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Preface

The research project on *Systems Analysis of Technological and Economic Dynamics* at IIASA is concerned with modeling technological and organisational change; the broader economic developments that are associated with technological change, both as cause and effect; the processes by which economic agents – first of all, business firms – acquire and develop the capabilities to generate, imitate and adopt technological and organisational innovations; and the aggregate dynamics – at the levels of single industries and whole economies – engendered by the interactions among agents which are heterogeneous in their innovative abilities, behavioural rules and expectations. The central purpose is to develop stronger theory and better modeling techniques. However, the basic philosophy is that such theoretical and modeling work is most fruitful when attention is paid to the known empirical details of the phenomena the work aims to address: therefore, a considerable effort is put into a better understanding of the 'stylized facts' concerning corporate organisation routines and strategy; industrial evolution and the 'demography' of firms; patterns of macroeconomic growth and trade.

From a modeling perspective, over the last decade considerable progress has been made on various techniques of dynamic modeling. Some of this work has employed ordinary differential and difference equations, and some of it stochastic equations. A number of efforts have taken advantage of the growing power of simulation techniques. Others have employed more traditional mathematics. As a result of this theoretical work, the toolkit for modeling technological and economic dynamics is significantly richer than it was a decade ago.

During the same period, there have been major advances in the empirical understanding. There are now many more detailed technological histories available. Much more is known about the similarities and differences of technical advance in different fields and industries and there is some understanding of the key variables that lie behind those differences. A number of studies have provided rich information about how industry structure co-evolves with technology. In addition to empirical work at the technology or sector level, the last decade has also seen a great deal of empirical research on productivity growth and measured technical advance at the level of whole economies. A considerable body of empirical research now exists on the facts that seem associated with different rates of productivity growth across the range of nations, with the dynamics of convergence and divergence in the levels and rates of growth of income, with the diverse national institutional arrangements in which technological change is embedded.

As a result of this recent empirical work, the questions that successful theory and useful modeling techniques ought to address now are much more clearly defined. The theoretical work has often been undertaken in appreciation of certain stylized facts that needed to be explained. The list of these 'facts' is indeed very long, ranging from the microeconomic evidence concerning for example dynamic increasing returns in learning activities or the persistence of particular sets of problem-solving routines within business firms; the industry-level evidence on entry, exit and size-distributions – approximately log-normal – all the way to the evidence regarding the time-series properties of major economic aggregates. However, the connection between the theoretical work and the empirical phenomena has so far not been very close. The philosophy of this project is that the chances of developing powerful new theory and useful new analytical techniques can be greatly enhanced by performing the work in an environment where scholars who understand the empirical phenomena provide questions and challenges for the theorists and their work.

In particular, the project is meant to pursue an 'evolutionary' interpretation of technological and economic dynamics modeling, first, the processes by which individual agents and organisations learn, search, adapt; second, the economic analogues of 'natural selection' by which inter-

active environments – often markets – winnow out a population whose members have different attributes and behavioural traits; and, third, the collective emergence of statistical patterns, regularities and higher-level structures as the aggregate outcomes of the two former processes.

Together with a group of researchers located permanently at IIASA, the project coordinates multiple research efforts undertaken in several institutions around the world, organises workshops and provides a venue of scientific discussion among scholars working on evolutionary modeling, computer simulation and non-linear dynamical systems.

The research focuses upon the following three major areas:

1. Learning Processes and Organisational Competence.
2. Technological and Industrial Dynamics
3. Innovation, Competition and Macrodynamics

Abstract

Organizational ecology is a theoretical perspective on organizations that attempts to explain long-term social evolution, especially the rise and fall of organizational populations. This article reviews the most successful research program of the perspective, one based on the density-dependent model of legitimation and competition. It discusses the model and evidence that has been offered in its support as well as criticisms that have been registered. Unsolved research problems of the program are identified and models-in-progress attempting to address these open questions are discussed and compared.

Long-term evolutionary change in organizational populations:

Theory, models and empirical findings

Since its inception over twenty years ago, organizational ecology has maintained a strong interest in the ways organizational change unfolds over long periods of time. This interest has sparked an abundance of research efforts and a wide variety of approaches to the study of organizational evolution (for recent reviews, see Barnett, 1996, Baum, 1995; Boone and van Witteloostuijn, 1995; Singh and Lumsden, 1990). However, the major accomplishment to date is the result of a sustained and highly focused research program on a single model of long-term organizational evolution, the density model of legitimation and competition (see Hannan and Freeman, 1984; Hannan and Carroll, 1992) . This model assumes that change proceeds mainly through the selective replacement of different organizations, rather than through the adaptations of individual organizations. It posits two general forces as the drivers of selection, social legitimation and diffuse competition. Both forces are linked to the organizational density of a population in nonmonotonic ways specified by the theory.

Development and testing of the density model of long-term change has progressed rapidly. In fact, the model is so well established in organizational theory that it has been virtually relegated to the status of control variable. (At least one editor has been heard to say that his journal will no longer publish basic tests of the model, presumably because it is so well established.)[1] Yet at the same time much of this activity has occurred in isolation from other work on similar and related topics in the fields of technology management, evolutionary economics, industrial organization economics and economic history.

The primary purpose of this article is to take stock of the research program on density-dependent organizational evolution. In doing so I will, of course, review the theory, pertinent evidence and criticisms they have generated. I will also point to issues in need of further attention and describe some of the newer modelling approaches that researchers concerned with these issues are currently pursuing. I conclude by suggesting that far from being a dead end for further research, the density model and long-term organizational evolution present many interesting challenges for the years ahead.

1. Organizational populations and evolutionary change

Most economically oriented approaches to organizations begin with a conception of the market and then commence analysis by examining organizations competing directly within that market. Organizational ecology, by contrast, views the market as much the consequence of organizational actions; in other words, as endogenous. Ecologists thus begin analysis with a conception of the organizational population, defined broadly as the set of organizations characterized by a particular organizational form and dependent on a common set of material and social resources. Ecological analysis commences by identifying all organizations that might compete and then proceeds by modelling the interdependencies--including but not limited to competition--that emerge among them.

An example clarifies these differences. In 1992 Anand Swaminathan and I published an analysis of the contemporary American brewing industry (Carroll and Swaminathan, 1992). Our study focused on the period 1975 to 1990 and featured an analysis of two emerging organizational forms, microbreweries (producers of ale and

beer by traditional 'hand-crafted' methods) and brewpubs (producers of ale and beer who sell for consumption at the site of production, typically a brewery-restaurant), as well traditional mass production breweries. Our data collection efforts identified 200 breweries as operating in late 1989. These included 25 mass producers, 71 microbreweries and 104 brewpubs. Our analysis examined the founding rates and mortality rates of each of the three types of breweries, including the ways that numbers of the other forms affected them. We paid special attention to the different market contexts and consumer bases of the various organizational forms of breweries, including the fact that brewpubs operated in local markets and competed against other dining and drinking establishments.

