Organizational Mortality in European and American Automobile Industries
Part I: Revisiting the Effects of Age and Size

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Recent research on organizational mortality controls for the effect of age-varying organizational size and yields divergent results. Some studies find that ageing lowers mortality rates; others find the opposite pattern. We argue that this divergence reflects partly an overly simple specification of the effects of age and size. We argue that the effects of size on mortality rates differ by age group. Using complete data on organizational populations of automobile manufacturers in Britain, France, Germany, and the United States, we find that specifications with such age-variation improve over the usual specifications. The results for the American, French, and German populations indicate that age dependence is negative for the largest organizations and positive for small ones. The pattern is the reverse in the British population.

Introduction

The seemingly straightforward issue of age dependence in organizational mortality rates has become unsettled. Ten years of research had shown that ageing lowers mortality rates – at least beyond some brief initial interval. However, some recent studies have muddied the waters, by controlling for variations in organizational size over lifetimes. Roughly half of these studies (which control what had been unobserved heterogeneity in most prior research on the subject) find that mortality rates decrease with age and half show the opposite. Thus, there is an empirical puzzle: why do results about age dependence diverge? This paper seeks to resolve this puzzle by using an improved specification of the effects of age and size on organizational mortality rates.

Age dependence in mortality rates has deep theoretical implications. If age dependence is negative, then populations of mature organizations are stable. This result comes through clearly in simulation studies of the life histories of organizational populations. When age dependence is set to be negative (and other relevant parameters of founding rates and mortality rates are set equal to those found for real organizational populations), then the early entrants into the simulated population tend to persist throughout the population's history. Low baseline mortality rates for old organizations means that they can weather environmental shocks that can destroy their younger competitors (Barron, West, and Hannan, 1994). However, if age dependence is positive, then populations of mature organizations are fragile – environmental shocks can devastate old organizations, and new entrants can displace their older rivals. In other words, the pattern of age dependence in mortality rates plays an important role in shaping the dynamics of organizational worlds.

Given the importance of the issue, the relationship between ageing and mortality rates needs to be clarified. In particular, more attention needs to be paid to the way in which age and size might interact in shaping mortality rates. We do so here by examining mortality rates of automobile
manufacturing firms in five distinct national organizational populations, those of Britain, France, Germany, and the United States, over the period 1885–1981. We specify the effects of age and size on mortality rates differently than in prior research. We ask whether mortality rates of automobile manufacturing firms rise or fall with age when we use this new, more flexible specification. The findings suggest new ways of thinking about the relationships among age, size, and organizational mortality.

Age and Size Dependence in Organizational Mortality: Theory

The sociological analysis of age and organizational mortality began with Stinchcombe's (1965) claim that mortality rates of young organizations exceed those of old ones — organizations face a liability of newness. The logic of Stinchcombe's argument can be compared usefully with those of other social scientists by considering the theoretical processes invoked in drawing implications about the relationships between age and mortality, on the one hand, and size and mortality, on the other. The relevant processes build on five concepts: endowment, imprinting, inertia, capability, and positional advantage.

Endowments

Organizations differ in the quantities and qualities of their initial resources. Some are endowed with extensive financial and social capital, because their founders have great wealth, status, or political influence or because the social conditions of founding are favourable (resources might be abundant and few corporate actors might be competing for them). Others find themselves severely disadvantaged at founding, with these conditions reversed. Endowments bear on the issues under consideration in two ways. First, developing capabilities is costly, and extensive endowments permit greater investment in capability. Carroll and Hannan (1989) argue that organizations founded in periods of intense competition for resources face a 'liability of scarcity'. They cannot invest in developing capabilities, and the failure to make such investments at the outset has irreversible negative consequences for life chances.

Second, endowments can affect mortality rates directly. A well-endowed organization can maintain its structures and members even if it cannot continually mobilize resources from the environment. Endowments matter most in the first months and years of operation. Endowments depreciate unless replenished by continuing positive flows of resources from the environment. Until an endowment is depleted, the organization's risk of mortality is low. Once the endowment is exhausted, the risk of mortality jumps. There is an obvious implication for age dependence in mortality rates. At a given level of endowment, the mortality rate is low for the period of depletion and jumps afterwards. That is, mortality rates increase with age. In the usual formulation of this idea (Brüderl and Schüssler, 1990; Fichman and Levinthal, 1991), the level of endowment is regarded as an unobservable random variable, which makes the length of the period of exhaustion also an unobservable random variable. If the distribution of endowments is (roughly) continuous, one will observe that the hazard of mortality rises smoothly from zero to a peak (the point of exhaustion for the best endowed organizations).

Imprinting and Structural Inertia

Imprinting refers to a process in which events occurring at certain key developmental stages have persisting, possibly lifelong, consequences. The idea that firms and other kinds of organizations tend to be imprinted by their founding conditions comes from Stinchcombe's (1965) elaboration of Weber's account of the logic of organization building. Stinchcombe argued that social and economic structures have their maximal impact on new organizations. In attempting to accumulate financial and human capital, entrepreneurs expose their designs to intense scrutiny. Proposals get tested against taken-for-granted assumptions about structural forms and employment relations. Because conventional wisdoms and taken-for-granted assumptions change over historical time (as new forms flourish and others wane), the tests imposed on proto-organization also change. Consequently, the kinds of
organizations that emerge reflect the social structure of the founding period.

Imprinting requires an initial mapping of an environmental condition onto the nascent corporate actor. The imprinted characteristics must be inert (or at least possess a fair degree of hysteresis). Otherwise, subsequent modifications of the structure will erode the association of founding conditions and those features.

What are implications of imprinting for age dependence in mortality rates? Capabilities and positional advantages depend on the state of the social, cultural, technical, and political environments. What constitutes a valuable technical capability, for instance, changes with the evolution of a technology (Tushman and Anderson, 1986). Moreover, location in a bridge position between 'structural holes' (Burt, 1992) loses its value if the amount of activity to be bridged declines sharply. More generally, environmental change tends to erode the value of given capabilities and positions. According to the imprinting story, founders build organizations that fit time-specific environments and intense selection processes operating on new ventures sharpen the fit between organizational designs and planned capabilities and the environment. According to the theory of structural inertia (Hannan and Freeman, 1977, 1984), organizations get locked in by their early decisions and actions. So environmental change will tend to erode the fit between organizations and environments in this evolutionary view.

Barron, West, and Hannan (1994) articulate the implications of this line of argument for age dependence. They assume that the distance of an organization's current environment from its founding-period environment is proportional to its age. Then, the quality of the match declines monotonically with age, and age dependence is positive. In other words, there is a liability of obsolescence due to the joint action of imprinting, inertia, and environmental change.¹

Capabilities

An organization's capabilities consist of its stock of solutions to the problem of producing collective action in a specified environment. In other words, capabilities are context-specific. Capabilities are often based on routines that codify an organization's dispersed learning (March, 1988; Nelson and Winter, 1982). An important dimension of capability involves the capacity to reduce friction among the many activities and routines that typically must be undertaken to produce the organization's collective product (Williamson, 1981). The more refined and harmonized an organization's routines, the greater the organization's capability in the specified environment. Thus, in a stable environment, improvements in capability increase the expected quality of performance and thereby decrease the risk of mortality.

A major part of Stinchcombe's argument for the liability of newness concerns the effect of ageing on capabilities (in a constant environment). In particular, Stinchcombe argues that new organizations suffer from low average quality of performance because they lack experience. As youthful organizations age, they acquire experience and can potentially learn from it. The stylized image of the organizational learning curve captures this kind of process. As organizations learn from experience, they refine their productive routines and the meta-routines that co-ordinate them.

Stinchcombe also argues that new organizations face jeopardy because they must rely on the cooperation of strangers. To the extent that trust enhances collective action, lack of familiarity among co-workers is problematic. As time passes, trust tends to develop within work-groups. As a result, the organization's capabilities improve, because an important source of friction is reduced.

Subsequent theory has followed Stinchcombe's lead in emphasizing that experience improves capabilities. For instance, Hannan and Freeman's (1984) theory of organizational inertia holds that norms of rationality in the modern world demand that organizations achieve low variance in the quality of their outputs and make rational accounts of their activities. Not all organizations can achieve reliability and accountability; those that do have survival advantages. New organizations lack these capabilities, which are acquired in learning by doing and the accumulation of organization-specific human capital. Therefore, the development and refinement of these capabilities depends upon age.

