

# Industry Shakeouts and Technological Change

Steven Klepper, Carnegie Mellon University  
Kenneth L. Simons, Royal Holloway, University of London

Date of this version: October 2001

Print date: 6 November, 2001

Steven Klepper  
Dept. of Social & Decision Sciences  
Carnegie Mellon University  
Pittsburgh, PA 15213  
USA

phone +1 412 268 3235  
fax +1 412 268 6938  
email [sk3f@andrew.cmu.edu](mailto:sk3f@andrew.cmu.edu)

Kenneth L. Simons  
Dept. of Economics  
Royal Holloway College  
University of London  
Egham, Surrey TW20 0EX  
UK

phone +44 1784 443909  
fax +44 1784 439534  
email [K.Simons@rhul.ac.uk](mailto:K.Simons@rhul.ac.uk)

Acknowledgments: Klepper gratefully acknowledges support from the Economics Program of the National Science Foundation, Grant No. SBR-9600041 and support from IBM through its faculty partnership awards.

# Industry Shakeouts and Technological Change

## Abstract

We analyze the evolution of four new products that experienced an initial rise and then extreme shakeout in their number of manufacturers: automobiles, tires, televisions, and penicillin. Data on entry, exit, and innovation are collected for each product to test theories of industry shakeouts. Hazard analyses indicate that earlier entrants had persistently lower hazards during the shakeouts, which was related to their greater rates of innovation. Our findings suggest shakeouts are not triggered by particular technological or other events but are part of a competitive process in which the most able early entrants achieve dominant market positions through innovation. (JEL L1, L13, O31)

# Industry Shakeouts and Technological Change

## I. Introduction

After a buildup in the number of firms, many new industries experience a shakeout in which the number of firms falls sharply. Among a sample of 46 major new products analyzed by Gort and Klepper (1982) and Klepper and Graddy (1990), most products that had evolved for several decades experienced some degree of shakeout, and in extreme cases the number of producers fell by 90% or more over 15 to 20 years despite robust growth in output. Perhaps not surprisingly, severe shakeouts seem to be associated with eventual tight market concentration. Thus, healthy new markets are suddenly characterized by a sharp and sometimes prolonged decline in the number of producers and end up as oligopolies. What could be driving such profound shifts in market structure?

Understanding the causes of shakeouts is likely to provide insight into the broader question of what determines an industry's market structure, a long-standing interest in industrial organization. A number of alternative frameworks have been offered within both economics and other disciplines to account for the forces shaping industry structure. Many emphasize the role played by technological change, depicting market structure and technology as either co-evolving (e.g., Nelson and Winter, 1978; Flaherty, 1980; Metcalfe and Gibbons, 1988) or simultaneously determined (e.g., Shaked and Sutton, 1987; Dasgupta and Stiglitz, 1988; Sutton, 1998). Testing these theories, however, has been limited and largely indirect, no doubt partly due to the difficulty of measuring technological change. A similar state characterizes the literature on shakeouts. Shakeouts tend to be more pronounced in industries subject to greater technological change (Agarwal, 1998), suggesting a causal role for innovation in shakeouts. Indeed, it is not hard to envision how a major innovation or technological development could trigger intense competition leading to a shakeout, and several theories featuring innovation have been proposed to explain shakeouts (Utterback and Suárez, 1993; Jovanovic and MacDonald, 1994; Klepper, 1996). Paralleling the market structure literature, to the extent the theories have been tested empirically, they tend to be tested in isolation and indirectly using data on entry, exit, and sometimes firm survival rather than on technological change itself.

The main purpose of this paper is to develop and carry out more discriminating tests of the role of innovation in industry shakeouts. We examine theories with different mechanisms involving technology – some in which technological developments trigger shakeouts and one in which shakeouts are part of a broader evolutionary process shaped by innovation. These theories are difficult to test against each other with available technology-related data, but we show they have distinctive implications regarding firm survival that provide a way to distinguish among them. They all feature innovation in conditioning firm survival, and we use the implications of the theories regarding innovation and firm survival to distinguish technological from nontechnological theories of shakeouts.

The theories are tested on four industries that experienced severe shakeouts: automobiles, tires, televisions, and penicillin. The first three of these industries were examined in prior shakeout studies, but we collect more detailed data than have been used previously. From the inception of each industry through its formative evolution, we identify every entrant, its date of entry and exit, the ownership changes it experienced, and the innovations it introduced. This enables us to test detailed implications of the alternative shakeout theories regarding firm survival and innovation. Our empirical analysis reveals consistent patterns in all four products. Early entrants had markedly lower hazard rates by the start of the shakeouts in all four products and maintained these lower hazards as the shakeouts proceeded. Innovation was the driving force behind the longer survival of early entrants and shaped the survival of entrants from all periods. These findings suggest a rich-get-richer dynamic involving innovation that eventually compromised the ability of later entrants and less able innovators to survive, directly contributing to the shakeouts. Given the diversity of the products in terms of their underlying technologies and availability of substitutes, and consonant with our earlier qualitative analysis of technological change in the four products (Klepper and Simons, 1997), our findings suggest that shakeouts are part of a broader process of industry evolution in which innovation plays a key role in shaping market structure.

The remainder of the paper is organized as follows. In Section II, the nature and timing of the shakeouts in the four products is established. In Section III, theories featuring innovation that have been proposed to explain shakeouts are reviewed and econometric models to test the distinctive implications of the theories are specified. In Section IV the econometric models are estimated. Concluding remarks are presented in Section V.

## II. The Shakeouts

Annual counts of the number of firms, entry, and exit in each of the four products are presented in figure 1. These counts were compiled from lists and annual directories of U.S. manufacturers of each product.<sup>1</sup> We recorded annually each firm's name and address and combined the histories of firms with identical or nearly identical names and/or street addresses in nearby years. Acquisitions by firms that did not already produce the product were treated as continuations of the acquired firm, and mergers and acquisitions involving incumbents were treated as continuations of the main participant and censored exit of the other firm(s).<sup>2</sup>

The counts in figure 1 begin at the commercial inception of each product and extend for many decades, with the last year of data dictated by our sources. In each product, the number of producers rose dramatically for one to three decades following the inception of commercial production. In automobiles, tires, televisions, and penicillin the number of firms peaked in 1909, 1922, 1951, and 1952 respectively, after which the number of producers then fell by 70% to 97% over three decades or more.<sup>3</sup> These declines represent very severe shakeouts (cf. Gort and Klepper, 1982; Klepper and Graddy, 1990; Agarwal, 1998). Tight oligopolies also arose in all four industries. Ford, General Motors, and Chrysler (which evolved from Maxwell-Briscoe) had 46% of unit sales in autos in 1910, which increased to over 60% in the 1920s and over 80% in the 1930s. In tires, Goodyear, Goodrich, US Rubber (Uniroyal) and Firestone accounted for