Victor Tremblay, an industrial economist who has published a number of articles on the brewing industry, objected to our analysis (Tremblay, 1993). Tremblay complained that microbreweries and brewpubs do not compete with the mass production breweries. In his words, "it is inappropriate to include microbreweries and brewpubs in the same market with the mass producers...[because following the logic of substitutability in]...the 1982 Merger Guidelines...it is hard to believe that a 5% increase in Budweiser beer (the best-selling mass producer beer in America) will cause consumers to switch to the stouts and ales (which sell for about twice the price of Budweiser) produced by the microbreweries" (Tremblay, 1993, p. 94). He continues by asserting that "microbrewery beer competes more directly with imported than with the average domestic beer. Imported and microbrewery products have similar characteristics, being more full-bodied and having higher alcohol contents, and sell for about twice the price of the average mass-produced domestic beer" (p. 94). Tremblay's

position was supported by an anonymous reviewer who called microbrewers and brewpub operators, the "almost-hobbyist counterparts" of the larger brewers. He recommended publication of Tremblay's comment as a "useful corrective" to our article.

Why did we include the two new organizational forms when their combined market share was minimal? We did so because: both were involved in production of the same generic product as the mass producers; all three types of producers used the exact same ingredients; all three used roughly the same production techniques (albeit with great differences in scale); and all three made beverages purchased by consumer for the same purposes. So, despite slightly different organizational forms and despite dependence to some extent on separate consumer markets, the two new forms were potentially competitive with mass producers. Including them in the analysis allowed us to investigate the extent and exact nature of their relationship with mass producers. The fact that the forms were incipient and not strongly competitive at the time of analysis was no reason to exclude them because understanding organizational evolution was the goal. Indeed, excluding these forms until they become competitively important entails selection bias and blinds one to many of the underlying processes of evolution whatever the eventual outcome.[2]

Attempts to enumerate complete organizational populations usually generate many more organizations than are thought to exist. For instance, our data collection efforts in the American automobile industry from 1885 to 1981 identified 2149 producer organizations and over 3000 other organized attempts to produce that failed (Carroll and Hannan, 1995a). The majority of the "unknown" firms uncovered are small in size, leading some critics to suggest that they are unimportant and should be excluded from

analysis. While that might be appropriate for certain types of analysis, for evolutionary processes, we contend that it would again generate selection bias and likely preordain the findings.

Why? The problem is that only with hindsight--once the competitive outcomes are known--can we be sure to devise exclusion rules that do not omit firms or organizations that become dominant forces. And, even with hindsight, it is often impossible to do so because many great firms came from very humble origins. Consider the well-known cases of Microsoft or Apple Computers. And, consider the deleterious implications of applying of size exclusion rule to a specific historical population: for example, we have determined for the automobile industry that a scale exclusion rule of producing ten cars per year would omit the following firms because of their tiny early operations: Buick Motor Company, Marmon Motor Car Company, Olds Motor Works, Packard Motor Car Company, and U. S. Motor Company.[3] At the same time, firms such as the Williamson Motor Car Company of 1907 would need to be included because there is no way, with 100,000 dollars in capital (comparable value today of over 1.6 million dollars), that it could not be considered a potentially serious player, even though it never produced a car.[4] The issues are relevant not just for historical cases or for early periods of an industry. For instance, we find firms with a wide range of characteristics producing electric cars today. Some, such as Solectria Corporation, are large enough (with three models and annual production of about 100 cars) that little rationale for exclusion exists. Others, such as Suntera, have scant resources and appear highly fragile at the moment. However, a technological breakthrough in electric or solar power technology could change their positions quickly.

The theoretical point is that organizational evolution involves a great deal of uncertainty. Data collection schemes using arbitrary exclusion rules often eliminate this uncertainty, which usually comes in the messy form of many small and apparently "irrational" organizations. The issue is especially salient for the origins of an organizational population because a few events involving several (perhaps small) organizations might set off a path-dependent process that locks in a particular competitive structure (Arthur, 1989; Carroll and Harrison, 1995). There is also good reason to believe that organizational founding often involves genuine ambiguity about the commitment levels of many individuals, at least initially when organizing is minimal and prospects highly uncertain.

For these reasons, organizational ecologists interested in studying organizational evolution typically rely on a particular research design. That design is a comprehensive one. It involves going back to the origins of a specific organizational population or industry and then tracking all organizations that enter or exit from it, using a prescribed definition of organizational form. Although it seems to many nonevolutionists (equilibrium analysts, in particular) that the design errs on the side of overinclusion, the reverse is probably closer to the truth. Most ecologists will tell you that there is a fine grey line between some organizations in the population they have studied and other populations located nearby in the resource distribution.

This design possesses a number of research advantages. First, because it includes information on all the organizations in a population, the design can be used to model complex processes of competition among large numbers of individual

organizations. Second, observation of a population's inception means that estimates of the often critical early stages of evolutionary processes do not get truncated or overlooked. Third, by focusing on a single population, researchers gain institutional knowledge that assists them in developing appropriate control variables, thus mitigating against the possible deleterious effects of unobservable heterogeneity. The main disadvantage of the design is that it lacks representativeness, a deficiency overcome when many different population studies are undertaken.

The comprehensive population research design yields a stylized fact that has been the motivation for ecological work on long-term organizational evolution. That fact is a rough general pattern in the number of organizations in a population (density) over long periods of time (see Carroll, 1984; Hannan and Carroll, 1992). Characteristics of the pattern include initial slow and erratic increases in density, a subsequent period of rapid growth, and then a levelling off and a decline. Figure 1 shows an example, using the data from American automobile producers. Numerous diverse organizational populations show the pattern including labor unions, newspapers, banks, life insurance companies, typewriter manufacturers, television producers, telephone companies, wineries, beer brewers, trade associations, day care centers and others (see Gort and Klepper, 1982; Carroll, 1984; Klepper and Graddy, 1990; Hannan and Carroll, 1992; Utterback, 1994). The pattern is rough because the timing and levels of the various characteristics differ substantially across populations.

(Figure 1 about here)

2. The theory of legitimation and competition

Ecological theory explains the long-term evolution of organizational populations

by resort to two simple but precisely defined sociological forces. The first is social legitimation. It refers in this context to the taken-for-granted nature of particular organizational forms as the 'natural' ways of doing certain things. For instance, universities, with their medieval social structures, are the socially taken for granted organizational form for accomplishing basic research and advanced education in modern society. The definition derives the so-called institutional perspective on organizations, a decidedly phenomenological theory (Meyer and Rowan, 1977). The definition has been called a constitutive or cognitive conception of legitimation; it differs from many other conceptions, including widely used ones based on the legal or political standing of a practice or organization (Hannan and Carroll, 1995).