Recent lines of argument about capabilities run opposite to this mainstream view. Barron, West,
and Hannan (1994) draw on the analogy with senescence processes observable in animal and human life histories to suggest that organizations accumulate durable local structures that constrain collective action. Such encrustation erodes the capability for efficient collective action. According to this story, there is a liability of senescence: age dependence in mortality rates is positive.

Another opposing argument questions the relationship between capabilities and mortality rates. March’s (1991) account of organizational learning tells a cautionary tale about the consequences of the continual refinement of a competence. Organizations that seek to exploit their competencies, by searching for ever better refinements of their existing capabilities, can find themselves in a ‘competency trap’ if the world changes. Only organizations that have already achieved some competence and follow an ‘exploitation’ strategy can be trapped by it. Thus this line of argument opposes the mainstream story, at least in the case of the exploitation strategy. The polar opposite strategy, ‘exploring’ for solutions that lie far from the organization’s current capabilities, has no obvious relationship with aging, as long as the region to be searched is large relative to an organization’s radius of search (so that an old organization would not have searched most of the solution space) or the set of possibilities to be searched changes over time.

Positional Advantage

A final set of relevant arguments about the effects of age and size on mortality rates concerns the organization’s position in the social structure. Stinchcombe (1965) points out that trust also matters in building ties with other organizations (e.g., potential suppliers and customers) and important actors in the social environment (e.g., holders of capital, government officials and regulators, and so forth.) Just as it takes time for trust to develop within organizations, it also takes time to build trust in external relations. Because maintaining good relations with key external actors enhances organizational performance and also arguably affects survival chances directly, the build-up of favourable external ties over organizational lifetimes lowers mortality rates. This argument too implies negative age dependence in mortality rates.

Positional advantages come in many forms. These include occupancy of positions that bridge structural holes (Burt, 1992), favourable reputation (Kreps, 1996), high status (Podolny, 1991; Podolny, Stuart, and Hannan, 1996), occupancy of positions in multiple markets (Barnett, Greve, and Park, 1994), and political influence. Some positional advantages such as bridging structural holes would seem not to depend upon age and experience. Others, such as market power, and possibly political influence, appear to be more influenced by size than by age. Still others, such as favourable reputation and high status presumably depend upon some demonstrated history of performance and thus depend in part upon age. New organizations thus find themselves at a disadvantage when reputation and status matter. Although not all kinds of positional advantages accrue to experience, we are unaware of any argument that holds that such advantages decline systematically with age. Thus, arguments about position advantage, if they are relevant to the issue at all, concur with Stinchcombe’s original assertion of negative age dependence.

Summary

Despite the apparent simplicity of age effects, there is obviously no shortage of theory to account for observed patterns. Theorists invoke arguments about endowments, imprinting, position, and capabilities to explain patterns of positive, negative, and non-monotonic age dependence. Endowment theories are seen to imply positive age dependence. Theories about imprinting effects lead to predictions of positive age dependence. Arguments about capabilities can imply either negative or positive age dependence, depending on whether the relevant capabilities are thought to improve or deteriorate with age. Finally, positional advantages are usually argued to produce negative age dependence.

 theorists frequently use a mixture of two or more processes to make predictions. For instance, those who emphasize the role of endowments in shaping early mortality experiences have overlaid this process of positive age dependence with standard stories about age-dependent accumulation of competence and positional advantage. Thus Brüderl and Schüssler (1990), Fichman and Levinthal (1991), and Brüderl, Preisendörfer, and Ziegler (1996) assume
that mortality rates rise with age initially due to the exhaustion of endowments and then fall with age beyond the peak with further ageing. In other words, there is an inverted-U shaped relation between age and the mortality rate. This image leads them to posit a liability of adolescence.

Size

A major complication in investigating any ageing process is untangling the relationship of age and size. This is true regardless of the process thought to be underlying the age effect. Growth and decline from an organization's initial size affect its mortality hazard directly. Small organizations (either those that started small and never grew or those that have shrunk to a small size) abut an 'extinction boundary'. A random shock that merely inconveniences a giant organization can destroy a small one. Levinthal (1991) formalized this intuition as the implication of a random walk in a space representing 'organizational capital'. In this formulation, organizations begin with different endowments and experience a series of random shocks from a specified distribution. Positive shocks cause capital to grow; negative shocks cause it to contract. Each organization continues to exist until its organizational capital hits zero, at which time it disbands. Organizations with small endowments have meagre life chances, and small size (capital) at any subsequent time has the same implication. In other words, very small organizations have high mortality rates because they exist close to the edge. Large organizations can shrink for extended periods, spending down their assets, before disbanding. The temporal scale of the mortality process depends upon the size of the organization (Hannan and Freeman, 1977).

Large organizational size has long been thought to facilitate the accumulation of superior capabilities. A tradition in the social sciences, dating to Durkheim (1933) as reconceptualized by Hawley (1950), Weber (1968), and Schumpeter (1950) holds that large organizations gain efficiencies from an expanded internal division of labour. For instance, Schumpeter (1950) argued that large firms have superior capacities in producing new knowledge because they can develop more elaborated research and development processes. As evidence has mounted that large size no longer conveys unambiguous advantages in modern industrial economies, scholarly opinion about the relation of size and capability has shifted. Today giant firms are more often seen as dozing Gullivers besieged by nimble Lilliputians. Analysts of the organizational world are much less prone to attribute superior capabilities to large organizations. The well-documented negative effect of size on mortality rates stems from processes other than the accumulation of capabilities, according to the contemporary understanding.

A special kind of positional advantage (or disadvantage) arises from an organization's position in the size-distribution of an organizational population. Received theory from industrial-organization economics holds that the scale economies give firms above the minimum efficient scale an advantage (producing at lower average cost) over smaller ones. They might also have an advantage stemming from economies of scope, gaining from the complementarities resulting from grouping certain diverse activities within the scope of the firm. Arguments about economies of scale and scope imply that very small organizations cannot win head-to-head competition with larger ones.

None the less, small organizations can sometimes find viable niches within which to escape such direct competition, that is to pursue a strategy of horizontal differentiation. One way is by exploiting market segments that are too small to be exploited profitably by very large organizations. Another way is by specializing so as to produce goods and services whose appeal comes from socially constructed images of high-fashion or craft production (Carroll, 1984). Whether these two strategies are viable depends on the structure of the market and the organizational community (Carroll, 1985; Swaminathan, 1995). In any event, taking account of the possibilities for various kinds of specialization strategies makes it clear that the cost advantages accruing to large size can differ considerably between markets.

In short, the theory about age and size effects on organizational mortality is rich but fragmented – there are many pieces available but not much guidance about how to achieve integration. For now, note that the various theoretical elements all potentially pertain to any type of organization – theoretical integration must address the question about how and when the various processes are
combined and at what time in the organizational life cycle one process might dominate others. Formulating a comprehensive theory that tells how the processes get mixed is a complex undertaking. Disentangling effects of age and size empirically is also a non-trivial matter, as the two often are highly correlated. Understanding these phenomena and developing useful theory demands empirical research that explores more complex models for combining age and size effects on organizational mortality rates. A major step along these lines involves relaxing assumptions about proportionality in effects, as we show below.

Age, Size, and Organizational Mortality: Empirical Findings

A great deal of research has found support for Stinchcombe's argument that mortality rates of young organizations exceed those of old ones (Carroll, 1983; Freeman, Carroll, and Hannan, 1983). However, some research found that mortality rates sometimes rise during a brief early portion of the life-span — while endowments are exhausted — before declining over most of a typical life-span (Carroll and Huo, 1988; Brüderl and Schüssler, 1991; Fichman and Levinthal, 1991; Brüderl, Preisendörfer, and Ziegler, 1996). Until recently, the voluminous research on this issue failed to consider how variations in size over organizational lifetimes might interact with ageing. Indeed, size variations might account for the observed low mortality rates of old organizations: organizations tend to grow as they age, and mortality rates decline with size (Dunne, Roberts, and Samuelson, 1989; Wholey, Christianson, and Sanchez, 1992; Barron, West, and Hannan, 1994).