---

<sup>1</sup> Lists of manufacturers and their dates of production were compiled using: for autos, Smith's (1968, pp. 191-267) list A; for tires, *Thomas' Register of American Manufacturers* 1905-1981 (after 1981 the register changed its categorization of tire producers), plus *Hendrick's Commercial Register of the United States for Buyers and Sellers* 1901-1903 (the 1904 issue could not be obtained) to identify earlier entry dates for producers listed in 1905 or 1906; for tvs, *Television Factbook* 1948-1989 (the period when manufacturers were reported, except vol. 51 which could not be obtained), plus the 1945-1948 monthly issues of *Television Digest and FM Reports* to identify earlier entry dates for producers listed in 1948 and to determine the number of producers in 1947; for penicillin, *Thomas' Register* 1944-1993 and *Synthetic Organic Chemicals* 1944-1993 (each source by itself was incomplete), plus FTC (1958) to determine 1943 manufacturers. The list of tire manufacturers excludes firms known to produce only solid tires or only non-automobile tires, both with substantially different markets from pneumatic automobile tires. The list of tv manufacturers includes several makers of self-assembly kits to ensure comparability of the data over time. Simons (1995) discusses the advantages of these sources over available alternatives and shows that key empirical patterns are robust across the alternatives.

<sup>2</sup> Mergers and acquisitions were recorded using information compiled by industry analysts, including: for autos, Smith (1968); for tires, Gettell (1940), Epstein (1949), Bray (1959), FTC (1966), Dick (1980), French (1991), a Uniroyal internal document kindly provided by French, and surviving issues of a trade periodical, the *Tire Rate Book*, from the 1920s; for televisions, Datta (1971), Levy (1981), Willard (1982), LaFrance (1985), and Teitelman (1994); and for penicillin, FTC (1958).

<sup>3</sup> The peak year of 1951 in tvs results using counts separately in the initially quarterly and then biannual editions of *Television Factbook*; combining firm listings within each year would yield a peak year of 1949 with the number of firms remaining nearly as high through 1951.

53% of sales in 1926, which they increased to 72% by 1933 and then maintained for many years thereafter. In tvs, five major firms held at least 67% of unit sales in 1958, and by 1968 two firms alone, Zenith and RCA, sold 50% of color sets before losing the market to foreign competitors. In penicillin, four large producers, Lilly, Wyeth, Squibb, and Bristol, had 60% of dollar sales in 1960 and 69% in 1973.<sup>4</sup>

The shakeout patterns were similar in the four industries. Entry was high initially but then became negligible within approximately five years of the peak number of firms in tires, tvs, and penicillin and approximately ten years of the peak number of firms in autos. Exit continued for many years after the peak number of firms, which coupled with negligible entry resulted in a long-term decline in the number of firms. Consolidations played a minor role in all the shakeouts, with acquisition-related exits constituting 5%, 1%, 6%, and 0% of exits before and 8%, 5%, 11%, and 3% of exits after the peak number of firms in autos, tires, tvs, and penicillin respectively. Output grew at robust rates after the peak in the number of firms in each of the products,<sup>5</sup> suggesting the shakeouts were not driven by demand factors. International trade was also not prominent in any of the shakeouts except tvs, and in tvs it became significant 20 years after the start of its shakeout, suggesting that the shakeouts were not driven by international competition. So what can account for the shakeouts and the evolution of tight oligopolies in the four products?

### **III. Contrasting Perspectives on Industry Shakeouts**

Recently, a number of theories have been developed or adapted to explain shakeouts. They can be divided into two groups. One group features innovation as playing a key role in shakeouts. The other group either implicates nontechnological factors or factors related to technology but not necessarily innovation per se, such as learning by doing, as causing

---

<sup>4</sup> Market share data cited were obtained from FTC (1939, p. 29), Kimes and Clark (1996), French (1991, p. 47), Levy (1981, pp. 84-88), and Schwartzman (1976, pp. 131-132).

<sup>5</sup> Automobile output grew from 127,000 cars in 1909 to 1.7 million in 1919 and 5.3 million in 1929, and would rise further after setbacks during the Depression and World War II (FTC, 1939, p. 7). Tire output grew from 40 million tires in 1922 to 73 million in 1928, and as in automobiles output would grow further following World War II (Gaffey, 1940, p. 54). Television output leveled off after attaining a peak of over 7 million sets in 1950, but then rose to over 11 million sets with the growth of color tv set production in the 1960s and 1970s (Levy, 1981, pp. 99-100, 112). Penicillin output grew from 671,000 pounds in 1952 to 10,200,000 pounds in 1987 (U.S. Tariff Commission, 1952-1987).

shakeouts.<sup>6</sup> Our goal is to test the role of innovation in shakeouts and to distinguish among the different mechanisms that have been proposed for how innovation might be related to shakeouts. We draw out distinctive testable implications from three of the leading theories of shakeouts that feature innovation. These implications enable us to distinguish between the theories and to test them against the nontechnological theories of shakeouts.

### A. Three Theories

Two of the theories featuring innovation depict shakeouts as being triggered by technological developments. In Jovanovic and MacDonald's (1994) theory, which we label the **radical invention** theory, a new industry is created by a major invention, and firms enter the industry until expected profits are driven to zero. Subsequently a major invention occurs that opens up the possibility of a new innovation. This innovation is challenging to develop and increases substantially the efficient scale of production. It may induce entry, but if entry occurs it will be profitable for it to occur immediately, after which entry will be zero. In each period, firms that have not yet innovated based on the new technology have a constant probability of doing so. Successful innovators expand to their new efficient production scale, and the pressure of output growth on prices pushes out some fraction of the unsuccessful innovators. As the unsuccessful innovators exit, the industry undergoes a shakeout, which ends when all the unsuccessful innovators have been forced to exit.

In Utterback and Suárez's (1993) theory, which we label the **dominant design** theory, a new industry is created and firms enter based on alternative innovative designs for the industry's product. Eventually some firm or regulatory body hits upon a design combination, synthesized from past innovations, that crystallizes demand around a *de facto* product standard, dubbed a "dominant design." Product innovation and entry slow as opportunities to break into the market on the basis of new product designs are diminished. Process innovation rises as firms compete to produce the standard product at the lowest possible cost, and firms that are less successful at process innovation are driven out of business. Coupled with diminished entry, this exit leads to a

---

<sup>6</sup> Nontechnological factors triggering shakeouts include overconfidence (Camerer and Lovallo, 1999), herd behavior (Bikhchandani, Hirshleifer, and Welch, 1998; Geroski and Mazzucato, 2001), information cascades (Horvath, Schivardi, and Woywode, 2001), wars of attrition (Bulow and Klemperer, 1999), and density delay (Carroll and Hannan, 1989). For models addressing learning by doing and industry aggregate technological change, see Petrakis, Rasmusen, and Roy (1997) and Carree and Thurik (2000).

shakeout in the number of producers that continues until all the unsuccessful innovators have been forced to exit the industry.