The second driving force of long-term evolution is diffuse competition. It refers to the competition that arises when organizations depend on the same set of finite resources. Diffuse competition implies that the viability of particular types of organizations are diminished when there are many as opposed to few examples of the type present. Diffuse competition may or may not be recognized by members of the various organizations; diffuse competition may or may not coincide with overt rivalry--direct competition--between specific organizations. So, for example, although labor unions may cooperate with each other and even be members of a common federation, they also each try to organize the same limited pool of workers. This situation creates diffuse competition because a worker belonging to one union is not available to the others.

3. A model and its empirical detection

The ecological theory of long-term organizational evolution posits that when a

new organizational form appears, say automobile manufacturing in the late 19th century, that it lacks legitimation or social taken-for-grantedness. Low or absent legitimation implies that organizing is difficult: capital sources are wary, suppliers and customers need to be educated, employees may hard to identify and recruit, and in many instances hostile institutional rules must be changed. As the form proliferates, legitimation increases. Initially, when the number of organizations is low, the returns to legitimation of adding another organization are great. However, when many organizations are present in the population, legitimation increases little or none as the density of the population rises. In other words, legitimation of an organizational population increases with density at a decreasing rate.

Diffuse competition rises within an organizational population as a function of the number of potential bilateral competitive relations. In a population of N, as N increases linearly, the number of such possible competitive ties increases geometrically (Hannan and Carroll, 1992). This implies that diffuse competitive rises with a population's density at an increasing rate.

At low levels, the strong effect of density on legitimation means that this force dominates organizational evolution. At higher levels, the impact of density on competition prevails. Social legitimation and diffuse competition are thus in some ways opposing forces. Figure 2 depicts their relationships with organizational density and each other. See Hannan and Carroll (1992) for formal specifications and Peli (1993) for logical analysis.

(Figure 2 about here)

How do we know that organization evolution proceeds as the theory holds? A

second part of the theory (described below) posits links between social legitimation, diffuse competition and observable rates of organizational founding and mortality. When legitimation is on the rise, entrepreneurs sense the opportunity and are increasingly attracted to the organizational form. Organizations founded during periods of increasing legitimation also find it easier to attract capital, suppliers, customers and employees. They also face fewer institutional obstacles. So as legitimation rises, not only do organizational founding rates increase, mortality rates decline as well. By contrast, when diffuse competition in an organizational population intensifies rapidly, entrepreneurs become wary. So too do industry gatekeepers who provide access to information, capital and other resources needed to found an organization. Founding rates fall in these periods. And, those organizations in operation at the time find the going tougher, leading to higher rates of failure and mortality.

Because rising density triggers legitimation when the population density is low and spurs competition when it is high, the theory yields two straightforward (but nonlinear) predictions about the relationships between density and vital rates. First, founding rates should rise and then attenuate as a function of density, thus resembling an inverted U-shape. Second, mortality rates should fall and then climb as a function of density, creating a U-shape pattern. Figure 3 illustrates these general nonmonotonic patterns, which have been fitted to a variety of specific functional forms including the log-quadratic and the generalized Yule (Hannan, 1991; Hannan and Carroll, 1992; Kamps and Peli, 1995).

(Figure 3 about here)

The generality of the theory and the widespread availability of relevant data

(organizational population life-history information, including density, founding events and morality events) quickly generated a large number of tests of the basic predictions. Conducted on a highly diverse set of populations, the overwhelming majority of these tests yield positive support for the theory (see Singh and Lumsden, 1990; Hannan and Carroll 1992; 1995; Baum 1995). The few disconfirming tests that have appeared typically are the consequence of flawed research designs, most notably left-truncated observation schemes that exclude the early history of a population. Efforts to delineate classes of non-conforming populations (e.g., service industries) have generally failed to be convincing. In fact, in many analysts' view, the empirical evidence of density dependence is so convincing that analyses of long-term organizational evolution not including these variables are suspect. Clearly, one way in which various approaches to organizational evolution could become more unified would be for researchers to look across traditional disciplinary boundaries and recognize such contributions and deal with them in their own work.[5]

4. Other evidence of legitimation and competition in organizational evolution

Another, less systematic way of verifying the theory involves examining the natural histories of organizational populations and looking for evidence of the large-scale operation of processes of legitimation and competition. That is, does a population's natural history conform to the general predictions of initial growth and development driven by social legitimation and later, high density evolution fuelled primarily by competition. This approach is decidedly more subjective but it does lend plausibility to the theory when, for example, a variety of such histories illustrate similar long-term struggles for establishing social legitimation or taken-for-grantedness. If

legitimation had existed initially at the low density points of these populations, then we believe that these histories would read differently.

Natural histories of organizational populations also suggest embellishments of the theory. An interesting recurring observation of this kind concerns the level of nature of social organization found early in the history of many industries or organizational populations. Simply put, origin periods of industries typically look and feel to sociologists like social movements.[6] This is true for telephones (Barnett, 1995a), newspapers (Olzak and West, 1991), automobiles (Carroll and Hannan, 1995a), labor unions (Hannan, 1995a), credit unions (Barron, 1992; 1995), and health maintenance organizations (Strang, 1995). Other industries have for the most part not been examined in this way.

What does this observation mean? A social movement is generally considered to be "the organized, sustained, self-conscious challenge to existing authorities" (Tilly, 1984, p. 304). It is defined as "a deliberate collective endeavor to promote change, in any direction and by any means possible....a movement's commitment to change and the raison d'etre of its organization are founded upon the conscious volition, normative commitment to the movement's aims or beliefs, and active participation on the part of the followers or members" (Wilkinson, 1971, p. 27). So to say that the origin periods of industries resemble social movements means that they are populated with individuals and organizations devoted to causes, lifestyles and visions of a better future for all rather than profit-maximizing entrepreneurs engaged in competitive battles based primarily on self-interest.

The theoretical implications of this observation have yet to be explored in any

depth. But, they might be profound. Consider that the usual explanations of industry emergence and initial growth have to do with either market needs (demand-driven explanations) or the great potential of unleashed technologies (supply-driven explanations). Comparable explanations of social movements rely on the severity of particular social problems or the economic and social deprivation of particular social groups. However, these intuitive explanations have proven spectacularly unsuccessful in empirical research. Instead, to explain social movements analysts now rely primarily on theories highlighting the organization and solidarity of social group as well as their ability to mobilize resources (Tilly, 1978; McCarthy and Zald, 1987; Olzak, 1992). Among other things, these theories feature the roles of preexisting organizational structures (which provide forums for discovering solidarity as well as focus and resources for articulated interests), social movement entrepreneurs (evangelical individuals who engage in institution-building and resource acquisition) and social movement organizations (entities designed to foster and protect the interests of the movement). These phenomena are all associated with processes that generate mutualism or positive feedback in the organizational population. An interesting research question thus asks whether among latent and nascent industries or organizational populations similar phenomena and processes might be able to account for early industry and organizational growth. If so, our views of industry origins would be radically changed.