We have identified 18 studies reporting results from analyses that relate organizational mortality rates to age and size and also update size repeatedly over the life-spans of all (or nearly all) organizations in a population. Five studies find monotonic negative effects of age, even after controlling for age-varying organizational size. These are studies of savings-and-loan associations in California, 1977–87 (Haveman, 1992), California wineries, 1946–84 (Delacroix, Swaminathan, and Solt, 1989), New York State life insurance companies and assessment companies, 2 1881–1931 (Lehrman, 1994), producers of certain recently developed medical devices over the histories of the sub-industries, 1952–89 (Mitchell, 1994), and American automobile manufacturers (Hannan et al. 1995).


The remaining nine studies find positive age dependence once age variations in organizational size have been taken into account. This is the case for New York life insurance companies, 3 1860–1937 (Ranger-Moore, 1990), Manhattan banks, 1840–1980 (Banaszak-Holl, 1991), day-care centres and nurseries in Toronto, 1971–87 (Baum and Oliver, 1991), American brewpubs and microbreweries, 1975–90 (Carroll and Swaminathan, 1992), Manhattan hotels, 1898–1990 (Baum and Mezias, 1992), American credit unions, 1980–89 (Amburgey, Dacin, and Kelley, 1995), New York City credit unions, 1914–90 (Barron, West, and Hannan, 1994; Hannan, West, and Barron, 1994), Illinois banks (excluding Chicago), 1900–95 (Barnett and Hansen, 1996), and commercial banks in Tokyo, 1867–1985 (Han and Torres, 1995).

What can we conclude from these 18 studies? A natural way to group them would combine studies reporting monotonic negative age dependence and those showing inverted-U shaped age dependence, because both imply that the mortality rates of old organizations are lower than those of younger ones. Giving equal weight to each study, this grouping yields nearly a heat: nine studies find positive age dependence and nine studies find (long-run) negative age dependence. We doubt, however, that all of the studies deserve equal weight in informing issues of age dependence. Several technical and substantive matters must be clarified first before we can understand the joint effect of age and size on mortality rates. The issues requiring attention include (1) the proportional specification of the effects of
organizational size, (2) the conceptualization and measurement of organizational size, (3) variations in organizational form, and (4) truncation of observation schemes.

Improving Specifications of Age and Size Dependence

Proportionality of Effects

The most important theoretical issue in our analysis concerns the specification of age and size effects. All of the prior studies assume that effects of size are separable from the effects of age. More precisely, they assume that the effects of age and size are proportional (in the sense of Cox, 1975). This means that the mortality rate (at any age and size) can be represented as the product of a first component which depends only on age and a second which depends only on size. Such an assumption might not be warranted for at least two reasons. First, large size (absolute or relative) might have a more powerful bearing on the mortality chances of older organizations. This is so because large old organizations are more likely to have accumulated slack, a set of unused resources, which can provide a buffer against adversity. Second, large old organizations have established networks of suppliers, buyers, and distributors. Actors in this network partly share the fate of the large old organization; and consequently they are more likely to absorb or share risks, especially in the face of crisis.

A major focus of the research reported here concerns the substantive importance of possible non-proportionality of the effects of key covariates. Indeed, the assumption of proportionality of the effects of size does not fit well with the histories of populations of automobile manufacturers. Moreover, allowing non-proportional effects changes greatly the pattern of age dependence in these populations.

Specification of Size Effects

We also investigate whether conclusions about the effects of age and size are sensitive to the scaling of organizational size. In so far as we can determine, all of the prior studies measure organizational size in natural units, on an absolute metric (e.g. dollar value of assets, number of employees, barrels of output). Such an approach seems best suited to analysing cross sections or brief histories during which the size distribution in the population remains (nearly) constant. Our analysis treats nearly the full histories of populations which contain some of the largest firms in the world. Over the period of observation, the average size of automobile manufacturers grew by several orders of magnitude. The largest manufacturer in the world in 1900 would be a tiny firm in today’s industry. If large scale conveys advantages leading to lowered mortality rates, what are we to make of this comparison? Are these advantages of scale absolute or relative? In other words, does a firm gain (dis)advantage by virtue of its absolute size or by its position in the size distribution?

Our review of extant theory indicates that positional advantages ought to matter. Large size relative to other organizations in a population is likely to convey advantage in intrapopulation competition. This advantage might stem from scale economies in production, which allow larger firms to enjoy lower average costs. Or it might come from disproportionate influence over suppliers and distributors. In either case, large size relative to competitors will lower rates of mortality.

Even if size matters most in this relative sense, very small absolute size might still matter, according to available theory. As noted above, very small firms exist close to an extinction boundary. Organizations close to such an extinction boundary are very likely to be destroyed by a single random shock, e.g. the loss of a key contract or key employee. This risk of very small size does not depend on the sizes of the other firms in the population. At the other end of the spectrum, large absolute size gives an organization leverage over its trading partners, regulators, and the like. This effect, too, should persist even if the population contains other large organizations. So, we expect that absolute size will also have a negative effect on mortality.

Organizational Form

Variations in organizational form might require more attention in efforts to understand the divergence of results in the prior research. The results of prior studies apparently divide by organizational
sector. Much of the evidence of positive age dependence comes from studies of populations of financial service institutions. Barron, West, and Hannan (1994) speculated that positive age dependence might be the rule in financial service industries—commercial banks, savings banks, credit unions, and life insurance companies—because deposit institutions demanded a high level of trust from depositors in the era before widespread deposit insurance. This feature of their service caused deposit institutions to grow by recruitment within established social networks. Because social networks have a tendency towards closure, the possibilities for network-based growth diminish as an organization ages. Early on, such organizations can grow rapidly by exploiting the networks of their early members. But, once the limits of the (relatively closed) set of strong ties are reached, the organization’s potential recruitment pool shrinks considerably. If this argument is correct, then we might expect to find different patterns of age-variations in mortality rates in organizational populations whose products or services are disseminated by more impersonal means (e.g., exhibitions at trade shows, advertising, distributors, and so forth) than in those relying on networks.

Mode of Entry

Important differences in life chances might follow from the ways in which organizations enter a population. Some are formed de novo, meaning that resources have been assembled from scratch for the sole purpose of building an organization of the particular kind. Other organizations enter the population from established bases in other industries or sectors. In such cases of de alio entry, the entity is a new member of the population, but it is not a new organization. Ageing processes are likely to differ for the two entry modes, yet prior studies gloss over this difference.

In comparing these modes of entry, Carroll et al. (1996) argue that lateral entrants have an initial advantage (deriving from greater average levels of capital and other resources) but that this initial advantage diminishes as organizations age. Why? One reason is that subsidies received by the lateral entrant are likely to decline as time passes (given that the new entrant is expected to become independently viable). Another reason is that de novo entrants are likely to possess greater flexibility in growth. When opportunities and problems arise, de novo entrants can move more decisively in redploying personnel, machines, and capital than lateral entrants, who are constrained by the justifications, plans, and agreements hammered out in their origin firms at the time of entry. These arguments suggest that lateral entrants will have initial lower mortality rates than de novo entrants but these differences will diminish as tenure in the industry increases. Indeed, the mortality curves might cross. We examine this possibility here, and we investigate whether allowing the curves to cross might affect conclusions about age dependence.

Methodological Issues

In addition to the theoretical and substantive concerns discussed to this point, an important methodological issue must be considered in interpreting the existing research. Most studies use left-truncated observation plans. This means that records on organizational life histories in these studies begin some time after the initial developments of the organizational populations. Analysis based on such observation plans are subject to survivorship bias. Left-truncated data provide some useful information about mortality, if analysed properly. Organizations entering during the window of observation provide information about survival at all observed ages. Those alive at the start of the observation window provide information on survival to later ages, conditional on survival to the start of the window. However, using this information requires conditioning explicitly on survival of these organizations until the start of the window. Most of the research reviewed above fails to do this. Instead, analysts have fitted parametric models of age dependence (e.g., Gompertz, Weibull, and log-logistic specifications) without correction for left-truncation (see Tuma and Hannan, 1984: 128–135 and Guo, 1993). Consequently, much available information about the effect of age and size on mortality rates comes from analyses with imperfect estimators.
Whether survivorship bias makes a substantively important difference in these studies cannot be readily determined. We doubt that this flaw would, by itself, reverse the sign of the effect of age on mortality rates. However, it could easily produce evidence favouring age dependence when the underlying process does not depend upon age. Correcting this fault might produce more consistent evidence. In any event, our observation plan has the advantage of avoiding such survivorship bias.