The other theory, developed by Klepper (1996, 2001), is labeled the **competitive advantage theory**. It depicts industry market structure and innovation as coevolving. The theory features a process of dynamic increasing returns to R&D in which firm size is limited by convex costs of growth, and larger firms benefit most from R&D – and hence choose to perform the most R&D – because they apply the resulting unit cost reductions and quality improvements to the largest amounts of output. Over time, new entrants arise with the requisite R&D capabilities to enter. As entry and growth occur over time, industry output expands, causing price to fall. Entrants consequently must be increasingly able at R&D in order to be profitable. Eventually even the most capable potential entrants cannot profitably enter, and entry ceases. The convex costs of growth limit the ability of later entrants to catch up with earlier entrants in terms of size, and as price continues to fall the smallest firms and least able innovators are forced to exit the industry. This leads to a shakeout of producers that continues until the entire output of the industry is taken over by the most capable early entrants.

#### *B. Contrasting Testable Implications*

Innovation is the root cause of shakeouts in the first two theories, but the implications of the theories regarding innovation are quite difficult to test. Jovanovic and MacDonald test their theory by showing its ability to explain aspects of the evolution of the tire industry, including not only the number of producers but also trends in tire prices and output and stock prices of publicly traded tire companies. Lacking detailed evidence regarding technological changes and how they affected the efficient scale of production, they tentatively identify the Banbury rubber mixer as a plausible scale-increasing innovation whose timing was suitable to trigger the shakeout. Utterback and Suárez proceed similarly, testing their theory on multiple industries, including autos and tvs. They identify the advent of the all-steel closed-body automobile in 1923 and the development of color broadcast standards in 1953 and the rising prevalence of 21-inch picture tubes as possible dominant designs whose timing could have plausibly triggered the shakeouts in autos and tvs. They present little supporting evidence, though, about these technologies, nor do they discuss alternative candidate technologies and their timing relative to the shakeouts. Klepper and Simons (1997) evaluate the technological histories of autos, tires, and tvs and



question the significance of the innovations identified by Jovanovic and MacDonald and Utterback and Suárez, but without more detailed evidence it is difficult to go beyond gainsaying.

An alternative way to test the theories is by drawing out their implications regarding firm survival. Jovanovic and MacDonald did not have data on firm entry and exit rates and thus did not consider the firm survival implications of their model, but their model has distinctive firm survival implications that are applicable as well to Utterback and Suárez's theory. In Jovanovic and MacDonald's model, after the initial invention that creates the new industry, there is no entry or exit until the subsequent invention that triggers the shakeout. While this invention may induce entry initially, it eventually leads to exit among both incumbents and entrants. Thus, their model implies that the hazard rate of incumbents must rise with the onset of the shakeout. Incumbents are assumed to have advantages over firms that enter after the invention that stem from their prior technological experience. Their advantage is embodied as a one-period head start at innovation. Given their head start, in every period a greater fraction of the pre-invention entrants have innovated than the post-invention entrants and hence they have lower hazards of exit. The hazard of exit of both early and late entrants must decline over time since the percentage of firms that have not yet innovated declines and the probability of innovation is the same in every period.<sup>7</sup> Eventually all unsuccessful innovators exit, and the exit rate of early and late entrants converges to zero or to the pre-invention exit rate, all else equal. The model is silent regarding other factors such as firm age that might play a role in the exit process.

The dominant design theory also portrays shakeouts as being triggered by technological developments that alter the basis for competition. This leads to the exit of firms least able to cope with the new situation, which should be manifested as a rise in the firm hazard rate at the

---

<sup>7</sup> Denote the fraction of non-innovators among surviving firms, surviving early entrants, and surviving late entrants as  $x_t$ ,  $y_t$ , and  $z_t$  respectively, for  $t$  greater than or equal to the first period in which firms exit following the major invention triggering the shakeout. As Jovanovic and MacDonald show,  $x_t$  must decline over time, and it is easy to prove that the same property holds for  $y_t$  and  $z_t$ . As Jovanovic and MacDonald indicate, the price  $p$  remains constant once the first exit has occurred following the major invention, and therefore industry output must remain constant. The fraction of non-innovators that innovate in period  $t$  is  $r$ . Hence in period  $t$  the fraction of all firms that innovate is  $rx_t$ , and the similar fractions for early and late entrants are  $ry_t$  and  $rz_t$ . Since all innovators expand from output  $q^l$  to  $q^h$ , for each innovator there must be  $(q^h - q^l)/q^l$  exits among non-innovators so that output remains constant. Hence the fraction of all firms, early entrants, and late entrants that have survived but exit in period  $t$  are  $kx_t$ ,  $ky_t$ , and  $kz_t$  respectively, where  $k = r(q^h - q^l)/q^l$ . Since  $k$  is a constant and  $x_t$ ,  $y_t$ , and  $z_t$  decline over time, the rate of exit must fall over time among all firms and within each cohort of entrants. Jovanovic and MacDonald make no assumption about the composition of firms that exit, and we presume, consistent with the intuition of their model, that within each period non-innovators have equal rates of exit regardless of entry time. The model allows for the

start of the shakeout. As the least able firms exit, a smaller percentage of firms are at risk for subsequent exit, which should cause firm hazard rates to decline over time, similar to the radical invention theory. Utterback and Suárez (1993) and Suárez and Utterback (1995) conjecture that experience will make it easier for firms to adapt to the new environment, so that at the start of the shakeout earlier entrants should have a lower hazard rate, similar to Jovanovic and MacDonald. Alternatively, Christensen, Suárez and Utterback (1998) conjecture that in fast changing environments, it may be easier for firms that have entered shortly before the emergence of the dominant design to adapt to the new environment because they are less committed to technologies rendered obsolete by the dominant design. In either case, with unsuccessful adapters of all vintages exiting over time, it would be expected that any differences in cohort exit rates would decline over the course of the shakeout, as implied by Jovanovic and MacDonald's model.