5. Criticisms and refinements of the theory

As might be expected given its fast popularity, the theory of density-dependent legitimation and competition has received ample criticism. Virtually all of this

commentary has been directed at the theory or at theoretical interpretations of the evidence. That is, little debate has centered on whether the widely observed empirical associations of nonmonotonic density dependence in vital rates are valid (see, however, Petersen and Koput 1991; Hannan et al., 1991; Hannan and Carroll 1992, pp. 132-138).

Critiques of the theory and its interpretation convey three general themes. The first of these deals exclusively with the social legitimation process. While economists usually find this part of the theory intriguing, sociologists sometimes find it lacking. Why? What would cause sociologists to question the operation of a key sociological process? Some of the criticism is pure folly, symptomatic of the rhetorical chest-puffing that has infected social science and often makes it look bad. However, the serious complaints usually call for either more direct measures of legitimation or for a broader conceptualization that includes legal or socio-political legitimacy. Nothing is wrong with either suggestion. Nonetheless, waiting for a breakthrough in measurement technology that allows one to assess directly and to compare across contexts the taken-for granted nature of persons and other actors living decades and even centuries in the past might delay the project (Hannan et al., 1995). In the meantime, using a formal model to infer the operation of legitimation processes seems a sensible strategy.

In the view of most sociologists, legal or socio-political legitimacy is distinct from legitimation as taken-for-grantedness or constitutive legitimation (Hannan and Carroll, 1995). Little value would result from mixing the two into a single concept or measure, thus muddying up the waters. Taken alone, no one doubts that legal or socio-political legitimacy is a powerful determinant of organizational evolution---consider, for instance,

the organizational consequences of the Volstead Act, which prohibited the production and sale of alcohol products from 1920 to 1933. However, it is hard to build a predictive general theory around idiosyncratic, historically-specific acts of legislation and the like. Instead, the better approach would seem to be to incorporate these developments as control variables based on an understanding of a population's history. Without such controls, tests of the density-dependent theory of legitimation and competition would be flawed. But this is clearly not the case, as examination of any major study of the theory will show.

The second general theme of critiques focuses on the density variable itself. According to these views, organizational density is an incomplete way to analyze evolution (Winter, 1990; Dosi et al., 1993; Haveman, 1994). The opinion expressed recently by Nelson (1995, p. 69) typifies this position: "In assessing the relative importance of a particular routine in the industry mix, or analyzing whether it is expanding or contracting in relative use, it is not sufficient to 'count' the firms employing it. One must consider their size, or whether they are growing or contracting." Again, it is hard to disagree. However, it is also not entirely clear what the critique implies for research on the density model. One interpretation holds that tests of density dependence in organizational evolution need to control for organizational size, industry size and temporal variation in both. No debate here. Although early tests often ignored these factors because of data unavailability, numerous recent tests all include such measures. These tests show unequivocally that density dependence is a unique and general phenomenon. Another interpretation of Nelson's (1995) and others' remarks implies that we ought to have other, possibly complementary, possibly competing

general evolutionary theories of organizations based on characteristics such as size. Sure enough. But development of such theory need not be made the obligation of those who have already advanced one.

The third critical theme targets the diffuse competition component of the model. It argues that direct competition constitutes a better representation of late-stage evolution than does diffuse competition. The operational consequences of this position entail either redrawing the boundaries for counting density so that only direct competitors are included or weighting density counts of population members based on proximity along some competitive dimension such as price or geography (McPherson, 1983; Barnett and Carroll, 1986; Baum and Singh, 1994; Baum and Mezias, 1992). This approach might best be regarded as an extension or refinement of the basic density model applicable to particular contexts. Studies to date demonstrate high promise for its use in understanding and modelling interorganizational relationships. Nonetheless, questions remain about whether diffuse competition as modelled in the basic density model captures a distinct process or simply represents a good short-hand approximation to direct competition averaged across an entire population.

The theoretical challenge the direct competition approach presents concerns where to draw the boundaries for density counts (or, alternatively, how to weight potentially competing organizations in a complete population). The extremes involve, on the one hand, following the basic density model and counting (equally) every organization in the population and, on the other hand, following the logic of direct competition and circumscribing local competition very narrowly, so narrowly that every focal organization appears as an island and its relevant density count is one (Hannan,

1995). Obviously, something in between these two extremes is what direct competition theorists have in mind. But there is a lot of room in between and exactly where the boundary should be drawn is a theoretical issue and at the moment no compelling general theoretical rule has been advanced--instead, researchers circumscribe local competition on an ad hoc basis.

Oddly enough, progress has been made in developing general theory about the appropriate geographical boundaries of social legitimation and diffuse competition relative to each other. Both Hannan and Carroll (1992) and Hannan et al. (1995) have argued that legitimation operates on a broader geographical scale than diffuse competition, mainly because political and physical barriers disrupt the flow of plants, products and people more severely than they do cultural images. The argument leads to a multilevel specification of density dependence where the density variables associated with legitimation are counted across political boundaries and those associated with competition are counted only within boundaries. So, for instance, automobile manufacturers in European countries benefitted from the legitimation processes of other countries but experienced competition primarily from firms operating in the same country (Hannan et al., 1995). The specification shows promise but has yet to be thoroughly tested in a wide variety of contexts. Among the questions it raises is whether competition is restricted by geographical constraints or by political constraints. Current evidence is unclear.

6. Unsolved research problems of the program

As is obvious from the above review, the research program on density-dependent organizational evolution has achieved considerable success. However,

more than fine-tuning remains to be addressed. Two major research questions sit at the top of the agenda, the resolution of which is required to round out the model. Both concern late-stage evolution, organizational change in mature or well-established industries.

The first major question remaining unresolved in the program on density dependence is how to explain the precipitous decline in density frequently observed in mature organizational populations. For instance, in Figure 1 the number of automobile producers drops from a peak of almost 350 around 1910 to fewer than 50 in 1945 and then stays at relatively low levels. Simulations of the basic model of density dependence show that with the usual nonmonotonic relation in vital rates, the projected population follows an S-shape pattern (Hannan and Carroll, 1992; Carroll and Harrison, 1995). That is, the model of density dependence can reproduce observed population trajectories up to and including a peak but it cannot account for the subsequent common decline in density.

