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Fitness and Age: Review of Carroll and Hannan's *Demography of Corporations and Industries*[1]

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1. *Introduction*

THE DEMOGRAPHY of Corporations and Industries (2000) by Glenn R. Carroll and Michael T. Hannan is about the birth, aging, and death of organizations and industries. The authors are sociologists who teach at prominent business schools and are familiar with economics. Their research program is broader than the title of the book suggests. They discuss things like the founding of a firm, its incorporation, its first product prototype, its initial public offering, growth, and death, and they discuss organizations like unions, schools, local governments, and utilities. The book treats us to a feast of facts, figures, tables, simulations, regressions—in short, a documentation of a vast array of phenomena, all to do in one way or another with the life cycle of firms and industries, their birth, growth, and eventual decline and death.

The book is not an easy read. It is not easy to portray that much data in a coherent and imaginative way and theorize about them at the same time. The authors resolve this by presenting the facts and throwing in some interesting ideas along the way. The recipe works insofar as the book coherently documents the facts and implicitly challenges the applied theorist to get to work.

The authors do not strongly push a specific view. When they do theorize, they do it by assuming properties, say, of industry entry and exit, without saying precisely why firms would choose to behave in a way consistent with those properties. In Hannan and Carroll (1992, ch. 9) they argued that restricting aggregate behavior directly may well lead to a more reliable theory than if we build from specific microeconomic foundations, simply because the microeconomic foundations we bet on may turn out to be wrong. They looked then for a robust macrotheory where "robust" refers to properties of aggregative behavior that would hold under several microfoundations, one of which, perhaps, is individual rationality. In their 1992 book, the authors never got as far as to show that the aggregate laws that they *did* posit were actually consistent with individual rationality.

[1] *The Demography of Corporations and Industries*. By Glenn R. Carroll and Micharl T. Hannan. Princeton: Princeton U. Press, 2000. 490 pages. $49.50. ISBN 0–691–01030–7.

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That is pretty much how things stand in the new book too, except that now the authors simply forge ahead with measurement and do not worry aloud that the theory does not keep up. In a way, the book succeeds precisely *because* the authors do not force the material into a tight theoretical straightjacket. For those of us who are looking for something to theorize *about*, the facts that this book serves up are just the sort of ammunition we need.

Among studies by economists that take a life cycle or inherently dynamic view of industries and firms, the milestones are Simon Kuznets (1930), who studied the time series of the outputs and prices of 57 products and found that they grew like logistic curves, which suggested a product life cycle; George Stigler (1958), who applied "survivor analysis" to several manufacturing industries in an effort to determine the optimum scale of the firm; Michael Gort and Steven Klepper (1982), who documented the historical development of 46 products in terms of their sales, price, output, and numbers of producers; and Byong-Hyong Bahk and Gort (1993), who, in fifteen manufacturing industries, studied the productivity of plants as a function of their age. The book is a worthy addition to this literature and to an apparently parallel literature in sociology that the authors also mention.

I will start with a review of some facts I found in the book, and then I will summarize the theory. I shall then discuss some tests of that theory, and then conclude with an endorsement.

2. *Some Facts*

The strength of the book is its inspired presentation of facts, some of which we can be more sure of, others less. Here are some that I found interesting:

1. Organizational capital is sticky;
2. "Shakeouts" are followed by entry of specialized producers; and,
3. Garage tinkering was as common 100 years ago as it was in the heyday of the computer hobbyist.

I shall now elaborate on each one.

2.1 *Adjusting Organization Capital Is Costly*

It is said that old firms are bureaucratic and overmanaged, and that the young firm is the agent of change. Why is that? More generally, why aren't all firms equally efficient? The book describes an ongoing study—the Stanford Project on Emerging Companies (SPEC)—that will shed light on this question. The data come from questions posed to founders of a collection of high-tech firms in Silicon Valley. Founders were asked if, at the outset, they had an organizational form in mind, if they relied on direct oversight or on incentive pay, if they employed scientist-"stars," if they were bureaucratic or autocratic, if they had turned control over to a non-founder CEO, and so on. The general question is how much initial conditions matter and how strongly they encumber a firm should it wish to redefine itself. In economists' language, the authors are measuring the costs of adjusting organization capital. I haven't seen this done anywhere and I find the project promising, but the evidence is, for several reasons, still incomplete.

For one thing, much of the information is qualitative and subjective. The probable reason for not having a much larger array of firm characteristics is the companies' desire to keep such things secret. The data include the firm's age, employment, industry, and the number of its managers, administrators and women, as well as whether the company was still in private hands or had gone public. There seem to be no data on costs, outputs, revenues, or the values of the publicly traded firms.

Based on qualitative information, companies are sorted into five groups, each group corresponding to an organizational form. The groups are called Engineering, Star, Commitment, Bureaucracy, and Autocracy. A firm is put into one or another organizational bin based on qualitative responses to three questions. The answers to these questions were multiple choice (three, three and four), and, out of a total of 36 possible answers, a clustering procedure revealed that roughly half of the responses fell into five of those cells. The SPEC web site reports that over a period of seven and a half years (that, at least was the median age of all SPEC companies), the autocratic firms were the most likely (60 percent) to change their organizational form, and firms that stressed commitment the least likely (29 percent). I rejoiced at seeing the high 60-percent likelihood that autocracy does not persist, until I realized that this is a sample of survivors and that, therefore, it gives us no inkling of how many companies may have gone under because their autocratic founders refused to change their ways. The sample is still so short that, as far as I could tell, no failures had occurred between the two interviews. Although the time-period is short, the flexibility of organizational forms can be measured in some ways that the study does not pursue. Besides estimating transition rates among the five organizational forms, one also could fit stochastic difference equations to the time series for managerial intensity and human resource intensity, and get persistence parameters in that way.