Thus, both the radical invention and dominant design theories suggest that firm hazard rates should rise with the onset of the shakeout, entrants during the shakeout should have higher initial hazards than earlier entrants, and over time the hazard rates of entrants in all cohorts should decline and converge. These predictions contrast with the implications of the competitive advantage theory regarding firm hazards (cf. Klepper, 2001). In the competitive advantage theory, the shakeout begins when entry ceases and its onset does not correspond with any particular development regarding exit. Therefore, the theory does not predict a rise in firm hazard rates at the start of the shakeout. The theory does allow for changes in entry cohort hazard rates over time due to changes in unobserved heterogeneity. The theory predicts that early entry should confer a competitive advantage, manifested as a lower hazard rate. This may not be apparent when the early entrants are young because entry is easier in the early evolution of the industry, allowing a wider range of entrants in terms of their capabilities. By the start of each of the shakeouts, however, the less capable early entrants will have disproportionately exited, and the lower hazard of the earlier entrants should be apparent. Thus, like the radical invention and one version of the dominant design theory, the competitive advantage theory implies that at the start of the shakeout firm hazards will be ordered by time of entry. Unlike the

---

possibility that the entire shakeout occurs in a single time step, in which case the decline in exit rates likewise occurs across one period.

alternative theories, however, the competitive advantage theory predicts that differences in entry cohort hazard rates will persist and might even grow over time.

### *C. Econometric Specification: Survival by Cohort*

To test the contrasting firm survival implications of the theories, we distinguish three cohorts of entrants. The last, denoted cohort 3, contains the firms that entered after the start of the shakeout. The second, denoted cohort 2, contains the firms that entered just before the start of the shakeout. Cohort 1 contains all the other firms that entered early.

The first two theories do not offer clear predictions about how the hazards of cohorts 1 and 2 will differ prior to the shakeout, but the radical invention and dominant design theories predict that the hazards of firms in both cohorts will rise with the onset of the shakeout, with the firms in cohort 3 having a higher initial hazard than those in cohorts 1 and 2. Both theories also predict the hazards of all three cohorts will decline and converge as the shakeout proceeds. In contrast, the competitive advantage theory predicts no rise in the hazard of firms in cohorts 1 and 2 with the onset of the shakeout and persistent differences in firm hazards according to the time of entry as the shakeout proceeds. One way to test these conflicting predictions is by estimating for each product hazard curves for each of the three cohorts of entrants. We do this using nonparametric smoothing methods. We also test the conflicting implications using parametric methods. For each product, we estimate the following specification for  $r_{it}$ , the hazard of firm  $i$  in year  $t$ :

$$(1) \quad r_{it} = h(\text{age}_{it}) \exp\{\beta_1 S_t + \beta_2 \text{cohort}2_i S_t + \beta_3 \text{cohort}3_i S_t + \beta_4 S_t(t - S) + \beta_5 \text{cohort}2_i S_t(t - S) + \beta_6 \text{cohort}3_i S_t(t - S)\},$$

where  $S$  is the year of the start of the shakeout,  $S_t$  is a 1-0 dummy equal to 1 for all years of the shakeout,  $\text{cohort}2_i$  and  $\text{cohort}3_i$  are 1-0 dummies for firms in cohorts 2 and 3 respectively, and  $h(\text{age}_{it})$  is a function that allows firm hazards to vary with age.

Equation (1) allows firm hazards to change with age and also the onset of the shakeout. In the exponential term of (1), the first variable  $S_t$  allows the hazard of firms in both cohorts 1 and 2 to change with the onset of the shakeout. If the hazards of these cohorts rise, as predicted by the radical invention and dominant design theories, then  $\beta_1$  will be greater than zero, whereas  $\beta_1$  will equal zero if their hazards do not rise, as predicted by the competitive advantage theory. The next two variables,  $\text{cohort}2_i S_t$  and  $\text{cohort}3_i S_t$ , allow the hazards of the three cohorts to differ

as of the start of the shakeout. If they are ordered by time of entry, as predicted by all three theories (in one version of the dominant design theory), then  $\beta_3 > \beta_2 > 0$ , in which case  $\beta_1 + \beta_2$  and  $\beta_1 + \beta_3$  are both greater than zero. If the alternative version of the dominant design theory applies, then  $\beta_3 > 0 > \beta_2$ .

The next three variables allow the hazards of each cohort to change, and at different rates, as the shakeout proceeds. The parameter  $\beta_4$  calibrates how the hazard of cohort 1 changes as the shakeout proceeds, and  $\beta_4 + \beta_5$  and  $\beta_4 + \beta_6$  play the analogous role for cohorts 2 and 3. Thus, if the hazards of all three cohorts decline over time, as predicted by the radical invention and dominant design theories, then  $\beta_4$ ,  $\beta_4 + \beta_5$  and  $\beta_4 + \beta_6$  will all be negative. The competitive advantage theory, aside from changes in unobserved heterogeneity, does not imply changes in the hazards of each cohort as the shakeout proceeds. If age adequately controls for changes in unobserved heterogeneity, then the theory implies  $\beta_4$  will equal 0. If the hazards of the three cohorts converge as the shakeout proceeds, as predicted by the radical invention and dominant design theories, then either  $\beta_6 < \beta_5 < 0$ , or in the alternative version of the dominant design theory (corresponding to  $\beta_2 < 0 < \beta_3$ )  $\beta_6 < 0 < \beta_5$ . In contrast, the competitive advantage theory predicts that cohort hazard rates will not converge and may even diverge, which implies  $\beta_5 \geq 0$  and  $\beta_6 \geq 0$ . The contrasting predictions of the various theories for the coefficients of equation (1) are summarized in table 1.

#### *D. Econometric Specification: Innovation*

The firm survival implications of the three theories provide a way of distinguishing among the theories, but do not distinguish the theories from nontechnological explanations for shakeouts. This requires data on innovation. All three theories predict that innovation is the key determinant of firm hazard rates, which is a distinctive implication shared by the theories. The theories predict that successful innovators will have lower hazards and earlier entrants will be more successful innovators. The former hypothesis is tested using a variant of equation (1) that incorporates innovation. Firms are crudely distinguished according to whether they were successful innovators, and the three entry cohorts are collapsed into two to economize on degrees of freedom. To allow firm hazards to differ according to both time of entry and innovation, the following model is estimated:

$$(2) \quad r_{it} = g(\text{age}_{it}) \exp\{\beta_1 I1_{it} + \beta_2 I2_{it} + \beta_3 NI2_{it}\},$$

where  $r_{it}$  is the hazard of firm  $i$  in year  $t$ ,  $g(\text{age}_{it})$  allows firm hazards to vary with age,  $I1_{it}$  is a 1-0 dummy equal to 1 if firm  $i$  was in the early entry cohort and was a successful innovator in year  $t$ ,  $I2_{it}$  is a 1-0 dummy equal to 1 if firm  $i$  was in the late entry cohort and was a successful innovator in year  $t$ , and  $NI2_{it}$  is a 1-0 dummy equal to 1 if firm  $i$  was in the late entry cohort and was *not* a successful innovator in year  $t$ .