This problem has long been recognized. Indeed, in attempting a solution Hannan and I (Carroll and Hannan, 1989) introduced a "density delay" component in the mortality function of the model, consisting of a competitive effect of density at time of founding. We reasoned that such a persisting effect might result from either resource scarcity or tight niche packing. The delay in competitive feedback has the potential to produce population declines, including severe ones. It can also generate cycles of decline and growth (Leslie, 1959).

It winds up that density delay is a major find. Numerous studies have reported the predicted positive effect of density at time of founding on rates of organizational

mortality. In fact, empirical findings suggest that density delay may be the most robust element in the entire model and this component of the model is now considered an essential part of the theory (Singh and Lumsden, 1990; Baum, 1995). However, within the range of coefficients usually estimated, the effect is rarely strong enough to generate density declines of the magnitudes observed. Although there is always the possibility that estimates are biased downward in some unknown way (and thus density delay can generate the observed declines), most analysts have decided that, valuable as the density delay term is, some other mechanism or process is likely responsible for late-stage precipitous declines in organizational density. So, the first pressing research problem for the program is to explain these declines.

The second unresolved research problem is to account for the resurgence in organizational density that sometimes occurs very late in a population's evolution, usually after a major decline. An example of this pattern, not widely known, can also be detected in Figure 1, where the number of American automobile producers rises from 1970 to the end of observation in 1981. (Date we are currently collecting for the subsequent period to 1995 suggests that the trend has not reversed itself.) An even stronger reversal of this kind has occurred in American beer brewing, where the number of brewers has climbed to over 400 producers in 1995, after experiencing a low of 43 in 1983 (Swaminathan and Carroll, 1995). Although not ubiquitous, and not as regularly observed as late-stage declines, these renewals are common enough to require attention in any model of long-term evolution.[7]

In principle, the basic density model can explain late-stage resurgences in organizational density--these would be the result of diminished and then reinvigorated

legitimation. However, this interpretation does not seem plausible to many analysts, who note that once established, legitimation as social taken-for-grantedness in organizational forms does not erode rapidly. And, that certainly seems to be the case for the two populations we considered as examples for the renewal phenomenon--automobile manufacturing and beer brewing.

A slight reformulation of the density model does, however, make it applicable and potentially powerful in explaining renewals. The reformulation involves identifying new organizational "subforms" or subpopulations associated with the renewal period and arguing that these subforms require distinct (but perhaps not total) legitimation. For instance, Carroll and Swaminathan (1992) argued that the two organizational subforms fuelling the renewal process, microbreweries and brewpubs, both initially lacked recognition and social acceptance, despite the fact that each is essentially a manifestation of the well-known brewery organizational form.[8] Carroll and Swaminathan (1992) presented some empirical evidence supporting their position (microbreweries and brewpubs show positive density dependence). They also described an institutional arena surrounding these subforms displaying the social movement-like character typically found in populations undergoing the legitimation process.[9] My hunch, based on preliminary research in the contemporary automobile industry is that the renewal process there consists largely of producers of alternative fuel cars, who also show great collective commitment and zeal.

The reformulated model shifts the research problem from explaining the renewal to predicting the emergence of new organizational subforms. Unfortunately, theory here is lacking. We do not have good models for predicting the appearance of new

organizational forms generally. The question of subform emergence adds to this problem the conceptual one of distinguishing subforms from forms. Although these problems may very well be solvable, their current status leaves the door open for other possible explanations of the renewal process often observed in organizational populations.

7. The coming great model shoot-out

It is fairly easy to come up with explanations for the observed declines and renewals of any particular historical organizational population. Usually these have to do with the specific resources used by the population, including technology and customer base. By this reasoning, for instance, the rise of microbreweries and brewpubs might be accounted for by the development of so-called turnkey brewing equipment and by the increasingly diverse tastes of affluent beer drinkers.[10] Such explanations, however, often have little predictive power--they ring true mainly when used retrospectively. They also usually lack generality.

When dealing with regularly occurring patterns among highly diverse kinds of organizations, most analysts insist on predictive general explanations. For this reason, some organizational ecologists are attempting to account for late-stage population declines and renewals with models of general processes of organizational change. Although there may be other efforts underway of which I am unaware (including eventually successful ones), current work on each of three different models holds out promise for solving the mysteries of population decline and renewal. Described below, the three models are complementary but also distinct; implications of each have yet to be fully worked out and the relationships between them are not entirely clear.

Nonetheless, it seems unlikely that all three will demonstrate value in this context: thus, an exciting shoot-out is shoring up, with each model trying to outperform the others on relevant data.

The first model likely to be involved in this exercise is the resource-partitioning model (Carroll, 1985; Carroll and Hannan, 1995b). Developed originally in the context of newspaper populations, the resource-partitioning model makes predictions about the viability of specialist organizations in a population. It does so by examining the competition among large generalist organizations and then assessing how much resource space might be left for smaller specialist organizations. Competition among generalists is assumed to involve strong economies of scale. The key prediction of the model states that when markets are highly concentrated, opportunities for specialists increase, thus elevating specialist founding rates and lowering mortality rates. The model has been supported in tests of a variety of industries, including newspaper publishing, winemaking (Swaminathan, 1996), automobile manufacturing (Torres, 1995), integrated circuit manufacturing (Wade, 1993), medical diagnostic imaging (Mitchell, 1995), and banking (Lomi, 1995). It also has been used to interpret developments in the book publishing and music recording industries.

How does resource-partitioning account for the unsolved problems of long-term decline and renewal in organizational populations? The explanation of renewal is the more straightforward. Many observed late-stage renewal processes take place under conditions of increasing market concentration. Organizationally, late-stage renewals also typically involve a preponderance of specialist organizations, often (but not always) small specialists. Thus, Hannan and Carroll (1992, p. 48) suggest that late-

stage evolution might involve both density dependence and resource partitioning: "low density and low concentration (often occurring early in a population's history) seem to create very different conditions than low density and high concentration (often occurring late in the history). The primary difference pertains to the mix of generalist and specialist organizations. With high concentration, specialist organizations often often find small pockets of resources on which they can exist. This leads in turn to lower mortality rates and eventually to a larger population."

Resource-partitioning theory also posits a mechanism--economies of scale--that might explain long-term population decline. Because the specialist prediction is considered counterintuitive, it has received the bulk of the research attention (but see Carroll and Swaminathan, 1992). The generalist side of the model, so to speak, remains relatively underdeveloped. However, a full model of resource partitioning would need to include a specification of economies of scale, especially as they pertain to generalist organizations. One possibility would be to include in the mortality function a time-varying term measuring the ratio of the largest firm to the size of the focal firm. Evidence of economies of scale would be indicated by a positive coefficient for this variable, showing relative disadvantage by overall size differentials. A more complex specification, suggested by resource-partitioning theory, would expect scale economies to operate primarily for the generalist firms. Thus one could specify the size differential term as a function of organizational form, perhaps by interacting it with a measure of generalism. Taking the logic of the model even further, one might predict diseconomies of scale for specialists. This would generate a specification with nonmonotonic effects of the size differential or, alternatively, one with measures of generalism and specialism

both interacted size differentials (and opposing effects expected). Although researchers have frequently estimated mortality models with organizational size data (usually demonstrating strong negative effects of size on mortality), they have not to my knowledge attempted to estimate similar models specified with scale economies in mind. In my view, this is something that clearly needs to be investigated because with such a developed specification, resource partitioning theory might go a long way towards explaining both late-stage population decline.