Automobile Industries

We chose to study automobile industries to produce a sharp contrast with the financial service industries that have been the source of the best data on the issues of interest. In particular, unlike banks, life insurance companies, and credit unions, automobile manufacturers did not grow primarily through recruitment in social networks and were not limited strongly by regulatory restrictions. Many firms also entered automobile production as established manufacturers of other products, especially bicycles, carriages, and engines. Comparing these lateral entrants and de novo entrants allows us to examine the implications of alternative entry modes for age variation in mortality processes. For both reasons, analysis of the effects of age and size on mortality rates of automobile manufacturers might reveal the limits of the prior research discussed above.

At a more general level, our efforts here represent an attempt to identify and measure the major sources of heterogeneity in organizational mortality rates. This is important, because uncontrolled unobserved heterogeneity has long been known to generate spurious negative age dependence (Tuma and Hannan, 1984). As better data and research designs become available, organizational researchers can turn previously unobserved characteristics into observed ones in analyses of mortality processes. In this case we focus on size (absolute and relative) and entry mode, paying special attention to their joint effects with age in driving mortality processes. Analyses using this more complete information and a more flexible, non-proportional stochastic specification might well lead to different findings about age dependence in organizational mortality.

Research Design

This study analyses the three largest European automobile industries – those in Britain, France, and Germany – and the world’s largest automobile industry, that of the United States. It considers nearly the full history of these industries from 1885, the start of the industry, through 1981 (the last year of full coverage from our most comprehensive source of data).

The data come from a study that coded histories of automobile manufacturers worldwide from reports of automobile historians and collectors (Hannan, et al. 1995; Carroll and Hannan, 1995b). The most comprehensive information comes from two encyclopedias: Georgano (1982) and Baldwin et al. (1987). These sources organize their reports around marques, not firms. For instance, although Georgano (1982) does not contain an entry for British Leyland, it does contain entries for Austin, Jaguar, Morris, Rover, Range Rover, Triumph, and other marques produced at various times by British Leyland. Entries for marques had to be combined to create a record for each firm. The records contain information about spells of automobile production by firms but not about their complete lifetimes, which sometimes involved operation in another industry before and/or after a spell of automobile production. In some cases, the sources do tell about the creation and destruction of the firms. In so far as the sources permit, we reconstructed the organizational histories of the firms in these industries.

In the case of the American industry, we also had access to another source, which provides especially thorough coverage: the Standard Catalogue of American Cars (Flamang, 1989; Kimes and Clark, 1989; Gunnell, Schripf, and Buttolph, 1992). We also consulted Kutner (1974) and Automotive News (1993) for recent periods.

The national populations of automobile manufacturers contain many more firms than people would imagine. We have data on 995 British firms, 828 French firms, 373 German firms, and 2197 American ones. Not unexpectedly, most of these firms
were small, short-lived, and obscure. The historical record does not provide many important details about the life histories of such firms. A clear strategic research choice presents itself. Excluding the obscure firms introduces sample selection bias by systematically eliminating firms with short life-times. In other words, including information on such obscure organizations is crucial to sound inference about the causes of organizational mortality. But doing so means relying on incomplete information. Therefore, we have made several assumptions about obscure, short-lived firms to allow them to be included in the analysis. These assumptions appear reasonable in the context of the history of this industry, as we explain next.9

Beginning and Ending Events

Firms entered automobile production by several paths. Three were especially common: (1) a firm is built de novo — it has no prior organizational experience at time of entry, (2) a new firm results from a merger of auto-makers or by the division of one automobile manufacturer into two or more firms, (3) a firm enters from another industry. Although the American data provide reasonably complete coverage of type of entry, this information is unavailable for most cases in the European populations (Table 1). For the obscure European firms, we know only that they began automobile production but not whether they migrated from other industries.10 This set presumably includes both newly founded firms and entrants from other industries. The more complete American data indicate that both types of entry were very common.

The life chances of lateral entrants and firms that arise by merger or fission of auto-makers were better than those of firms that began de novo or whose type of entry is unknown in these populations. However, using the distinction between lateral entry and start by merger or fission does not improve model fits significantly. Therefore, we use only one distinction about type of entry in this analysis: whether a firm has prior existence of any kind (either in the automobile industry or in some other industry). We treat firms with unknown entry events as not having existed previously.

For ending events, the most important distinctions concern (1) disbanding, (2) exit to another industry, and (3) merger or acquisition. Disbanding has an unambiguous meaning: the firm failed as a collective actor. Exit to another industry also suggests a lack of success in automobile manufacturing. The other ending events are harder to interpret. Although merger and acquisition both result in the loss of one or more independent collective actors, firms merge and acquire for diverse reasons. Sometimes a firm flounders and its owners seek to recover some fraction of their investment by selling the firm. In other cases, a thriving firm’s competencies command great value from potential acquirers or merger partners. Because of the ambiguous meaning of mergers and acquisitions, we concentrate on disbanding and exit to another industry.

We often do not know exactly what happened to most firms when they dropped from the set of producers, especially in the European populations (Table 2); this is invariably the case when spells of automobile production were short. Apparently automobile historians could rarely reconstruct the

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<td>Founding</td>
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<td>Entry from another industry</td>
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</tbody>
</table>
Our reading of the historical materials suggests to us that most exits of unknown type were disbandings or exits to other industries — and this is clearly the case in the American population (Table 2). So we treat these two events alike: the dependent variable in this analysis is disbanding/exit to another industry, defined to include events of unknown type. Firms known to have ended by other events (merger, acquisition, nationalization) are treated as (non-informatively) censored on the right at the times of these events.

### Measuring Organizational Size: Absolute and Relative

We measure size as scale of operations, specifically the firm's annual production of automobiles. This measure is available more regularly than accounting measures of performance, and it is likely to be measured more reliably in most cases. Despite an exhaustive search, we did not uncover precise information on annual production for most short-lived firms. Our understanding of the industry's history leads us to believe that the absence of any information about a firm's size indicates clearly that its scale was very small. The counts often come from new vehicle registrations, which were presumably exhaustive, and from counts of surviving automobiles. Often the sources indicate that the firm produced only 'a few' automobiles. In others, no mention is made of the scale of production. Often the sources suggest that production levels were substantial, but they do not provide exact counts. For instance, this is the case when there are gaps in the yearly series at the end of a firm's history and previously reported

### Dating Events and Measuring Organizational Age

What is normally called organizational age in the literature is, with few exceptions, actually a measure of duration: tenure in a particular organizational population. Tenures in automobile production can be calculated straightforwardly when dates are exact or nearly exact. The archival sources contain varying degrees of precision in dating events. Sometimes, the sources give the exact date; other times, they give only the month and year, season and year, or only the year. To make analysis tractable, we converted all of the information about timing to decimal years. Dates given to only the year were coded as occurring at the midpoint of the year. In this case, our coding rules assign the starting time to the middle of the first year and the ending time to the midpoint of the next year, giving a completed tenure of one year (which is, again, the expected tenure under the assumption of a uniform distribution). These rules, which are consistent with Petersen's (1991) recommendations for dealing with the problem of time aggregation, generalize to handle all the cases we encounter.
Table 3. *ML* estimates of the baseline proportional hazard models: mortality rates of automobile manufacturers 1885–1981