SPEC must also face the age-old inference problem—is it persistence or unmeasured heterogeneity? The authors mention the issue, but I see no evidence that they actually deal with it. Suppose we see a firm starting out in life with a workforce composed entirely of engineers and suppose that ten years later, the engineers are still there. The firm's organizational form is, in other words, "engineering," and it stays that way for ten years. Engineering employment is *persistent* if the firm would like to fire the engineers, maybe because their skills are outdated, but cannot because a union will not allow it, or because their contract promises severance pay. In that case, the firm's initial decision or, rather, the then-prevailing conditions that made the firm hire only engineers, is *imprinted* on the firm and stays with it through time. That is what we think of as persistence. But, we could have observed the same thing even if there were no persistence and even if the organizational form were perfectly flexible and adjustable at a stroke. If all we see is that the firm's employment of engineers stays at 100 percent over time, we could also take it to mean that the firm is just different from other firms. Maybe it just makes the sort of product that is most efficiently produced if every employee is an engineer. In that case, the firm is perfectly happy with its engineers today, and it was happy with them ten years ago, which is why it hired them in the first place. This is the explanation that invokes unmeasured heterogeneity.

One way to disentangle persistence from heterogeneity is to measure costs of change directly or indirectly. Dollar measures will be hard to come by, but there are some ways of measuring adjustment costs indirectly. For instance, the SPEC web site reports that organizational changes were accompanied by a shedding of older workers, and this is an indicator of costs. Another possibility is to look at companies that change their products, and check to see if they also change the way they are organized.

As SPEC gets older (!), these things will probably get sorted out. Here are some other things that one may want to learn from SPEC:

1. *Organizational form and age.* What are the mean levels of employment of each type of firm? If small firms are autocratic and family-held, then are they the first step in a sequence of forms as the firm grows?
2. *Source of the intangible capital.* Where did founders get their start-up ideas from? While working for other companies? How many, for instance, had worked for IBM, Microsoft, Apple, or Xerox? By looking at the young companies in SPEC, we can learn about the well-known weakness of *old* companies—that of not being able to recognize good ideas and retain the best workers.
3. *The imprint of technology*. How many of the companies have patents? Do patents raise the chances of survival? Are patents taken out before or after the founding date?

2.2 *Variety Proliferation in Mature Industries*

In the last twenty years, the number of automobile producers, the number of banks, and the number of beer brewers have gone up. The authors argue that the growth of varieties comes at a certain late stage in the life of the primary base product. Earlier, the number of brewers and automobile manufacturers had fallen, which the authors interpret as a consolidation and an emergence of a few mass producers in the two industries, and this left those consumers with more extreme tastes unsatisfied. As the problem gets more severe, this segment of the market gets recognized by small entrants. The large firms do not respond in time and, once the new market segment is established, specialty firms may then lure even more consumers away from large firms.

Is this fact the result of industry-aging and consolidation, or is it a response to a rising demand for variety by an ever-wealthier consumer? Specialty beers in Figure 12.1 gain ground in the mid-1980s which is exactly when the stock market starts its climb and people feel wealthier. And the proliferation in the number of banks in Singapore (figure 2.3) does not seem to follow any consolidation. The trouble with the wealth-causing-variety story is that it does not explain why old firms stick to old products rather than also produce the new varieties. But, if the authors are right, the Gort and Klepper (1982) list of industry-life-cycle facts needs to be modified to something like the following four stages:

1. Pioneers introduce a product;
2. Mass entry follows;
3. A shakeout and consolidation may then occur;
4. New fact: A secondary entry of new firms and products then takes place.

Before we can be sure of life-cycle fact number 4 we need to see it in other industries and other epochs. From Robert Chirinko and Huntley Schaller (1995) we learned that old firms tend to be in manufacturing industries, which happen to be older. But now we learn that even within industries, old firms make old, standardized products. What models do we economists have that may explain the pattern? Maybe old firms are inert because they are large, but that only begs the question of why they should choose to be large if that will reduce their efficiency. A better explanation is needed, and economists have come up with several reasons why inertia and age may go hand in hand. First, Jennifer Reinganum (1983) shows that an incumbent firm will not look for new products as hard as a challenger will, because, if it succeeds, it would merely augment an already existing market position, whereas the challenger has the entire market as bait. Second, David Martimort (1999) shows that as the firm ages, its insiders can more easily collude against its owners, and one way they can do that is by relaxing their inventive effort. And, third, Gene Grossman and Carl Shapiro (1985) model risky specialization that can lead a firm into a competency trap in which the firm will wish that it had remained a generalist. The model suggests a large shock will play into the hands of generalist entrants, or, better yet, entrants with the right skills. Such a shock, argues Gort (1969), will spawn mergers and acquisitions in order to remove management that is unfit for the new tasks at hand.

One thing we sometimes find in an aging firm is a CEO who has lost touch with operations, but who will not delegate authority. SPEC contains information about delegation and about handing control over to the non-founder CEO. It turns out that an "autocratic" founder—one who relies on direct oversight and pre-specified job descriptions for his employees—is much less likely to transfer control of the firm to an outside CEO, less likely to take the firm public, less likely to hire human resource personnel, and more likely to be bureaucratic and to emphasize frugality. We find an autocratic founder in the small dictatorial family firm. Economists have stressed—perhaps overstressed—the point that unskilled workers do not easily adapt to change, and the findings in SPEC may induce us to shift our theoretical focus onto the resistance to new things by people at the *top* of the economic power structure. Such resistance probably does more harm to progress in the long run simply because it is the people at the top who decide on what technologies are adopted, what products get made, etc.

2.3 *Tinkering by Automobile Pioneers*

For some products, a garage tinkerer can try his hand at building a prototype. One product like that is the desktop computer. Another new product, 100 years ago, was the automobile. Carroll and Hannan (p. 347) identified 3,845 preproduction organizing attempts—"tinkers"—in the automobile industry. Of these, only 11 percent managed to sell any cars. The median pre-production time was less than a year, and some tinkerers were at it for more than ten years.

