational ecology's niche theory. In A. E. Raftery (Ed.), *Sociological Methodology*, pp. 1–46. Oxford. Blackwell.

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.

Péli, G. and B. Nooteboom (1999). Market partitioning and the geometry of the resource space. *American Journal of Sociology 104*, 1132–1153.

Podolny, J. M., T. E. Suart, and M. T. Hannan (1996). Networks, knowledge, and niches: Competition in the worldwide semiconductor industry, 1984-1991. *American Journal of Sociology 102*, 659–689.

Popper, K. (1959). *The logic of scientific discovery*. London. Hutchinson.

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

Shepherd, W. (1987). Concentration. In J. e. a. Eatwell (Ed.), *The New Palgrave*, pp. 563–564. London. Macmillan.

Sørensen, A. B. (1978). Mathematical models in sociology. *Annual Review of Sociology 4*, 345–371.

Suppes, P. (1968). The desirability of formalization in science. *Journal of Philosophy 65*, 651–664.

Sutton, R. I. and B. M. Staw (1995). What theory is *not*. *Administrative Science Quarterly 40*, 371–384.

Swaminathan, A. (1995). The proliferation of specialist organizations in the American wine industry, 1941-1990. *Administrative Science Quarterly 40*, 653–680.

Swaminathan, A. and G. R. Carroll (1995). Beer brewers. In G. R. Carroll and M. T. Hannan (Eds.), *Organizations in Industry*. Oxford. Oxford University Press.

Thornton, P. H. (1999). Concentrated markets in cultural industries: The decline of new firms in the higher education publishing industry. Paper presented at the American Sociological Association.

Wade, J. (1996). A community-level analysis of sources and rates of technological variation in the microprocessor market. *Academy of Management Journal 39*, 1218–1244.

Wos, L., R. Overbeek, E. Lusk, and J. Boyle (1991). *Automated Reasoning* (2nd ed.). New York. McGraw-Hill.