<table>
<thead>
<tr>
<th>Duration ((m))</th>
<th>Britain</th>
<th>France</th>
<th>Germany</th>
<th>USA</th>
</tr>
</thead>
<tbody>
<tr>
<td>(u &lt; 0.5)</td>
<td>-4.90 (-6.07)</td>
<td>-5.69 (-6.09)</td>
<td>-9.77 (-6.98)</td>
<td>-0.690 (-3.39)</td>
</tr>
<tr>
<td>(0.5 \leq u &lt; 1)</td>
<td>-4.55 (-5.65)</td>
<td>-5.66 (-6.06)</td>
<td>-9.46 (-6.78)</td>
<td>-0.797 (-3.86)</td>
</tr>
<tr>
<td>(1 \leq u &lt; 3)</td>
<td>-5.31 (-6.58)</td>
<td>-6.32 (-6.79)</td>
<td>-10.0 (-7.15)</td>
<td>-1.30 (-6.32)</td>
</tr>
<tr>
<td>(3 \leq u &lt; 7)</td>
<td>-5.43 (-6.68)</td>
<td>-6.34 (-6.79)</td>
<td>-10.3 (-7.26)</td>
<td>-1.56 (-7.37)</td>
</tr>
<tr>
<td>(u \geq 7)</td>
<td>-5.74 (-7.06)</td>
<td>-6.73 (-7.22)</td>
<td>-10.6 (-7.56)</td>
<td>-1.73 (-7.91)</td>
</tr>
</tbody>
</table>

Prior existence

| In (relative size) | -0.459 (-5.09) | -0.463 (-4.94) | -0.718 (-5.07) | -0.110 (-2.39) |
| In (size)          | -1.46 (-4.23) | -1.60 (-3.98) | -3.55 (-6.25) | -0.090 (-5.81) |
| Size < 50          | -0.054 (-2.03) | -0.028 (-0.798) | 0.066 (0.960) | -0.099 (-3.93) |
| Density at founding| 0.580 (3.67) | 0.700 (4.67) | -0.082 (-0.436) | 0.338 (2.34) |
| Density \(_2/1000\) | 0.004 (2.45) | 0.007 (1.44) | 0.136 (3.24) | 0.136 (3.24) |
| Depression year    | 0.005 (-0.963) | -0.013 (1.72) | 0.023 (1.16) | -0.006 (-4.31) |
| In (GDP)           | 0.306 (1.19) | 0.800 (4.01) | 0.753 (2.14) | -0.246 (-3.74) |
| GDP               | -0.079 (-0.516) | -1.14 (3.21) | -0.102 (-0.243) | -0.004 (-5.18) |
| Number of spells   | 5582 | 5171 | 2272 | 8893 |
| Number of events   | 810 | 718 | 309 | 2051 |
| Log-likelihood    | -1897.6 | -1754.4 | -666.1 | -3701.2 |
| LR test vs. model with \(m_p = m\) | 203.6 (4 d.f.) | 84.4 (4 d.f.) | 43.7 (4 d.f.) | 291.0 (4 d.f.) |

Note: figures in parentheses are t-statistics; \(u\) denotes tenure in the industry in years. All specifications also contain historical period effects — see text.

production totals were large. In such cases, we distinguished 'middle size' (we infer that the firm's production level in a year was much higher than 'small' but considerably smaller than the scale of the largest firms in the industry at the time). In the very few cases (mostly occurring during the interwar years) in which we inferred that the firm's production level approached those of the industry's biggest firms, we coded size as 'large'.

We used the size distributions of firms whose production levels are observed to impute sizes for these three categories. When a firm's yearly observation was coded as 'small', we assigned a value from a uniform distribution ranging from zero to the first quartile of the size distribution for the historical period. Firm-years coded as 'medium' and 'large' were assigned the second and third quartile values, respectively.

We analysed the effects of size in two ways. In one, we merely distinguished the three qualitative size classes: small, medium, and large. In the second, we used the (natural logarithm of the) quantitative value. We see little substantive difference in the results of the two kinds of analysis: both tell that the disbanding/exit rate is very high for the smallest firms and declines as a function of size. Because we want to examine how the effects of size depend upon tenure in the industry and we want to conserve degrees of freedom, we use the constructed metric measure of size. We measured relative size of a firm as the ratio of each firm's size to the size of the largest firm in the national population at the time.

Finally, we controlled for environmental conditions with sets of period effects. The analyses reported below also contain effects of contemporaneous density and its square, density at founding, economic depression, the level of the gross domestic product (GDP) adjusted for inflation (taken from Maddison, 1991), and the period effects. We excluded the years of the Second World War from the analysis because the production of motor vehicles for private use was stopped in all of these countries.

**Stochastic Model and Estimation**

Tenures in these industries have been extraordinarily short. The half-life (considering all kinds of ending events) of an automobile producer has ranged from...
one year in the American population, to 1.8 years in the British and German populations, to 2.6 years in the French population. Clearly the hazard of mortality was very high at short tenures, as can be seen clearly in Figure 1, which plots the integrated hazard of disbanding or exit (including events of unknown type) for the four populations. These plots suggest that the disbanding-exit rate falls monotonically as tenure increases in all four populations.

Despite the near monotonicity of the integrated hazards in Figure 1, we found that simple parametric specifications, e.g. Weibull and Gompertz, did not fit well compared to less constrained alternatives. Therefore, we represent tenure variation as a piecewise-exponential function. After examining life tables and exploring estimates of a variety of choices of the breakpoints, we decided to break the duration scale (in years) at: 0.5, 1.0, 3.0, 7.0. With this choice, the first segment (0, 0.5) includes dated events that occur within the first six months in the industry along with cases that enter and exit at unknown times within the same year (as discussed above). The second segment (0.5, 1) includes dated events that occur within the second six months along with cases that enter at unknown time in one year and exit at unknown time in the next year. The third and fourth segments are defined similarly. The final segment begins at seven years and is open on the right.

We specify that the disbanding-exit rate is a function of tenure in the industry ($\lambda$), industry or population age ($\phi$), absolute organizational size ($\delta$), relative organizational size ($\rho$), a dummy for very small size ($\theta$), prior organizational existence ($\psi$), and other measured covariates ($x_i$), including density at founding. The general class of models we estimate has the form:

Figure 1. Product limit estimates of cumulative hazard rates for Britain, France, Germany and the USA.
\[ \ln \mu_i(t) = m_p + \gamma_p \ln n_i + \theta_p \ln n_i + \zeta_p u_i + \lambda_p u_i + x_i n_i, \]

Here \( m_p \) denotes a set of tenure-specific effects. The (tenure) period subscripts on the effects of size and prior experience indicate that we allow these effects to vary by tenure. This general specification sets the hazard of disbanding or exiting to be a non-proportional function of tenure and these covariates. We estimate models with this general form with the method of maximum likelihood as implemented in TDA 5.7 (Rohwer, 1994; Blossfeld and Rohwer, 1995).

Results

Estimates of a Model of Proportional Effects

The central question is whether effects of size and prior existence on mortality rates are proportional and, if they are not, whether allowing non-proportionality makes an important substantive difference. So we begin with the results of a proportional hazard specification of the effects of tenure, size, and prior experience. The results appear in Table 3.

In this proportional specification, all of the information about tenure effects is contained in the constants (baseline hazards), \( m_p \). Controlling for size and prior existence (and the other covariates and period effects), the effect of tenure is monotonic negative beyond the first year for each country. Under the assumption of proportional effects, we have strong support for the notion of a liability of newness.

The various measures of size have the predicted effects on mortality rates, with the details about which effects are statistically significant varying somewhat among countries. Relative size has a large, significant negative effect on mortality rates for all populations. The effect of absolute size is negative and significant for Britain and the USA, and the effect of small size \( (r < 0) \) is positive and significant for all but Germany. Overall, we conclude that this analysis supports the argument that there is a liability of smallness, both absolutely and relatively, as well as a special liability of ultra-smallness.

Prior existence lowers rates of disbanding or exiting significantly in each population. This effect is much stronger for the European populations, reducing the rate by one-third to one-half, than for the American population, where the reduction is only one-tenth. We suspect that this difference reflects the different character of the lateral entrants on the two continents. Many of the firms seeking to enter the American industry were modest-sized makers of carriages, engines, or bicycles (Carroll et al., 1996). In contrast, some of Germany's largest firms entered its automobile industry. For instance, the two giant electrical equipment manufacturers Allegemeine Elektrizität Gesellschaft (AEG) and Siemens produced automobiles during the early years of the industry; the highly successful Opel was introduced by Adam Opel, Germany's largest manufacturer of sewing machines and a dominant player in its bicycle industry. France, too, saw major industrial firms enter the automobile industry. According to Laux (1976: 150), 'After the turn of the century, when the permanence and profitability of automobile manufacturing became clear, many well established metal-working firms decided to move into this field.' These included SA Hotchkiss et Cie. (armaments), Citroen (armaments), Delauny-Belleville (steam engines), De Dietrich (locomotives), and Peugeot (bicycles). Although most lateral entrants in Britain were craft-oriented machine shops (Torres, 1995), several of the more successful British entrants arose from lateral entry by reasonably large firms, including Rover (bicycles) and Rolls-Royce (one of whose parent firms, Royce and Co., was a medium-sized manufacturer of electrical equipment).