The model allows innovators to have a different hazard than noninnovators in each cohort and also allows the time of entry to affect the hazard differently for innovators and noninnovators, with the omitted reference group noninnovators in cohort 1. If innovation lowers the hazard for all entry cohorts,  $\beta_1$  and  $\beta_2 - \beta_3$  should be negative and substantial. The competitive advantage theory also predicts innovation will lower the hazard more for early entrants because they have a larger output over which to apply their innovation, which implies that  $\beta_1 - \beta_2$  should be negative and, since noninnovators do some unmeasured innovation,  $\beta_3$  should be positive. In addition to testing these predictions, we will also test the common prediction of the three theories that earlier entrants will be more successful innovators.

## IV. Empirical Tests

### A. Parametric Survival Tests

We begin by estimating equation (1) for each of the four products using the data we collected for each entrant on its year of entry and exit. Acquisitions by incumbents are treated as censored exits, allowing for the possibility of continued survival were it not for the acquisition, although treating them as ordinary exits had little effect on our estimates. For each product, we define three cohorts of entrants, as itemized in table 2. Cohort 3 is defined as firms that entered during the shakeout, which we operationalize as firms entering in the ten years following the peak number of producers.<sup>8</sup> Cohort 2 is defined as firms that entered just before the shakeout, which we operationalize as five years preceding the peak number of firms for automobiles, tires,

---

<sup>8</sup> While entry declined sharply within ten years of the start of the shakeouts in each of the products, as predicted by all the theories, the histories of each of the industries is sufficiently long to encompass a nontrivial number of later entrants. It does not seem sensible to treat firms that entered well after the start of the shakeouts as significantly affected by events that might have triggered the shakeouts. Accordingly, we restricted our focus to firms that entered within ten years of the start of the shakeouts, which we defined as when the number of firms peaked. We also experimented with other cutoffs for the inclusion of firms in the sample, but this had little effect on our results.

and penicillin and four years prior to the shakeout for televisions.<sup>9</sup> Cohort 1 is composed of all the firms that entered prior to those in cohort 2. We set  $S_t$  equal to 1 for the 15 years beginning at year  $S$ , the year of the peak number of firms, under the presumption that if shakeouts are triggered by particular events, their effects will largely be dissipated within 15 years. The theories provide little guidance on how firm hazards change with age. Accordingly, we estimated two versions of the model. In one, we used the exponential form  $h(\text{age}_{it}) = \exp\{c\}$  to constrain the hazard to be constant and independent of age. In the other, we used the Cox partial likelihood approach, which effectively allows  $h(\text{age}_{it})$  to differ at each age according to the best fit on the data.

Maximum-likelihood estimates of the coefficients for the four products are presented in table 3, first for the exponential hazard, then the Cox, with standard errors in parentheses. Consider first the estimates of  $\beta_1$ ,  $\beta_2$ , and  $\beta_3$ . In both the exponential and Cox versions of the model, half the estimates of  $\beta_1$  are positive and half are negative, with only the exponential estimate for tires significant. This suggests there was not a pronounced rise in firm hazards around the start of the shakeouts. The estimates of  $\beta_2$  and  $\beta_3$  are all positive for autos, tires, and tvs in both the exponential and Cox versions of the model, with five of the six significant in the exponential version and two of the six significant in the Cox version of the model. The estimates of  $\beta_2$  and  $\beta_3$  for penicillin have opposite signs in the two versions of the model, with none of the estimates significant. Thus, in three of the four products the earliest entrants had lower hazards at the start of the shakeout, as predicted by the radical invention and competitive advantage theories and one version of the dominant design theory. The estimates of  $\beta_2$  and  $\beta_3$  are not consistently ordered nor significantly different, suggesting that entrants just before and during the shakeout were initially comparably disadvantaged.

Consider next the estimates of  $\beta_4$ ,  $\beta_5$ , and  $\beta_6$ . The estimates of  $\beta_4$  are all negative in the exponential version of the model and three of the four are negative in the Cox version of the model, but only one of the eight estimates is significant. Thus, there appears to be some tendency for firm hazards to decline as the shakeout proceeds, but a significant rise ( $\beta_1 > 0$ ) and fall ( $\beta_4 < 0$ ) in the hazard is estimated to occur only in tires (using the exponential model). Regarding the eight estimates of  $\beta_5$  and  $\beta_6$ , five are greater than or equal to zero in the

---

<sup>9</sup> The slightly shorter period for cohort 2 for televisions was dictated by the smaller number of years preceding the

exponential version of the model and six are greater than or equal to zero in the Cox version of the model, with only one of the estimates significant and positive. Thus, it appears that the hazards of the entry cohorts did not converge and may even have diverged as the shakeouts proceeded. Furthermore, the estimate of  $\beta_5$  was less than the estimate of  $\beta_6$  for all four products in both versions of the model, suggesting that the hazards of the second and third cohorts diverged over time, with the earlier cohort having lower hazards.

### B. Nonparametric Hazard Plots

The estimates of equation (1) indicate no consistent rise in firm hazards at the start of the shakeout and persistent inter-cohort differences that if anything became accentuated as the shakeouts proceeded. We now probe the robustness of these inferences by estimating hazard curves for each entry cohort using a nonparametric procedure that imposes no particular functional form on how the hazard varies with age. The procedure uses a smoothing technique to eliminate the gyrations in the annual cohort hazards that would otherwise make the curves difficult to interpret. The estimates for each cohort treat separately years prior to S versus later years to ensure that the smoothing does not obscure any abrupt change in the hazard around the start of the shakeout.

The smoothing technique used is a well-established local likelihood method for binomial exit processes (Loader, 1999). For a given cohort, the number of exits in year  $t$ ,  $x_t$ , given  $n_t$  firms is a binomial process with probability  $h_t$ . Corresponding to this process is a local weighted likelihood function defined for each time  $\tau$ :

$$(3) \quad L_\tau = \sum_{t=\tau-b}^{\tau+b} \left(1 - \left|\frac{t-\tau}{b}\right|^3\right)^3 \sigma(t, \tau) \binom{n_t}{x_t} h_t^{x_t} (1-h_t)^{n_t-x_t}.$$

The summation is across years in a window of  $\pm b$  around  $\tau$ , where  $b$  is the lowest integer such that  $b \geq 5$  and the interval  $[\tau-b, \tau+b]$  includes at least 200 firm-years of data from the period before S if  $\tau < S$  or thereafter if  $\tau \geq S$  (or all data if fewer than 200 firm-years are available).<sup>10</sup> The

---

shakeout in televisions versus the other three products.