Tinkering identifies the quality of the idea at hand. The duds—the left tail of the quality distribution of ideas—will never get to production. Figure 1 illustrates this point. If we knew at the outset which kinds of cars were best, we could skip the tinkering stage altogether. But the fact is that sometimes even tinkering is not enough to reveal the duds. Sometimes they have to be marketed before we know if consumers like them, how much they will cost, and so on. Jovanovic (1982) models post-entry learning that removes inefficient entrants. This is probably why Carroll's and Hannan's figures 2.1, 2.2, and 2.4 show waves of entry being followed by massive shake-outs. In terms of figure 1, tinkering identifies and removes the bottom third of the distribution, and early production identifies and removes the middle third. Only the top third survives this initial experimentation era.

Experimentation is an investment that the National Income and Product Accounts do not include. I wonder how much of what we now call leisure or unemployment is spent in this sort of

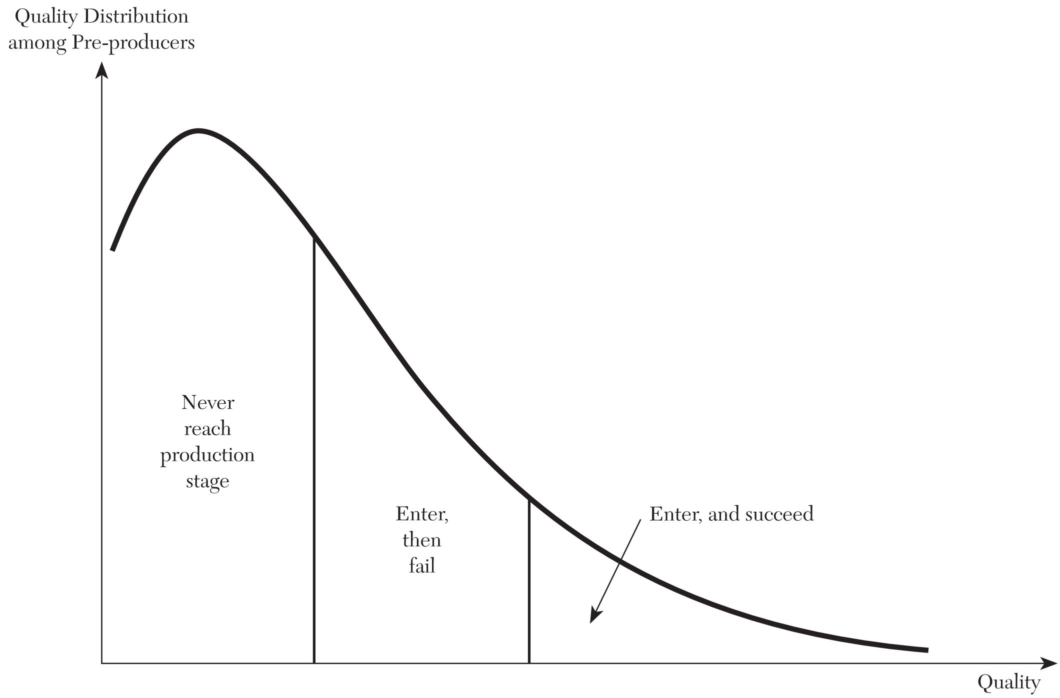

Figure 1. The Distribution of Quality among Pre-producers

experimentation. One way to estimate it is from the value that new entrants fetch on the stock market. When new firms come in with very little on their books but fetch a high price, we can infer that the market believes that they have built up an intangible capital stock. In sum, we can use an entrant's market-to-book ratio to infer his intangible capital and, in the appendix, I present a simple tinkering model that has this property, and I choose the parameters of the model to fit the 11 percent success-rate of the automobile tinkers. Needless to say, the lower the success rate, the higher the market-to-book ratio will be for the successful tinkerers.

Before we leave tinkering altogether, let us switch gears for a moment and think of tinkering as dating, of production as marriage, and of exit as divorce. Which couples will marry? Which marriages will last and which will fail? In figure 1, the left third of the distribution would, on this view, be instances of dating that do not lead to marriage. The middle third would be marriages that end in divorce because the quality of the enjoyment that they give rise to is not high enough. The right-tail contains the high-quality matches that last. Indeed, I wonder if dating leads to marriage more than about 11 percent of the time.

3. *Theory: Alignment and Survival*

I shall now summarize the theory in the book. The authors argue that organizations that are well aligned with the environment will survive and grow, as the rest decline and perish. The fitness criterion may extend beyond economic viability. For example, economic viability will not suffice for survival if it entails a violation of antitrust laws. Nor is it necessary for survival—recall how the then-bankrupt Chrysler Corporation was bailed out twenty years ago and survived. The general form of the theory is in chapter 13 and the application I will focus on is in chapter 17. We begin with the following assumptions:

Assumption 1: Superior alignment of form with environment implies a superior capacity to mobilize resources in that environment,

Assumption 2: A superior capacity to mobilize resources from a given environment implies a superior capacity to attract and retain members in that environment, and

Assumption 3: If a form has a superior capacity to attract and retain members in a given environment, then it has superior viability in that environment.