The second model that shows promise in dealing with late-stage evolutionary processes is being developed by Hannan (1995b). In reexamining the legitimation process among organizational forms, Hannan acknowledges that taken-for-grantedness might be irreversible, at least in the short-run. Why? He gives two reasons to expect that the relationship between density and legitimation might change as a function of time since emergence of the form or population, i.e., population age. The first is an argument about tradition: "simple persistence can contribute legitimation." The second argument notes that legitimation depends in part on the perceptions and plans of other actors, including especially those to which a population looks for resources, social and material. A population's network of these others actors is small and unimportant initially but it develops over time. This leads Hannan to argue that "as a population matures, taken-for-grantedness comes to depend more on network structures." He reasons further that "if a population becomes institutionalized in the sense of developing ties with diverse actors, then changing density ought not to affect its fact-like status" (p.9).

Hannan also claims that competition among organizations in a population might change with population age. He notes that as a population develops, competitive

relations become increasingly structured because "firms...develop reputations, form alliances, distinguish classes of products and so forth" (p. 10). The shift from an unstructured competitive structure to a stable structured one coincides with a shift from primarily diffuse competition to primarily direct competition. Because organizational density tracks diffuse competition, its relationship with vital rates again changes as a function of population age.

As might be expected, Hannan's (1995b) observations do not lead him to throw out the density model or even to suggest major changes its basic underlying structure. Rather he proposes a refinement of the model, one that allows the basic processes to operate in a more subtle and complex way. The refined model, which might be called a population inertia model, posits that legitimation and competition become increasingly inert with population age. This implies that density still operates as predicted but that its effects attenuate with population age. In other words, density shows strong effects--of both legitimation and competition--in nascent organizational populations but much weaker effects in mature ones: the population feedback process erodes with time. Hannan proposes to model this process by interacting a polynomial specification of population age with the basic density variables. Although the model is yet to be tested extensively, estimates of both founding and mortality models for five populations of European automobile producers show strong empirical support (Hannan, 1995; Hannan and Carroll, 1995).

Based on current evidence, the population inertia model shows that density still matters for mature organizational populations. As currently specified, the model would seem to be better capable of explaining population declines than resurgences--these

trends are a simpler function of population age. However, because density is a persistent evolutionary force, it is important to model its effects properly if one is to be able to estimate accurately other hypothesized late-stage processes such as resource partitioning (Hannan, 1995b). For this reason, as well for its own explanatory ability, this model clearly deserves attention in future research on long-term organizational evolution.

The third and final model I will discuss is Barnett's (1995b) model of competitive intensity. This model also builds on the theory of density-dependent evolution but in a quite different way. Barnett begins by distinguishing between the effect of an organizational characteristic on the survival of a focal organization from that of its effect on other organizations. So, for instance, the large size of an organization might diminish its probability of failure but may not necessarily imply that its presence threatens competitors. Barnett defines competitive intensity as this second process: "the magnitude of effect that an organization has on its rival life chances" (p. 3). He makes a general argument about the possible sources of competitive intensity but in the model he develops it is tracked by organizational age. That is, Barnett begins by assuming that older organizations are stronger competitors than newer organizations. This leads to a model depicting the competitive environments organizations face not only in terms of density but also in terms of the aggregated ages of all members of the population. The argument holds that organizations in populations with many new organizations face considerably less competitive pressure than those confronting primarily old organizations.

A second part of Barnett's model posits that organizations become weaker

competitors as they grow in size, despite an expected in increase in longevity. Why? His arguments have to do with the ways larger organizations involve the averaging of fitness levels across a variety of bundled activities, thus making it likely that some of those activities are essentially subsidized and could not survive on their own. He also contends that large organizations often avoid strong selection pressures because "institutional mechanisms provide a way for large organizations to survive other than by outcompeting their rivals in the technical environment" (p. 16). These arguments lead to an extended model of competitive intensity wherein the effects of aggregate age are coupled with a term aggregating interactions of firm age and size. The complete specification predicts that older populations are potentially more competitively intense but that this condition is mitigated when (as is often the case) the population also contains many large organizations. That is, the effects of aggregate age of the population depend on the sizes of the organizations.

Barnett (1995b) presents supporting estimates of the age- and size-based model of competitive intensity. The estimates use data from two organizational populations (beer brewing and telephone companies) and involve both founding rates and mortality rates. He also simulates population trajectories implied by the estimates and demonstrates that the model is capable of explaining late-stage declines. He further reasons that the model might be able to account for renewals: "Competition becomes increasingly an experience-based process as organizations age, with strong survivors setting the stage for concentration. However, the large organizations in concentrated industries suffer, over time, from retarded competitive development. As organizations grow large enough, this ultimately will lead to industries populated by a handful of

variable but competitively weak institutions...this weakness means that organizational founding rates will increase in these settings...[thus accounting for]...the well-known tendency of stable, concentrated industries to be struck by waves of new founding" (p. 35). Future research on this promising model will determine the plausibility of these claims.

8. Conclusion

When looking back over the last decade, most organizational ecologists share a sense of accomplishment. This feeling occurs in large part because of the speed with which ecological theory and research has cumulated, a development considered remarkable by other organizations researchers (Pfeffer, 1993). The mainstay of this enterprise has been the model of density-dependent legitimation and competition, which has proven highly robust and general. The model is now well established and it represents a potentially important starting point for those attempting to understand and explain long-term organizational evolution in any industry or population. However, the research program behind this model is far from finished: the major problems of late-stage organizational evolution, population decline and renewal, remain to be solved. The remaining work gives many ecologists an additional sense of urgency, as competing ideas and models are advanced regularly to explain these phenomena. Too often situations like this end up as propaganda wars, with the proponents of various ideas claiming more firepower than their theories can really muster. If the past decade is any indication though, then we have to reason to be optimistic that a different fate awaits organizational ecology: evidence, not rhetoric, will determine the most deserving model.