<sup>10</sup> The choice of  $b$  ensures reasonable estimates even when the sample of survivors becomes small, and the condition  $b \geq 5$  ensures a reasonable number of points to estimate the functional form for the hazard specified in (4). We experimented by using constant timespans  $b$  and alternative minimum numbers of firm-years, and this had little effect on our findings.

first term in the summation is a weight that declines as  $t$  moves away from  $\tau$ ,<sup>11</sup> and  $\sigma(t,\tau) = 1$  if ( $t < S$  and  $\tau < S$ ) or ( $t \geq S$  and  $\tau \geq S$ ) and 0 otherwise, ensuring years prior to  $S$  are treated separately from later years. Further, the hazard is assumed to follow a quadratic function near  $\tau$  according to

$$(4) \quad h_t = \alpha + \beta_1 t + \beta_2 t^2,$$

which allows the hazard to be a nonmonotonic function of time. At each point  $\tau$ , the local likelihood function is maximized by choosing the best fitting values of  $\alpha$ ,  $\beta_1$ , and  $\beta_2$ , and the hazard at  $\tau$  is estimated by  $\hat{\alpha} + \hat{\beta}_1 \tau + \hat{\beta}_2 \tau^2$ . This procedure allows the hazard for each cohort to be approximated by a different function at each point in time. Estimates for later years should be interpreted with caution since even with smoothing they are subject to high variation.

The hazard plots for the four products are presented in figure 2. In each plot, thicker curves pertain to earlier cohorts. The plots largely support the econometric analysis, although they reflect some nuances that were not apparent from the estimates of equation (1). Consider first the plot for autos. The hazards of all three cohorts rise initially with age and then fall, with no apparent rise in the hazard of the first two cohorts around the start of the autos shakeout in 1909. At the start of the shakeout the hazards of cohorts 2 and 3 are roughly twice as great as cohort 1 and as the shakeout proceeds the hazards of the three cohorts move in tandem, with no tendency for the hazards to converge. The pattern for tires is somewhat different, which to some extent parallels the estimates of equation (1). Unlike autos, there is a pronounced rise in the hazard of the first two cohorts around the start of the shakeout in 1922, after which the hazards of all three cohorts decline as the shakeout proceeds. Although this is consistent with an event triggering the tires shakeout, other distinctive factors in the 1920s severely depressed rates of return earned by all tire manufacturers (Reynolds, 1938) and may have caused the hazard rates of all cohorts to rise.<sup>12</sup> Similar to autos, the hazards of cohorts 2 and 3 are about twice that of cohort 1 at the start of the shakeout, and this inter-cohort difference persists over the first 20 years of the shakeout. Subsequently the hazards of the cohorts converge, although at this point few firms from the last two cohorts remain in the industry.

---

<sup>11</sup> The weights equal 1, .976, .820, .482, .116, and 0 for times at distances of  $\pm b$  times 0, 0.2, 0.4, 0.6, 0.8, and 1 respectively away from  $\tau$ .

<sup>12</sup> Historians cite the severe price war that occurred throughout the 1920s as well as a recession in 1920-21 and value lost in hedging rubber stocks following an attempt to control world prices as the reasons for the increased hazard of firms in the 1920s (French, 1991).



The hazard plots for tvs and penicillin in some ways suggest a more orderly process than in autos and tires. The hazards of the cohorts are consistently ordered by time of entry in all periods and they do not change greatly over time. There is no sign of a rise in the hazards of the first two cohorts in tvs around the start of the shakeout in 1951. There is some tendency for the cohort hazards in tvs to converge in the late 1950s and then diverge again in the 1960s. This may reflect the unusual history of color television, which was unsuccessful when first introduced in the 1950s and then successful when reintroduced in improved form in the 1960s. If hazards are closely tied to innovation, the convergence of the cohort hazards in the 1950s may reflect the stalled movement of the technological frontier, with the reverse occurring when the frontier resumed its movement in the 1960s. In penicillin, the hazards of the first two cohorts appear to have risen around the start of the shakeout in 1952, suggesting the possibility of some kind of trigger to the shakeout. But the cohort hazards are closely ordered by time of entry at the outset of the shakeout and if anything diverge as the shakeout proceeds, which belies the notion of a trigger with dissipating effects.

The dominant pattern that emerges from the smoothed cohort hazard graphs is a persistent difference in the cohort hazard rates according to their time of entry. By the start of all the shakeouts, the earlier cohorts had lower hazards, and they maintained these lower hazards for many years as the shakeouts proceeded. While these patterns are consistent with the econometric estimates, they are more pronounced than the econometric estimates suggested. They suggest that if the shakeouts were triggered by particular events, and there was some evidence for this in two of the cohort hazard graphs, there was no tendency for cohort hazards to converge, as would be expected if the effects of the events dissipated over time.

### *C. Innovation*

We now exploit our data on innovation to try to unravel the source of the persistent advantage that the earlier entrants enjoyed. Innovation is difficult to measure, particularly over the long periods of industry evolution that we examine. Innovation is also multifaceted, involving not only the development of original innovations but also the adoption of innovations through imitation or purchase. Our approach to measuring innovation was opportunistic. We found three existing lists of innovations: 631 product and process innovations for autos spanning 1893 to 1981 (Abernathy, Clark, and Kantrow, 1983); 53 major product innovations for tires

spanning 1895 to 1965 (Warner, 1966); and 35 major product innovations and 5 major process innovations for tvs spanning 1946 to 1979 (Levy, 1981). We supplemented these lists with our own lists of 264 process innovations in tvs spanning 1946 to 1970 and 44 process innovations in penicillin spanning 1946 to 1994, which we compiled from technical journals.<sup>13, 14</sup>