Table 3 also reports the effects of density at founding and contemporaneous density. We see consistent evidence of density delay (Carroll and Hannan, 1989) – the effect of density at founding is positive and significant for each population. The effects of contemporaneous density are less consistent. Part II (Hannan et al., 1998) shows that the effects of density are significant and in the expected directions when we use Hannan's (1997; see also Hannan and Carroll, 1995) extension of the model of density dependence to include interactions of density and industry age.

Estimates of a Model of Non-Proportional Effects

Next we examine possible non-proportionality in the effects of key variables. Because we use three
measures of size, the number of relevant parameters grows very large if we estimate specifications that allow free interactions with tenure. To retain simplicity and enhance interpretability, we estimated models that allow non-proportional effects but do not entail a great increase in the number of parameters. We began by allowing the effect of prior existence and relative size to shift when tenure reaches three years. This alteration improves the fit substantially for the European populations but not the American. We did not find any evidence from other choices of breakpoints that the effects of prior existence and relative size depended upon tenure in the American population. In contrast, the effects of absolute size and very small size do vary significantly with tenure for the American population but not the European populations. The results reported in Table 4 reflect this trans-Atlantic difference in the size effect.

The assumption of proportionality turns out to be a poor one, given the specifications we chose, as Table 4 shows. Allowing the effects of prior existence and (some measure of) size to vary by tenure improves the fit significantly (at the 0.01 level) for all four national populations, as shown by the likelihood-ratio tests reported at the bottom of the table.

Table 4. ML Estimates of models with nonproportional hazards: mortality rates of automobile manufacturers, 1885–1981

<table>
<thead>
<tr>
<th>Duration ($u$):</th>
<th>Britain</th>
<th>France</th>
<th>Germany</th>
<th>USA</th>
</tr>
</thead>
<tbody>
<tr>
<td>$u &lt; 0.5$</td>
<td>-2.73 (-2.67)</td>
<td>-4.30 (-3.75)</td>
<td>-7.68 (-5.21)</td>
<td>-1.00 (-4.52)</td>
</tr>
<tr>
<td>$0.5 \leq u &lt; 1$</td>
<td>-2.37 (-2.33)</td>
<td>-4.26 (-3.71)</td>
<td>-7.37 (-5.02)</td>
<td>-1.11 (-4.95)</td>
</tr>
<tr>
<td>$1 \leq u &lt; 3$</td>
<td>-9.97 (-3.71)</td>
<td>-4.92 (-4.30)</td>
<td>-7.94 (-5.38)</td>
<td>-1.61 (-7.21)</td>
</tr>
<tr>
<td>$3 \leq u &lt; 7$</td>
<td>-6.82 (-4.11)</td>
<td>-7.03 (-4.28)</td>
<td>-11.1 (-4.08)</td>
<td>-1.86 (-8.16)</td>
</tr>
<tr>
<td>$u \geq 7$</td>
<td>-6.12 (-5.20)</td>
<td>-8.21 (-4.92)</td>
<td>-18.8 (-5.12)</td>
<td>-0.793 (-2.34)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Prior existence:</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$u &lt; 3$</td>
<td>-0.616 (-4.94)</td>
<td>-0.733 (-5.14)</td>
<td>-0.752 (-4.35)</td>
</tr>
<tr>
<td>$3 \leq u &lt; 7$</td>
<td>-0.259 (-1.91)</td>
<td>-0.733$^c$</td>
<td>-0.972 (-3.08)</td>
</tr>
<tr>
<td>$u \geq 7$</td>
<td>-0.259$^c$</td>
<td>-0.212 (-1.66)</td>
<td>-0.323 (-0.785)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>In (relative size):</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$u &lt; 3$</td>
<td>-3.43 (-2.90)</td>
<td>-0.981 (-1.94)</td>
<td>-2.53 (-4.16)</td>
</tr>
<tr>
<td>$3 \leq u &lt; 7$</td>
<td>-1.72 (-2.58)</td>
<td>-1.86 (-2.56)</td>
<td>-3.86 (-3.26)</td>
</tr>
<tr>
<td>$u \geq 7$</td>
<td>-1.49 (-2.96)</td>
<td>-2.21 (-3.02)</td>
<td>-7.10 (-4.41)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>In (size)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$u &lt; 7$</td>
<td>-0.52 (-1.94)</td>
<td>-0.33 (-0.928)</td>
<td>0.087 (1.25)</td>
</tr>
<tr>
<td>$u \geq 7$</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Size &lt; 50:</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$u &lt; 7$</td>
<td>0.549 (3.46)</td>
<td>0.686 (4.56)</td>
<td>-0.100 (-0.050)</td>
</tr>
<tr>
<td>$u \geq 7$</td>
<td>-</td>
<td>-</td>
<td>0.566 (-2.00)</td>
</tr>
</tbody>
</table>

| Number of spells | 5582 | 5171 | 2272 | 8893 |
| Number of events | 810 | 718 | 309 | 2051 |
| Log-likelihood   | -1891.5 | -1750.3 | -659.0 | -3694.1 |
| LR test vs. model in Table 3 | 12.07 (4 d.f.) | 8.31 (3 d.f.) | 14.08 (4 d.f.) | 14.15 (2 d.f.) |

*Note: figures in parentheses are $t$-statistics; $u$ denotes tenure in the industry in years.

*indicates that the estimate was constrained to equal the one above it in the table.

All specifications also include effects of all covariates in Table 3 and period effects.
Thus the main contention of this paper is supported: age and size do not act proportionally in shaping disbanding and exit rates.

How do the results of the non-proportional specification differ from those of the common proportional one? We can begin to answer this question by considering the set of baseline tenure effects ($\hat{\mu}_{\tau}$). Whereas the baseline effects in Table 3 showed monotonic decline in the rate after the first year, only France and Germany display this monotonic pattern with the non-proportional specification. The British and American baseline rates fall and then rise as tenure increases. However, given the non-proportional specification, it is not very meaningful to interpret the baseline hazards without taking account of the other relevant effects. This is because the baseline rate is only one piece of a complicated joint effect of tenure with size and prior experience.

To provide a more meaningful summary of the results of the non-proportional specification, we next consider the how tenure and size interact in affecting the rate. We think that the most substantive insight is likely to come from contrasting the predicted rates during years three to seven and seven or greater. We ask: is the disbanding/exit rate higher in the earlier or the later of these tenure segments? If we find that the rate falls after three years, then we will conclude that the age dependence is negative over the later years. If, on the other hand, the rate rises after three years, we will come to the opposite conclusion.

The preceding paragraph oversimplifies the task by referring to a single rate that can rise or fall with increasing tenure. Because we find that tenure and size interact in affecting the rate, we must consider a function of tenure and size. Recognizing this complexity, we revise the question. Are there values of size such that the rate falls after seven years of tenure? Are there other values of size such that the rate rises after seven years of tenure? If the answers to these questions are affirmative, what is the level of size such that the relationship changes from (say) negative tenure dependence to positive tenure dependence?

To anticipate our findings, this kind of comparison might find that the form of age dependence differs for large and small organizations.

The basic idea is to create an index that gives the ratio of the predicted rate (as a function of size) for tenures of seven years or more ($\tau \geq 7$) to those for tenures of three to seven years ($3 < \tau \leq 7$). The index is defined as:

$$\Delta(\tau) = \frac{\hat{\mu}_{7+}(\tau)}{\hat{\mu}_{3-7}(\tau)} = \frac{\exp(\hat{m}_{7+}) \exp(\theta_{3-7})}{\exp(\hat{m}_{3-7}) \exp(\theta_{7+})}$$

for the European populations. In this index, $\hat{m}_{3-7}$ and $\hat{m}_{7+}$ denote the estimated constants (baseline rates) in eqn. (1) for the two tenure segments, $\tau$ is relative size, and $\theta_{3-7}$ and $\theta_{7+}$ denote the effects of relative size for the two tenure segments. If $\Delta(\tau)$ exceeds one for some value of size, then the rate of disbanding or exiting increases with increasing tenure at this relative size; if the ratio falls below one, then the rate decreases with increasing tenure.