Innocuous as they may seem, these assumptions raise several questions. For instance, what makes for a "superior alignment" in assumption 1? The authors stress that this is more than natural selection theory because of assumption 2, which asserts that a *social* selection process is essential to survival. But Darwin had also argued that socialization plays a role in the survival of traits, namely traits that attract the opposite sex and this is now, I gather, one favored explanation for the growth of human intelligence. And in assumption 3, it may seem obvious that a "superior capacity" should raise viability. But, in fact, we have examples in economics where that is not true. For instance, someone with a greater capacity to earn money may choose to overeat and die of obesity. Closer to home, consider a CEO whose firm gets a cash windfall. The windfall may enhance the firm's capacity to hire and retain workers, but the CEO may use the money to buy a corporate jet for personal use, and this can be the first step down a sharp descent. In other words, the firm may use its capacity in a way that will hurt its chances of survival. More generally, Robert Strotz (1956) showed that a decision maker can sometimes raise his lifetime utility if he imposes constraints on himself, and one such constraint may be a lower capacity. Assumption 3 rules this sort of thing out.

The assumptions lead to the following three propositions:

Lemma 1: Superior alignment with the environment implies superior capacity to mobilize members in that environment.

Lemma 2: Superior capacity for mobilizing resources from the environment implies greater viability.

Theorem 1: Superior alignment with the environment implies superior viability in that environment.

The result is so general that one could apply it to the viability of firms, unions, religions, or even colonies of ants. The implications of the theory, so far, are only *qualitative:* A better aligned organization is more viable, and this could be because such a firm is better able to mobilize resources. In Darwinian terms, the fit are more likely to survive, and they may or may not do that by eating more. Nothing is said about whether the death rate should rise or fall with the passage of time, or about how shocks to the environment will affect death rates. Chapter 13 tackles the question of how environmental shocks should affect the growth and death rates of firms of various ages. Roughly speaking, the firm will thrive if it has a lot of what I shall call "Organization Capital." Three components of this capital that the chapter mentions are:

Endowments (such as wealth, status, political influence);

Capability (such as an ability to solve problems);

Positional advantage (such as an alignment with the environment).

All three will change over time as the firm ages, and as the environment "drifts." If the firm is capable, well-positioned, and lucky, its endowments will grow, and its capability will probably grow with experience. But its ability to adapt may be outstripped by environmental drift, or *technological change*. At birth, the firm is flexible, and it will choose the location, technology, and product that it has access to and that it finds optimal. If, later, the firm finds it hard to change, it will retain the "imprint" of the events that shaped that initial decision, and so we have the result:

PROPOSITION 1: The date-of-birth "imprint" persists if repositioning is costly.

As the environment changes, the firm will try to change with it, but if it cannot alter its position very easily and if it faces costs of adjusting its organization capital, then its position will deteriorate compared to that of the flexible new entrant. Aging matters because it tracks the fit between an organization and its environment. In the extreme case, the firm may fall into a competency-trap (p. 295). We thus have:

PROPOSITION 2: Aging weakens the organization more in a changing environment.

In the end, the theory pays off in that it connects two concepts that I have not seen so explicitly linked before: The weakening of organizations as they age, and the imprinting of the environment on the firm. Both require that there be costly adjustment of organization capital and a drifting environment. Let us see what the data say about these propositions.

4. *Imprinting*

Back in section 2.1, I argued that SPEC cannot yet tell us how hard it is for the firm to reposition itself or about how long shocks to the capital-value of the firm should persist. I shall now show two much longer time series in which imprinting is evident. To set the stage for the evidence on firms, I will begin with a price series for vintage wines.

4.1. *The Imprint of Climate: Vintage Wines*

The quality of wine depends mainly on when and where the grapes were grown. Good wines trade frequently in secondary auction markets. Figure 2 gives the 1995 prices of about 150 Bordeaux wines that come from the same region in France and embody grapes that, in any year, grew under roughly the same climate. Several vintages of each wine are generally recorded in the sample, and the number of observations is 950. The recent vintages are much better represented (for instance, we have data on 105 wines of vintage 1982) than the early vintages and for some years we have no data. The data come from a website devoted to the study of the wine market and maintained by Orley Ashenfelter. They can be downloaded at http://www.nerc.com/~liquida/, under "*New York Prices.*"

The figure reports the average price in 1995 (per dozen bottles) of each vintage. It also plots the fitted value of the regression of the logarithm of the price of the wine on its vintage. The slope was −2.3 percent per year—wines appreciate with age at 2.3 percent per year. They appreciate for two reasons. First, the prices of stored wines grow with the passage of time, which allows wine dealers to get a return on their investment. The prices of surviving wines also rise because the lower quality wines in any vintages are the first to leave the market, and sometimes all the wines in a vintage disappear so that