The lists provide crude indicators of innovators. The autos and tvs lists were sufficiently detailed that many firms were mentioned, which made them useful for operationalizing the variables of equation (2). Firms were classified as innovators in year  $t$  if they developed one or more innovations in year  $t$  or the preceding five years, and the last two cohorts were combined into cohort 2, with cohort 1 the same as in the estimation of equation (1). Accordingly,  $I_{1it}$  equaled one for firms that entered in cohort 1 that developed an innovation in year  $t$  or the preceding five years, with  $I_{2it}$  and  $NI_{2it}$  operationalized analogously. In tires and penicillin, only a few firms accounted for all the listed innovations and thus the lists were not very useful in distinguishing innovators and noninnovators. Instead, we used data that we located on the speed of adoption of two major sets of innovations in each product—cord and balloon tires and the semisynthetic penicillins.<sup>15</sup> The cord tire and its later improvement, the balloon tire, was a major improvement in the design of tires that greatly improved tire mileage and comfort of ride and was eventually adopted by all tire producers. Our data on cord and balloon tires covered 155 tire producers as of 1920 (cf. Klepper and Simons, 2000a), and we coded as innovators the 111 firms that adopted the cord tire as of 1920, with  $I_{1it}$  coded as 1 for cord adopters that entered in cohort 1, with  $I_{2it}$  and  $NI_{2it}$  coded analogously. We estimated equation (2) for the years 1920 to 1930, which spans the era in which the cord tire eventually displaced its predecessor, the cotton-fabric tire. The semisynthetic penicillins, the first of which was developed circa 1958, represented a major breakthrough in the development of new forms of penicillin. Firms that subsequently

---

<sup>13</sup> Our innovation lists are based on articles cited in the *Industrial Arts Index* (later renamed the *Applied Science and Technology Index*), which comprehensively indexed major scientific and trade journals. Television process innovations were subjectively ranked on a 7-point scale according to estimated total impact on future manufacturing costs. Penicillin process innovations were veiled by secrecy, so the list compiled reflects any firms mentioned in the context of (mainly academic) articles about penicillin manufacturing improvements. For further detail see Klepper and Simons (1997, 2000b).

<sup>14</sup> Most of the innovation lists focus only on major innovations and do not rate the importance of the innovations. In autos and tv process innovations, we had rankings of the importance of the innovations. We used these rankings to compute weighted sums of innovations following Abernathy, Clark, and Kantrow (1983). The weighted sums yielded equivalent results to those reported here for counts of innovations, reflecting the fact that minor innovations in autos and in tv manufacturing processes stemmed from the same firms, at similar times, as major innovations.

<sup>15</sup> Adoption in these cases was neither simple nor a matter of mere purchase alone. Designing and producing cord and balloon tires and semisynthetic types of penicillin required a series of product and process innovations.

produced one or more of the semisynthetics by 1963 were classified as innovators (cf, Klepper and Simons, 1997). All of the survivors as of 1963 entered in cohort 1, so the estimates of equation (2) for penicillin reflect only how the hazards of innovators and noninnovators in cohort 1 differed over the period 1963-1992.

Maximum likelihood estimates of equation (2) for the exponential and Cox representations of  $h(\text{age}_{it})$  are reported in table 4. The estimates are similar for the exponential and Cox models. All the coefficient estimates conform to the predictions. Consistent with all three theories, estimates of  $\beta_1$  and  $\beta_2 - \beta_3$  are negative, and all are significant (at the .10 level or lower) except for  $\beta_2 - \beta_3$  in *tv*s. Consistent with the competitive advantage theory, the estimates of  $\beta_1 - \beta_2$  are uniformly negative and estimates of  $\beta_3$  uniformly positive, with 5 of the 12 estimates significant. The magnitudes implied by the estimates are substantial. The hazard of innovators is implied to be 63% to 91% lower than noninnovators in cohort 1, and 39% to 86% lower than noninnovators in cohort 2.<sup>16</sup> Across the three relevant products (there are no firms in cohort 2 in penicillin), the hazard is implied to be 49% to 82% lower for innovators in cohort 1 than in cohort 2, and 12% to 59% lower for noninnovators in cohort 1 than in cohort 2. All but one of the estimates of  $\beta_2$  is negative, implying that innovators in cohort 2 generally had lower hazards than noninnovators in cohort 1 (the omitted group). Thus, innovation was sufficiently important that it could compensate for the disadvantages of later entry.

Finally consider the common prediction of the theories that earlier entrants are more successful innovators, which coupled with the hazard results would explain the much greater longevity of earlier entrants in each product. We computed the number of innovations per firm per year in the first 20 years of each shakeout, or the fraction of firms adopting cord tires by 1920 or semisynthetic penicillin by 1963, for each of the original three cohorts.<sup>17</sup> Table 5 shows the resulting innovation rates for available cohorts. The Fisher exact test for differences in whether firms ever innovated indicates that nearly all inter-cohort differences in innovation rates

---

<sup>16</sup> The hazard of innovators in cohort 1 equals  $\exp(\hat{\beta}_1)$  times the hazard of noninnovators in cohort 1, so  $1 - \exp(\hat{\beta}_1)$  equals the fraction by which the hazard of innovators in cohort 1 is lower than that of noninnovators in cohort 1. The other magnitudes were computed similarly.

<sup>17</sup> The cord tires data covered only firms that had entered by 1920, necessitating different entry cohort definitions. Cohort 1a was defined as the firms that entered in 1901-1906, cohort 1b the firms that entered in 1907-1917, and cohort 2 the firms that entered in 1918-1920 (cf. Klepper and Simons, 2000a). In penicillin, the data on the adoption of the semisynthetics covered only firms that entered in cohort 1 and so the cohort comparison of innovation rates is confined to the data on penicillin process innovations.

are significant.<sup>18</sup> The reported innovation rates show that early entrants totally dominated innovation in each product. In autos, the first cohort introduced nearly every process innovation, and it had 4.5 times the product innovation rate of the second cohort and 9 times that of the third cohort. In tires, nearly every product innovation was introduced by the first cohort, and the rate of adoption of cord and balloon tires at the earliest observation of each was 4 times greater for the first cohort than the second. In tvs, every product and process innovation came from the first or second cohort, with the product innovation rate twice as high and the process innovation rate nine times as high for the first cohort than the second cohort despite the separation of only a few years between the cohorts. In penicillin, all process innovations came from the first cohort. Thus across all four products, nearly all major product and process innovations were introduced by the earliest entrants, which also were in the vanguard of adoption of the major breakthroughs in tires and penicillin.

## V. Conclusions

We investigated the nature of the firm survival patterns in four new products that experienced severe shakeouts despite continued growth in output. By the time of each of the shakeouts, the earliest entrants had a markedly lower hazard, and this advantage persisted for many years thereafter. Our innovation analyses suggest that the advantage of early entry was related to the greater survival of innovators and the greater proclivity of early entrants to innovate.