Figure 2 shows that the implied disbanding or exit rate in the French and German populations declines with tenure for relatively large firms and rises with tenure for relatively small firms. For France, $\Delta(\tau) \approx 0.31 \tau^{-0.345}$. So for the largest firm in this population (for which relative size equals one, by definition), $\Delta(\tau) = 0.31$. That is, the rate after a tenure of seven years is only a third as high as during years three to seven. At $\tau \approx 0.033$, $\Delta(\tau) = 1$, which means that the rate is the same before and after the start of the seventh year. In other words, a relative size of roughly 0.033 is the point at which the relationship of tenure and the disbanding or exit rate changes sign.

For the many firm-year observations in the French population for which the firm’s size is less than 3.3 per cent of the size of the largest firm, the disbanding or exit rate in the seventh year exceeds the rate before the seventh year. This means that tenure dependence in the rate is positive. For instance, the rate rises by 30 per cent after year seven for firms whose size is less than 2.5 per cent that of the largest. It is important to point out that many firms in this population were smaller than 2.5 per cent of the largest. Indeed, 63 per cent of all of the firm-year spells meet this criterion, as do 73 per cent of the spells that exceed seven years of tenure.

A similar pattern holds for Germany in Figure 2. In this case, $\Delta(\tau) \approx 0.0045 \tau^{-3.24}$. The implied rate for the largest firm is nearly zero (0.00045) after seven years of tenure in the industry. The rate declines as tenure increases for all firms whose size is at least 10 per cent as large as the largest firm. That is, tenure dependence is again positive for the many
small firms in this population. Indeed, 70 per cent of the full set of spells for the German firms and 48 per cent of all the German firms whose tenure exceeds seven years were less than 10 per cent as large as the largest firm. Not only is the sign of the tenure effect positive for the small firms, but also the tenure effect is quite large. For instance, consider firms whose size is less than 2.5 per cent of the largest firm. For such cases, the disbanding or exit rate after the seventh year is nearly 70-fold higher than before the seventh year.

In the case of the American population, we found that absolute size and small size had large and significant effects on the disbanding or exit rate. Thus we calculate the index as a function of absolute size ($i$). If we restrict attention, for the moment, to the portion of the absolute size range exceeding 50, then $\Delta(t) \approx 2.91r^{0.146}$ for the American population. The index equals 1 (meaning that the multiplier of the rate is the same in the two tenure segments), when $s \approx 1500$.

Figure 3 plots the relationship between $\Delta(t)$ and size for the American population. For firms larger than 1500, the rate declines with tenure; for firms smaller than 1500 (which comprise 76 per cent of the firm-year spells), the rate is higher in the oldest tenure category, tenure dependence is positive. For instance, according to these estimates, a firm producing 100,000 automobiles per year has a disbanding or exit rate that is roughly half (54 per cent) as high at tenures of seven plus as during years three to seven. But a firm producing 100 automobiles per year has a rate 50 per cent higher beyond the seventh year than in years three to seven. Thus the results for the American population parallel the French and German ones over most of the size range (specifically for sizes greater than 50).

An interesting complication arises in the American results. The effect of very small size is positive at low tenures ($\mu < 7$) and negative at high tenures ($\mu \geq 7$). (This condition holds for a surprisingly large number of cases: 309 firms have one or more year of observation in which their size is below 50 at some time after the seventh year.) Taken together, the pair of results for the American population suggests that increasing tenure lowers rates of
disbanding or exit for the largest and smallest firms in the industry (Figure 3).

The British results run opposite to those for the other three populations. According to the estimates in Table 5, $\Delta(r) \approx 1.17^{0.2}$, which implies the mirror image of the French and German pattern, as can be seen clearly in Figure 2. (This difference would be much greater if we compared the segment from years one to three and the oldest segment.) The rate for the largest firm rises 17 per cent after age seven. For firms roughly half as large ($r \approx 0.5$), the rate does not change at age seven. Firms smaller than this have lower rates at higher tenure. For instance, the rate is cut in half at the seventh year for firms smaller than 2.5 per cent the size of the largest. In other words, the disbanding or exit rate in the British population increases as tenure increases for the largest firms, but it decreases as tenure increases for the smallest firms.

Large, old firms face especially high risks of failure in Britain, according to our results. This finding fits some historical accounts of the evolution of the British industry, much of which focuses on the causes of the 'collapse' of the industry (meaning mainly the failure of its dominant firms). Lewchuk (1987) identifies a 'British system of mass production' in which workers were compensated on a piece-rate basis and labour control was delegated to the shop floor. This contrasts sharply with the American system in which compensation took the form of wages and labour control was centralized. Lewchuk argues that the decentralized British system prevented large firms from smoothly increasing levels of production to match growth in demand. As a consequence, large firms in the British industry could not reap the benefits of large scale. Chandler (1990) regards the failure of these mass-production automobile manufacturers as an instance of the general failure of British 'personal capitalism', which stunted the development of modern managerial functions and stressed high dividends over investment. Lack of professional management meant that marketing and sales were slighted; and low rates of reinvestment of profits hindered technical
advance. If these two arguments are correct, then large old firms were disadvantaged in the British industry. According to Lewchuk's argument, decentralized controls robbed large firms of their classical advantage: economies of scale. According to Chandler, older firms would fall behind technically (through lack of capital investment), which is a special problem for large, mass manufacturers.

Finally, we hypothesized that prior existence (entrance from other industries and firms built of automobile manufacturers) would lower disbanding or exit rates and that the advantages conveyed by prior existence would decline as tenure increases. This pattern holds for the three European countries. However, as noted above, the effect of prior existence does not depend upon tenure for the population of American automobile manufacturers.

Discussion

Previous research has shown considerable variation in the relationship between organizational age and mortality. The conventional wisdom suggests that there is a liability of newness such that mortality rates decline as organizations age. In some studies, this decline has been found to be delayed for a (usually relatively brief) period, suggesting a liability of adolescence. Recently, however, some research has found that, once variations in organizational size over lifetimes are controlled, there is a liability of senescence or obsolescence, such that mortality rates rise as organizations age.

Although many factors (including differences in the quality of observation plans) might account for the differences in results among studies, we suggested that two frequently uncontrolled characteristics of organizations — size and entry mode — might play a crucial role. We also argued that, for theoretical reasons, the effects of both size and entry mode might vary over the organizational life cycle, thereby further confounding estimates of common simple specifications. Using complete data on organizational populations of automobile manufacturers in four major countries, our analysis showed the merit of these arguments. Estimates of our non-proportionate specification reveal that the effects of both organizational size (both absolute and relative) and prior existence depend upon organizational age. Indeed, allowing non-proportional effects of size makes a fundamental difference in conclusions about age dependence.

The exact forms of the effect of size on mortality rates differ by country. The clearest difference lies between Britain and the other three countries. In the British case, large firms face rising mortality hazards as they age. For France, Germany, and the United States, we find that the largest firms experience declining mortality rates as their tenure in the industry increases and smaller firms (but not the smallest in the USA) experience rising mortality rates at long tenures. In other words, the pattern for smaller firms suggests the operation of processes of obsolescence and/or senescence. But life chances of the largest firms improve the longer they remain in the industry.

This difference between large and small firms for American, French, and German populations might reflect changes in the balance of importance of technical quality and scope of distribution at different tenures. The historical record provides many examples of firms (in some cases using what in hindsight seem extremely quixotic technical designs) that failed an immediate market test. Much of the selection in these industries was driven by differences in the technical quality of the products. (Recall that the majority of firms in these populations did not make it past their second year in the industry.) There was no advantage to large scale if a firm's products were clearly technically inferior, other than delaying the disbanding or exit for a year or two. So it should not be surprising that the beneficial effects of large size (either absolute or relative) are greater after rather than during the early shake-out period.