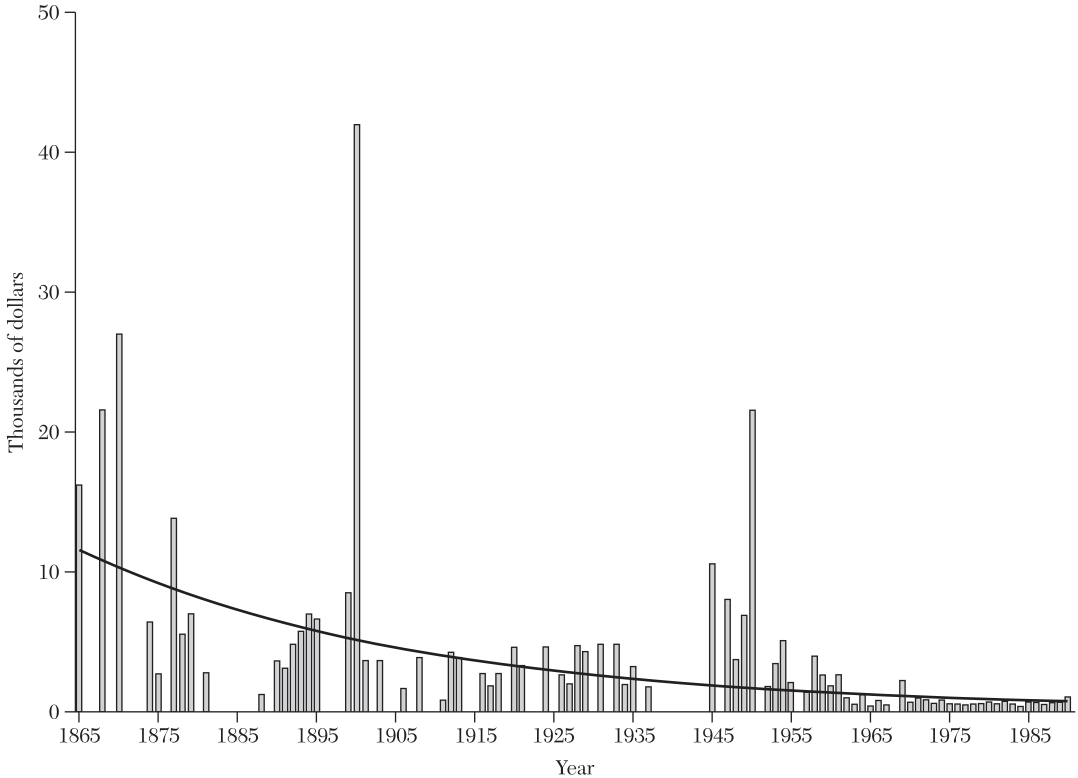

Figure 2. The Prices of Bordeaux Wines by Vintage

some of the early years, especially, are gone. This is a form of survivorship bias that one encounters in the process of firm growth as well.

The trend explains only 56 percent of the variation. The rest is a vintage effect. Evidently, the price differential between a good vintage and a bad vintage is large. Such differentials persist through time because one cannot convert a bad wine into a good one. If the imprint of climate were removable at a stroke, prices among vintages would not vary. Imprinting matters only if a bad imprint is hard to remove.

4.2 *The Imprint of Technology: Vintage Firms*

From wine prices at auctions, we now turn to the prices of firms on the U.S. stock market. Here, proposition 1 says that the technological climate at the firm's date of birth will affect the lifetime value of that firm, and the imprint of that technology can persist for years.

The same sort of survivorship bias occurs in the stock market because only the fittest firms survive in all vintages. The large spike in 1892 is due to General Electric which entered in that year and has done very well since. This time the trend regression explains only 21 percent of the variation in the data. The larger variability of prices around the trend line suggests that vintage effects matter more than they did for wines. The slope was −2.2 percent per year—a rate of appreciation one-tenth of one percent less than the holders of wine got. In spite of that, stockholders received a much higher return on their

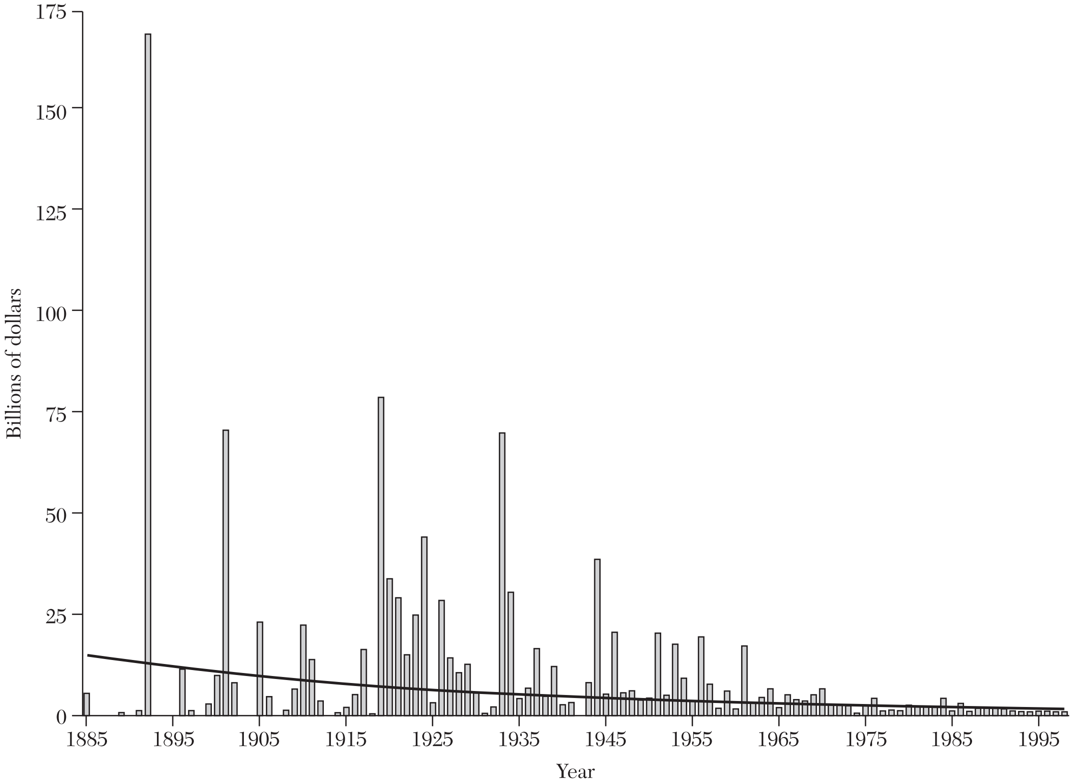

Figure 3. The Stock-Market Value of Firms by Vintage

investment than wineholders did because they also got dividends.

Why would such large vintage effects appear on the U.S. stock market? I mentioned above that vintage effects on wine are to be expected given that weather varies from year to year and that one cannot, legally anyhow, replace the label on a bottle of wine with that of a good vintage and sell it at a higher price. But, unlike a vintage wine, a firm can redefine and transform itself; it can copy the products, technologies, and organizational forms of other firms more successful than itself, and it can raid their personnel. If the firm had previously entered with a wrong technology, reorganization would allow it to remove an undesirable imprint. Yet reorganization does not seem to work smoothly—if it did, a firm from a bad vintage could transform itself and raise its value. Something, evidently, stands in its way. These are organization-capital-adjustment-costs such as labor strikes, golden parachutes for top management, and patent-infringement lawsuits. The future editions of SPEC will tell us more about how much such barriers to reorganization matter.