Notes

1. According to Jim March (1995), this is one of the signs that a theoretical perspective has been truly influential.

2. Consider the possible extreme outcomes. Should mass producers remain dominant as these new forms emerge, then it would be important to know the details about the potential competitors that were warded off. Or, should the new forms rise to prominence, then records of their early histories would likely be central to their understanding. It winds up that in the brewing case the outcome is yet to be resolved. However, the numbers and market shares of the new forms has continued to increase at dramatic rates through 1995. Most mass producer brewers now make at least one product aimed directly at these markets and many microbreweries have reached substantial scale and engage in national distribution of their products. Even on its own terms (of direct competition), Tremblay's argument for exclusion of these forms is no longer sustainable. Thus, analysis proceeding according to his logic would be forced to choose some arbitrary starting point in the early 1990's (when direct competition became discernible) as the "beginning" of the microbrewery movement. Would it not be preferable to choose the actual origins?

3. Other rules, such as including organizations only after they reach a certain size, carry other liabilities. Among other things, these inclusion points are arbitrary and give distorted views of histories and events.

4. Present value is calculated by applying the Consumer Price Index.

5. Obviously, there are many ways one could deal with such a development in a neighboring discipline. I doubt that many researchers are willing to accept whole-

heartedly a theory from another discipline. However, when the development involves empirical associations it would seem useful to attempt competitive testing with one's pet theory. Should an association withstand such an effort, then perhaps formulation of an alternative explanation would prove interesting.

6. We use here generally accepted broad definitions of social movements. As Tilly (1984) has pointed out, these definitions may be historically applicable only to the last two centuries. They may also be too broad for analysis of political movements, which is not our purpose here.

7. Because most studies of organizational populations examine organizational forms still alive (and thus involve right-censored observation), it could be that the lateness with which this pattern typically arises accounts for its less frequent observation. That is, observed populations may not be old enough at study's end to have undergone a renewal process.

8. Carroll and Swaminathan (1992) did not use the term subform but they did describe the two forms under discussion as constituting subpopulations.

9. In fact, microbrewers and their customers routinely refer to the "microbrewery movement."

10. Although heard regularly, it winds up that these particular explanations do not work very well, even for brewing. See Carroll and Swaminathan (1993).