Consider the pattern of mortality rates for relatively small firms in the French and German populations. The relationship of the rate of disbanding or exit has a bath-tub shape: the rate falls as tenure increases over the first three years and rises with increasing tenure beyond that point. Firms of sizes in the range of 50 to 1500 in the American population also show a bath-tub shape relationship: the rate declines over the first seven years and then rises. Such a relationship between tenure and disbanding-exit rates is unanticipated...
in the extant literature. What are we to make of this pattern?

There is an obvious analogy to processes of human mortality: the initial decrease in mortality rates past infancy reflects different mechanisms than the rise of mortality rates in old age. We suspect that the pattern in these three organizational populations also reflects a mixture of two (or more) processes. Perhaps these relatively small organizations experience both a liability of newness—adolescence and a liability of senescence—obsolescence and previous research designs and stochastic specifications were not detailed enough to detect their simultaneous presence. This would perhaps be pleasing to theorists because it suggests that their formulations (in whatever direction) were accurate, if incomplete. However, we suspect, as suggested above, that the initial decline in the rate of disbanding/exit reflects selection driven by unobserved heterogeneity in the technical quality of the products. If producers of very poor quality were winnowed from the population in the first or second year of their existence, then the disbanding or exit rate would fall subsequently. The substantial rise in these rates at older tenures seems to fit the revisionist story of obsolescence and/or senescence (Barron, West, and Hannan, 1994). That is, organizational inertia builds over time, causing both mismatches with social and technical environments and slowed response to opportunities and constraints in the environment.¹⁸

The largest firms face a different situation. Once beyond the technical shake-out period, their large size partly buffers the likely effects of obsolescence—senescence. They might lose market share for some time to newcomers before exiting the industry or disbanding. A firm like General Motors has been able to withstand losses of billions of dollars per annum for several years without failing. As we noted above, large old organizations can rely on stocks of slack resources to temper such shocks. They can also rely on extensive networks of long-term suppliers, buyers, and distributors. These external actors have a stake in the persistence of the focal firm and would be likely to be supportive should hazards encroach. Finally, old, large firms like British Motors, Chrysler, and Peugeot can often rely on national governments to provide subsidies that allow them to ride out difficult patches.

But this is clearly not the whole story, especially for the American population. In the case of the latter, we have the interesting result that very small firms (those producing fewer than 50 cars per year) do not experience rising rates of disbanding/exit at long tenures. Perhaps these small, old firms might have found viable specialized niches. The simultaneity of viable niches for small specialists and high concentration of large-scale mass producers within the same industry is anticipated by resource partitioning theory (Carroll, 1985).

British exceptionalism aside, what do these results tell us about the divergence of the results of prior studies? At the most general level, they imply that the pattern of age dependence one obtains from estimating a model of proportional effects of age and size would depend upon the size distribution over the population's history. If the population has consisted largely of small enterprises, then the pattern of age dependence ought to appear roughly positive. If, on the other hand, large organizations proliferated, then it seems likely that age dependence would appear to be roughly negative. These implications fit reasonably well with the pattern of findings over organizational populations discussed at the outset. Although important details on size distributions are not available in all cases, we think that the following populations contained mainly small organizations: New York City credit unions and hotels, American brewpubs and microbreweries, Toronto day-care centres, early Pennsylvania telephone companies, and Illinois banks outside of Chicago. Interestingly, the prior research on each based on proportionate specifications of the effects of age and size found evidence of positive age dependence, as our story would imply. And, for the population that most clearly contains mainly large firms, that of medical device manufacturers, the effect of age was negative. But not all of the findings fit the story so neatly. For instance, positive age dependence has also been found for populations of commercial banks in New York City and Tokyo, which contain many small banks but also some very large ones. More analysis, using non-proportional specifications like the one proposed here, is needed before we will have a firm grasp of the sources of variation over studies.
The more refined picture of age dependence presented here appears to have promise as a way of understanding differences in patterns of age-dependent mortality for diverse organizational populations. We believe that it must be coupled with an effort at theoretical integration, one that specifies how and when processes of endowment, imprinting, capabilities, and position interact and relate to each other.

Notes

1. This argument depends upon the assumption of continuous environmental change. The senescence argument does not; it holds that capabilities decline with age even in a stable environment.

2. Assessment companies were a form of co-operative insurance companies. Lehman (1994) finds no relationship between age and mortality rates net of size for the other main co-operative form: fraternal benefit societies.

3. The difference between Lehrman's and Ranger-Moore's results for life insurance companies might be due to the different periods of coverage or to the fact that Lehman did not use any covariates other than age, size, and period while Ranger-Moore controlled for population density, population growth, and economic conditions.

4. Some of these studies report results on two or more populations. Moreover, as we discuss below, many studies use observation plans that cannot provide dependable estimates of age dependence.

5. The only studies that apparently avoid problems of left-truncation are those of New York City credit unions (Barron, West, and Hannan, 1994), early telephone companies (Barnett, 1994, 1997), medical devices (Mitchell, 1994), and American automobile manufacturers (Caroll et al., 1995).

6. The problem is that the likelihood of the truncated data differs from the likelihood of the complete data; the standard software packages used in the papers in question calculate estimates based on the likelihoods of the full data. Consequently, these routines produce biased estimates for the left-truncated case when the underlying rate depends upon age (that is, the distribution of lifetimes is not exponential).

7. To be sure, early automobile industries had a strong social movement flavour and social networks were important to the early development of the industry. None the less, knowledge about the product and the industry diffused rapidly by relatively impersonal means. Industry historians emphasize the importance of races (initially on public roads through urban centres), trade shows, and the public display of the automobile entailed in ordinary use.

8. An obvious exception is Britain's so-called Red Flag Law, which required a pedestrian carrying a red flag to precede any mechanically powered vehicle on public roads, and did limit the early adoption of the automobile.

9. We believe that research in organizational ecology often relies on similar — and sometimes less plausible — assumption, despite a lack of acknowledgement. Our willingness to be explicit about these assumptions does not reflect a deficiency in our data vis-à-vis those of others but rather an attempt to make explicit these potentially problematic issues.

10. Individual entrepreneurs surely did come from others industries; and this information is sometimes available. However, our unit of observation is the organization, not the entrepreneur. For us, the key distinction is whether the organization is new at automobile manufacturing.

11. Our coverage is worst for France and Germany. We lack precise information for 81% of the firms in each country’s industry; these account for 68% of the firm-years in France and 65% in Germany. The sources covering the USA exclusively provide more complete information. In this case, 58% of the spells lack precise measurement of scale. Information on size is most complete for the British industry, for which we lack precise information on size for 62% of the firms in the British industry — these firms contribute 43% of the firm-years of observation.

12. For this analysis, we coded firm-years with precise information as small if the level was below the period's first quartile, medium if it fell in the interquartile range, and large if it exceeded the third quartile.

13. We also experimented with using the ratio of firm's size to the average of all firms in its national industry at the time. However, model fits were generally weaker with this measure.


15. We have also explored the consequences of using the multi-level model proposed by Hannan et al. (1995) for the European industries. This does not make
any appreciable difference in the results. We report the results of the national-level density terms here because this makes the European results more comparable with the US results.

16. Church (1994) argues that Lewchuk and Chandler have oversimplified a very complicated story. He points to a variety of macro-economic and political conditions that arguably contributed to the collapse of the British industry.

17. The differences between these findings and those of Carroll et al. (1996) deserve explanation. In addition to a different model specification, Carroll et al. (1996) excluded all cases not involving either de novo or de alio entry; this exclusion allowed the contrast of greatest theoretical interest in that paper. They also measured types of prior existence differently, taking account of the more detailed information available on spells of pre-production in the American industry. They coded firms having pre-production experience in the automobile industry as having prior existence. We did not do so in this paper because the relevant information is unavailable for the European populations. Finally, Carroll et al. (1996) used a different specification of the outcome state.

18. A reviewer suggested that the high mortality rate of old, small firms might reflect the fact that some old firms are 'doomed' to fail and experience a period of contraction, enter into the small size class, and then fail. The reviewer suggests controlling for previous growth and decline in addition to current size. Although this idea might be useful, it is not practical in the current setting. Because mortality rates are so high in these populations, many firms fail before they have established records of growth and decline. Moreover, unless one were to assume that some old organizations are 'doomed' but no young ones are, one will still have to explain why small size is so much riskier for old organizations than young ones.

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