5. *Aging and Technological Change*

Proposition 2 asserts that the onset of technological change will threaten an old firm more than a young one. Technological change should therefore raise the death-hazard more for an old firm, as shown in figure 4.

In support of this implication, in table 16.2 the authors report that small

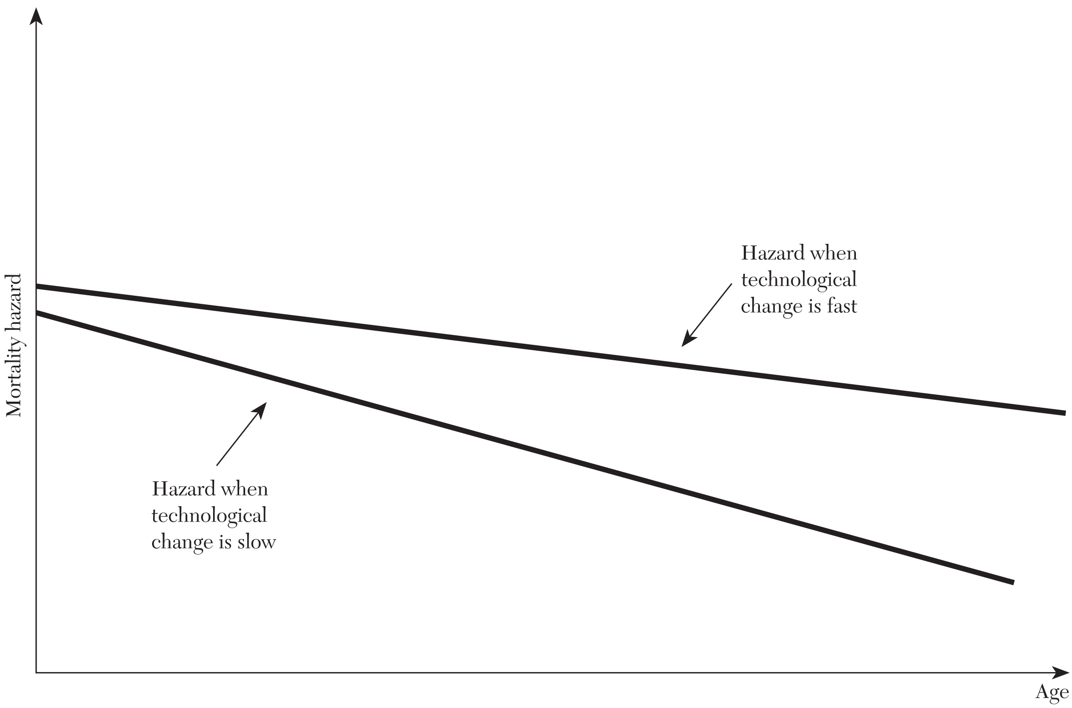

Figure 4. Death-Hazard Rates for Two Different Regimes

automobile firms raised their survival rates by more when they innovated than large firms did. Since large firms tend to be older, the results are encouraging, but the probable endogeneity of both the innovation variable and the size variable makes it hard to interpret these results with confidence. At any rate, it's good to seek evidence in more than one place, and I will now report some results from the U.S. stock market.

5.1. *Technology Shifts and Survival in the U.S. Stock Market*

The economic environment became riskier in the early 1970s and it remains riskier today. Some would say that this reflects a faster pace of technological change, to do with the computer and the internet. If we accept this interpretation, then proposition 2 states that old firms should be losing ground to new firms and young firms at a rate that is faster after the mid-1970s than before. [The first desktop computers were sold in 1974, and so this is probably a good date to designate as the start of the information technology (IT) era. Apparently, the first desktop computer was not the Altair (vintage 1975), nor the Apple II (1977)—eventually the first computer to sell 1 million units. PCs that predate Altairs and Apples are the Xerox Alto, the first personal system with a mouse and onscreen windows in 1974; the French had developed the Micral, and other models on sale were the Kenbak and the Scelbi (Steven Ditlea 2000)].

Figure 5 deals with the survival not of firms but of their value. It plots the combined stock-market value of all firms that entered the New York Stock Exchange (NYSE) before 1935. With the passage of time, attrition through de-listing reduces the number of firms