Figure 1. Density of American Automobile Producers
1885 - 1981

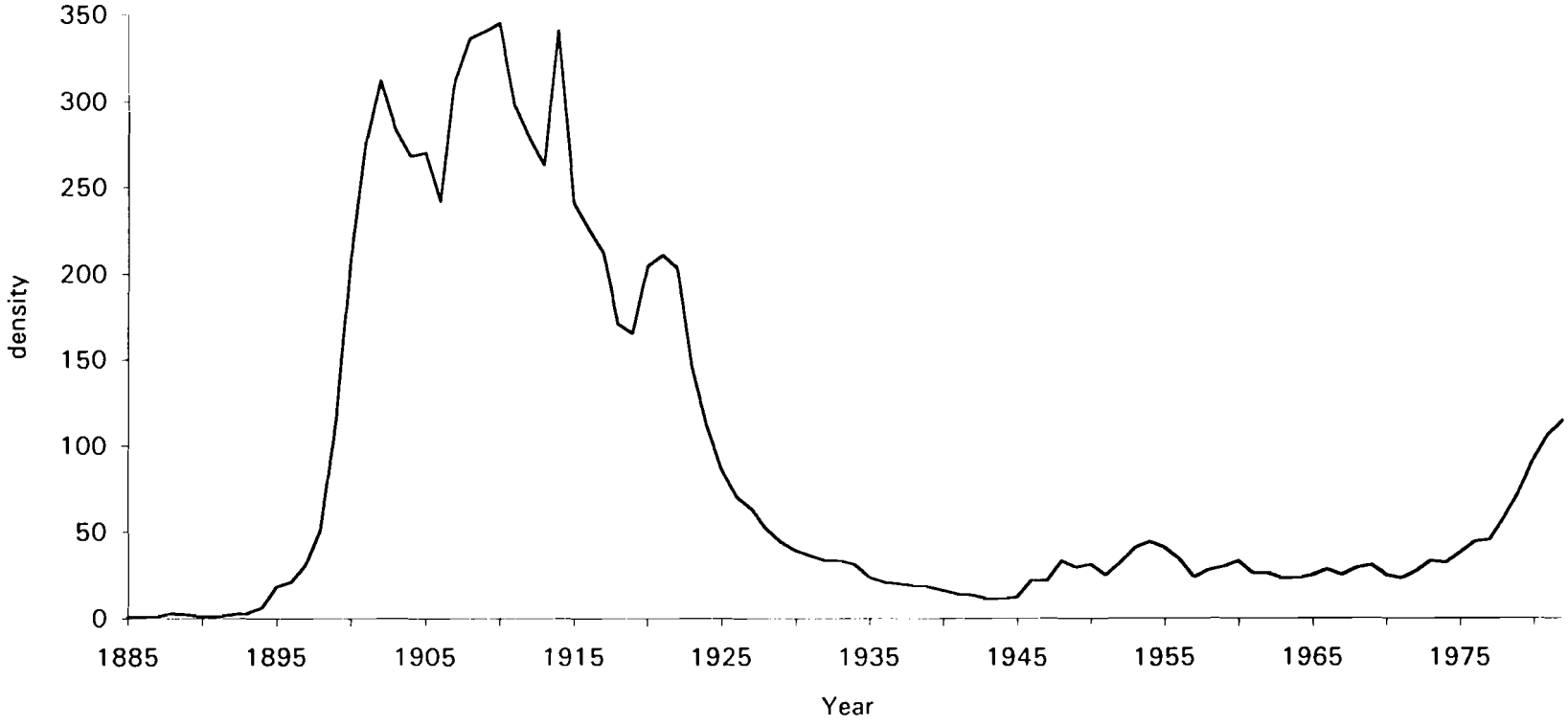


Figure 2. Legitimation and Competition

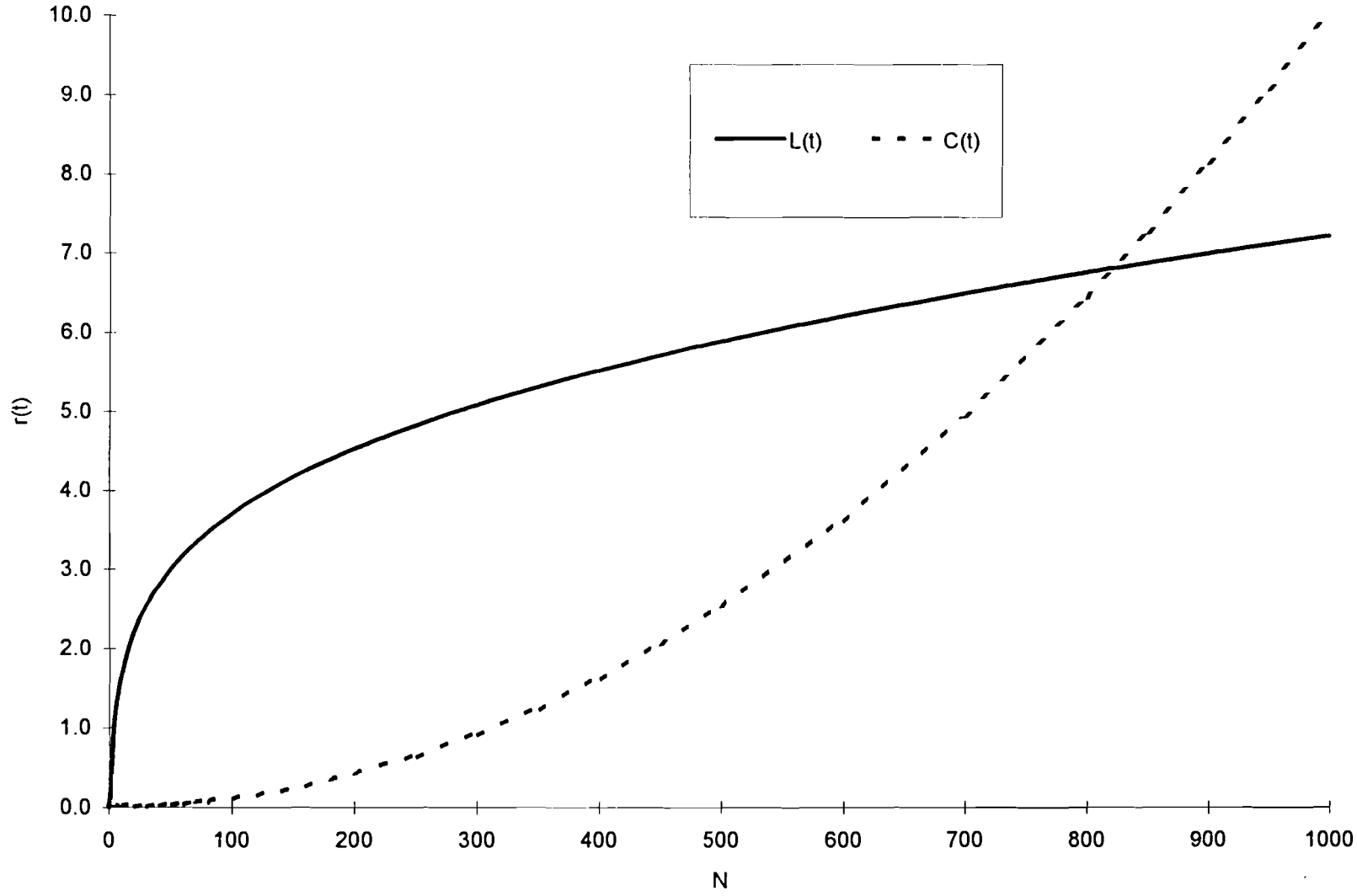
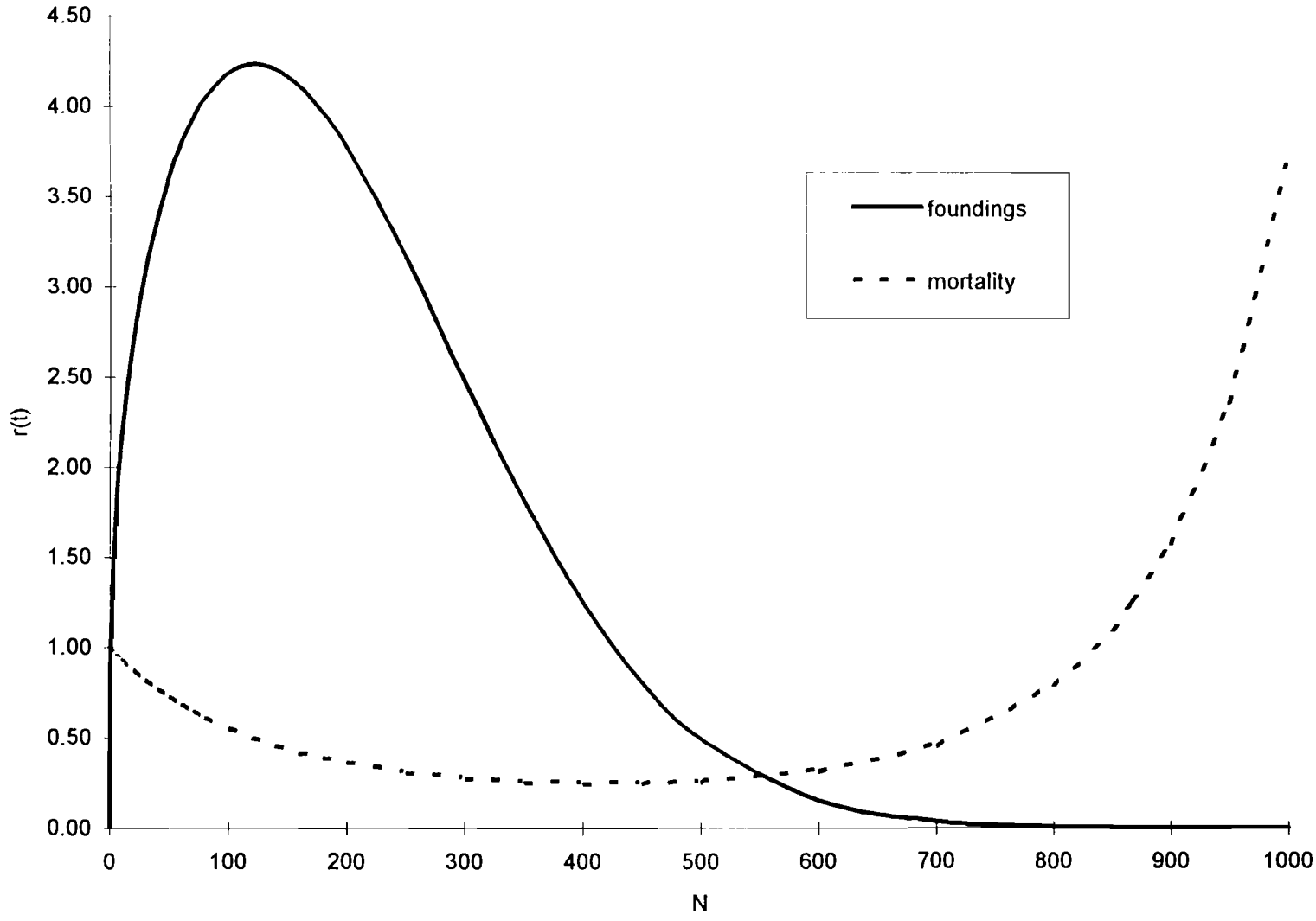


Figure 3. Foundings and Mortality



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