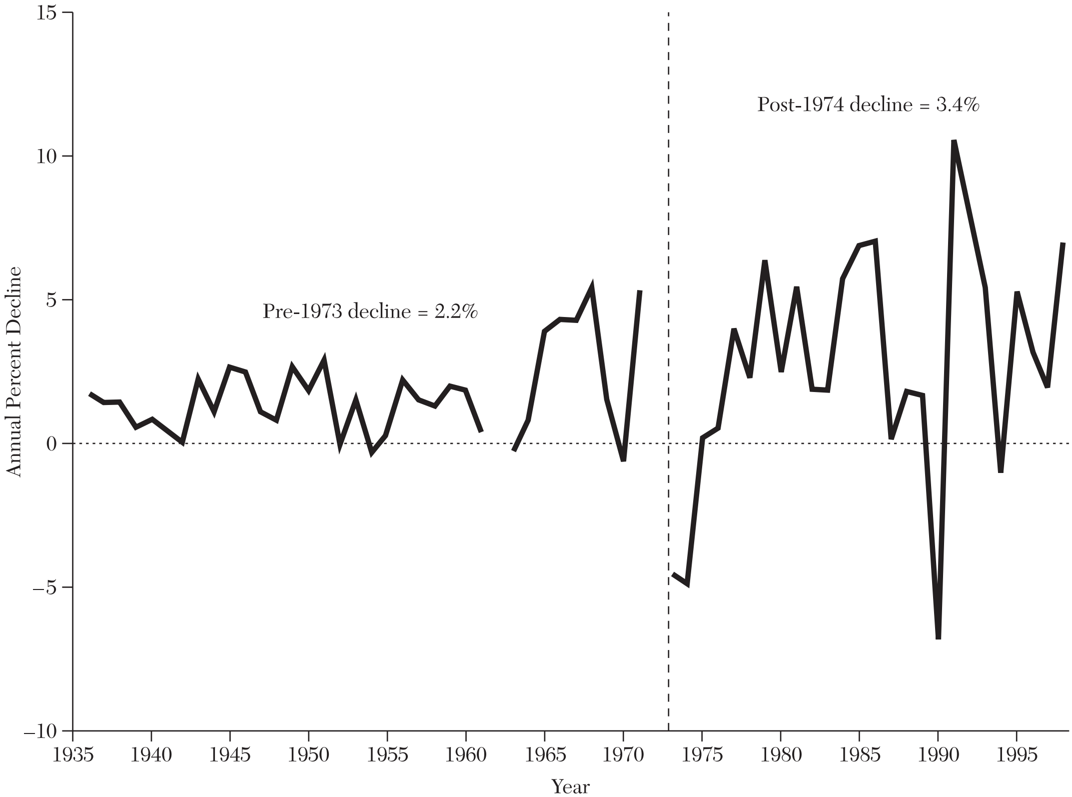

Figure 5. Aging and Value-Loss in the Stock Market

in the sample, but not necessarily their combined value. The vertical axis shows how much their share of total NYSE value declined each year, as a percentage of their beginning-of-year share. This variable measures how much market share the "old" pre-1935 firms are losing to the "young" post-1935 entrants. Sometimes the variable is negative, indicating that the old firms gained on the young firms, but this does not happen very often. The point of the figure is not that in an average year the old companies lose value to the young, but, rather, that the rate at which they are losing has, since 1974, been higher by 1.2 percent on average. (The panel data are from the Center for Research on Security Prices at the University of Chicago. They are known as the CRSP data. The CRSP data included only the NYSE firms until 1962, when they start to include the firms listed on AMEX. The firms listed on the NASDAQ exchange are included as of 1972. The loss rates for the years 1962 and 1972 would then be artificially high simply because of the way the data are collected, and they are therefore omitted from the plot in figure 2).

Did death rates of older firms go up too? I shall now report results from mortality regressions that use the sample of individual company data from 1885 until 1998. (The data include all the firms that traded on the New York Stock Exchange over this period, the post-1962 AMEX firms, and the post-1972 NASDAQ firms. There are 231,063 observations in all. The data are described in Jovanovic and Peter Rousseau 2000). I will assume that a technological shift takes place when a new multi-purpose technology arrives, when it is still not clear to everyone that the new technology will succeed, and when we can expect the big firms to resist it. Such resistance should continue until the new technology is recognized and is routinized in big firms. So, the initial stages of the technological revolution should pose the biggest problem for the large firm and we may take the first ten years of a new technology's life as being the "period of resistance."

The onset of IT was a technological breakthrough that has probably affected most firms in some way. But so did electricity. America started to electrify in 1894 with the building of the Niagara Falls dam, and the process was not complete until the 1930's. As we saw above, the first microcomputers were marketed in 1973, and so we may take the Microcomputer Age as starting in 1974.

The mortality regressions are formulated as follows. Let $d_{i,\,t} = 1$ if firm delists from the stock-exchange during year t, and $d_{i,\,t} = 0$ if it does not de-list. Assume the logit specification

$$E\{d_{i,t}|x_{1,t}, x_{2,t}, \ldots\} = \frac{1}{1 + \exp\{-\Sigma_i \beta_i x_{i,t}\}},$$

where $x_{i,\,t}$ is the i'th market-characteristic or firm-characteristic at date t, and I shall refer to them as regressors. Define the dummy variable for the onset of electrification as $D_{E,\,t} = 1$ for t between 1894 and 1903, and zero elsewhere, and define the dummy variable for the onset of IT as $D_{IT,\,t} = 1$ for t between 1974 and 1983, and zero elsewhere.

The regressors, $x_{i,\,t}$ will be calendar time, the age of firm i at date t, denoted by $A_{i,\,t}$, and the two dummy variables on their own, and interacted with the age

TABLE 1
LOGIT MORTALITY REGRESSIONS
Dependent variable: Firm-mortality (d_{IT})

Regressor	Coefficient	t-ratio
Firm's age, $A_{i,t}$	–0.01	14.14
Electrification dummy, $D_{E,t}$	2.00	10.74
IT dummy, $D_{IT,t}$	–0.002	0.08
$A_{i,t}\,D_{E,t}$	–0.02	1.38
$A_{i,t}\,D_{IT,t}$	0.002	1.26
Time	0.02	34.64
Constant	–4.66	73.19

of the firm. Proposition 1, as portrayed in figure 4 asserts that the new technologies should have raised mortality risk more for the older firms and that, therefore, the coefficients of the interacted terms should be positive. Table 1 reports the results. Aging reduces the risk of exit, but some of this is because of the survival of the fittest firms. The average firm age during the 1894–1903 epoch was 9.6 years, and in the 1974–83 epoch it was 7.2 years. The stock market is getting younger and younger with the passage of time, and one reason is the rising death rate reflected in the positive coefficient of time. The coefficients of $D_{E,\,t}$ and $D_{IT,\,t}$ are the effects of the two technologies on the death rates of the firms at age zero, or, rather, on the intercept of the hazards. Electrification therefore made life more difficult for the young firm, whereas IT seemed to make no difference to the young firms' survival. But if we add in the interaction effects and consider the impact of the two technologies on the population of firms as a whole by evaluating the derivatives of $A_{i,\,t}\,D_{E,\,t}$ and $A_{i,t}$ $D_{IT,\,t}$ at the mean age, the hazard did rise in both periods. The age-dummy interactions are not significant, however, and the sign is correct for the $A_{i,t}$ $D_{IT,\,t}$ variable, but not for the $A_{i,\,t}\,D_{E,\,t}$ variable.

The early IT era therefore confirms

proposition 2. The initial impact of IT did more harm to old firms than to young ones. But electrification had the opposite effect. This may be because electrifying a factory was expensive, but did not place great intellectual demands on management. Computers, on the other hand, are cheap, but in order to use them one needs to be skilled.

6. *Conclusion*

The questions of demography have mainly to do with the effects of the passage of time on the shape of organisms and their populations and on how organisms of different ages coexist. This means that empirical work must take on a time-series perspective, and this book does that in a suggestive and clear way. It documents far more than I have been able to cover here; some of it describes work that the authors or their students have done, yet the presentation is relaxed and clear. A couple of unnecessary obstacles are the absence of an author index, and the use of symbolic logic to derive propositions such as Theorem 1 that, when expressed verbally, are perfectly obvious. But these are minor blemishes. The book contains, literally, dozens of figures and tables; at every turn one encounters illuminating plots of a whole variety of data and of simulated equations, histograms, mortality tables, hazard rate estimates, transition matrices, even reproductions of pages from obscure trade papers where some of the data come from.

The book is useful even for the study of problems that one would, at first, not associate with demography. For instance, take the evidence from some cross-section studies, that profits are higher in markets that are concentrated. From this we may infer that a monopolist can raise price above cost because barriers to entry that prevent other equally efficient firms from coming in. But we could also infer that the monopolist raises price above his own cost, but not above the costs of his competitors because they are less efficient. If we cannot observe the barrier to entry or the costs of the potential entrants, we cannot tell whether the monopolist owes his position to barriers to entry, or to his superiority. But the history of the market would reveal if, for instance, the monopolist survived a shakeout or whether he was alone in the industry all along, and this may identify the answer.

The book does more than merely present facts. The Darwinian type of theory brings a coherence to it, and some of the insights are thought provoking, especially those on inertia in organizations and imprinting. Parts of the book should be required reading in some graduate economics courses. It will inspire new theory by economists and sociologists alike.

Appendix: Tinkering and Market-to-Book Values

Let k be the amount that a tinkerer must invest in preproduction tinkering. This will be the *book value* of his firm if it should go public. If it succeeds, the project yields a net revenue of Ak in each subsequent period. Some tinkerers are more likely to succeed than others. Let x be the prior probability of success. Every potential tinkerer knows his own x. The number of type-x prospective tinkerers is $f(x)$. For example, a high-x tinkerer would have been someone trying to use the Daimler-Benz internal combustion engine, while a low-x tinkerer would have been trying out the steam engine or an electric battery.

If he does not succeed, the tinkerer gets a payoff of zero. This happens with probability $1 - x$. His profit stream therefore is

$$\begin{bmatrix} 0 & \text{forever}, w.prob. 1 - x \\ Ak & \text{forever}, w.prob.\ x \end{bmatrix}$$

The lifetime value of a successful idea is Ak/r, and if the project succeeds and the firm goes public, its market-to-book value will be

$$\frac{1}{k}\left(\frac{1}{r}Ak\right) = \frac{1}{r}A \equiv Q \tag{1}$$

To want to engage in the activity, a prospective tinkerer must have positive expected lifetime profits from it, which means that

$$xQk \geq k$$

Only those people for whom x satisfies the inequality

$$x \geq \frac{1}{Q} \tag{2}$$

will become tinkerers. The level of x at which expected lifetime returns are zero is $x = 1/Q$ and anyone whose x is less than $1/Q$ does something else. The fraction, T, of tinkerers in the population therefore is

$$T = 1 - F(1/Q) \tag{3}$$

So, tinkering rises with Q and with a stochastically larger F in the sense of first-order dominance.

Which of the two—more profitable inventions or easier-to-find inventions—explains the large number (3,845) of tinkerers in Carroll and Hannan's sample? Probably the smaller F that would have arisen if potential inventors were inspired by the development of the internal combustion engine and electricity just before the turn of the twentieth century, and from the still unexplored remaining avenues of the steam engine.

The fraction that make it to the production stage is 11 percent, and so

$$\frac{1}{1 - F(1/Q)} \int_{1/Q}^{\infty} xf(x)dx = 0.11 \tag{4}$$

where the 11 percent number in eq. (4) is taken from p. 347 of the book. Recent technological developments seem to have made the business climate riskier. If true, this means that for the projects that are undertaken in equilibrium, A has risen, and according to eq. (1), so has the market-to-book ratio Q, because the real rate of interest has not changed. According to eq. (3), this should have lured more people into tinkering. And, according to eq. (2), we are now taking more longshots, just as automobile tinkerers did a century ago. At the same time, market-to-book ratios have risen to unprecedented levels.

EXAMPLE: Let us solve for T explicitly for the case where x is distributed uniformly on the interval $[0, \lambda]$, where $1/2 < \lambda < 1$. Then $F(x) = x/\lambda$ for $x \in [0, \lambda]$. These days Q is around three. But that is higher than it has been historically. Let us suppose (since this is just an example) that around 1900 for the automobile companies Q was around two. Then $T = 1 - F(1/2) = 1 - 1/2\lambda$. If $Q = 2$, Eq. (4) reads

$$2 \int_{1/2}^{\lambda} xdx = \lambda^2 - \frac{1}{4} = 0.11$$

which can hold only if $\lambda = 0.6$, and then we can infer that the fraction of the population that tinkered 100 years ago was 0.17.

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