What do these findings reveal about each of the theories? The radical invention theory's main implications arise from the technological development triggering the shakeout. The theory predicts a rise and dispersion in cohort hazard rates that dissipates over time, leading to a convergence in cohort hazard rates. In one or two of the products there is some evidence of a rise in the hazard at the start of the shakeout and then a subsequent fall in the hazard, but there is almost no sign of the convergence in cohort hazard rates predicted by the theory. The dominant

---

<sup>18</sup> For innovation rates, the test is biased by the fact that early entrants survived longer and thus had more time to innovate. We therefore checked the results using bootstrapping methods. We drew a same-size sample with replacement from each original cohort, replicating the procedure 20,000 times, and computed the fraction of times that the first cohort had a higher innovation rate than each later cohort, then classified the results as significant at the .05 level for fractions less than 2.5% or greater than 97.5%. Comparing the first cohort to each later cohort, the inter-cohort differences in innovation rates are significant at  $p < .05$  for all types of innovation except autos process innovation and tvs product innovation. The findings thus confirm the impression from Table 5 of significant inter-cohort differences in innovation rates.

design theory suggests an alternative technological development yielding similar patterns to the radical invention theory and hence it too is not supported by our findings. It also predicts that experienced firms will have a lower hazard at the start of the shakeout, but that experience with older technologies rendered obsolete by the dominant design could actually be detrimental. Our findings do not support this version of the theory either—firms that entered later but prior to the shakeout and presumably the emergence of the dominant design in fact had much higher hazards during the shakeout than the earliest entrants. The evidence is considerably more favorable to the competitive advantage theory. The persistently lower hazard of the earliest entrants and the dominance of innovation by the earliest entrants are in accord with the predictions of the theory. The strong relationship between the firm hazard and innovation is also in accord with the theory and distinguishes it from nontechnological theories of shakeouts. The cohort hazard patterns are more varied than implied by the competitive advantage theory, as evidenced by the eventual convergence of the cohort hazards in tires and the initial convergence and then divergence of the cohort hazards in televisions, and there is some sign of a rise in the hazard at the start of some of the shakeouts that is not addressed by the theory. Overall, though, the patterns provide considerable support for the theory.

Our interpretation of the findings is consistent with our detailed investigation of technological change in the four products in Klepper and Simons (1997). We found instances of major innovations such as color TV and the semisynthetic penicillins that appear to have had significant competitive ramifications, consistent with the premise of the radical invention theory. We also found some evidence of increasing attention being devoted to improving the production process over time, as predicted by the dominant design theory. But we did not find these developments distinctively concentrated around the start of the shakeouts in the products. Indeed, a key conclusion was that for a number of reasons even the most important technological improvements had limited competitive ramifications and it seemed doubtful that any of the shakeouts could be attributed to any one stream of technological developments. The products were characterized by continual technical challenges of many types and firms had to continually keep up with these challenges in order to maintain their leadership. Our findings here concerning firm survival and innovation clearly indicate that the earliest entrants were best able to address these challenges. The shakeout in each of the products appears to be a byproduct of a

competitive process in which the earliest entrants came to dominate their markets by continually being in the vanguard of innovation.

## REFERENCES

- Abernathy, William J., Kim B. Clark, and Alan M. Kantrow, *Industrial Renaissance: Producing a Competitive Future for America* (New York: Basic Books, 1983).
- Agarwal, Rajshree, "Evolutionary Trends of Industry Variables," *International Journal of Industrial Organization* 16(4) (1998), 511-525.
- Bikhchandani, Sushil, David Hirshleifer, and Ivo Welch, "Learning from the Behavior of Others: Conformity, Fads, and Informational Cascades," *Journal of Economic Perspectives* 12(3) (1998), 151-170.
- Bray, Warren C., *A History of Capital Development in the American Tire and Rubber Industry*, Ph.D. dissertation, New York University (1959).
- Bulow, Jeremy, and Paul Klemperer, "The Generalized War of Attrition," *American Economic Review* 89(1) (1999), 175-189.
- Camerer, Colin, and Dan Lovallo, "Overconfidence and Excess Entry: An Experimental Approach," *American Economic Review* 89(1) (1999), 306-318.
- Carree, Martin A., and A. Roy Thurik, "The Life Cycle of the U.S. Tire Industry," *Southern Economic Journal* 67(2) (2000), 254-278.
- Carroll, Glenn R., and Michael T. Hannan, "Density Delay in the Evolution of Organizational Populations: A Model and Five Empirical Tests," *Administrative Science Quarterly* 34(3) (1989), 411-430.
- Christensen, Clayton M., Fernando F. Suárez, and James M. Utterback, "Strategies for Survival in Fast-Changing Industries," *Management Science* 44(12-2) (1998), S-207-220.
- Dasgupta, Partha, and Joseph Stiglitz, "Learning-by-Doing, Market Structure and Industrial and Trade Policies," *Oxford Economic Papers* 40(2) (1988), 246-268.
- Datta, Yudhishter, *Corporate Strategy and Performance of Firms in the U.S. Television Set Industry*, Ph.D. dissertation, State University of New York at Buffalo (1971).
- Dick, J.S., "How Technological Innovations Have Affected the Tire Industry's Structure," *Elastomerics* 112 (1980), 43-48.
- Epstein, Ralph C., *Concentration and Price Trends in the Rubber Tire Industry, 1930-47*, study submitted to the Federal Trade Commission (1949).

- Federal Trade Commission (FTC), *Report on the Motor Vehicle Industry* (Washington, D.C.: U.S. Government Printing Office, 1939).
- Federal Trade Commission (FTC), *Economic Report on Antibiotics Manufacture* (Washington, D.C.: U.S. Government Printing Office, 1958).
- Federal Trade Commission (FTC), *Economic Report on the Manufacture and Distribution of Automotive Tires* (Washington, D.C.: U.S. Government Printing Office, 1966).
- Flaherty, Therese, "Industry Structure and Cost-Reducing Investment," *Econometrica* 48(5) (1980), 1187-1209.
- French, Michael J., *The U.S. Tire Industry* (Boston: Twayne Publishers, 1991).
- Gaffey, John D., *The Productivity of Labor in the Rubber Tire Manufacturing Industry* (New York: Columbia University Press, 1940).
- Geroski, P. A., and M. Mazzucato, "Modeling the Dynamics of Industry Populations," *International Journal of Industrial Organization* 19(7) (2001), 1003-1022.
- Gettell, Richard, *Pluralistic Competition: With an Illustrative Case Study of the Rubber Tire Industry*, Ph.D. dissertation, University of California at Berkeley (1940).
- Gort, Michael, and Steven Klepper, "Time Paths in the Diffusion of Product Innovations," *Economic Journal* 92(3) (1982), 630-653.
- Hopenhayn, Hugo A., "The Shakeout," manuscript, Universitat Pompeu Fabra (1993).
- Horvath, Michael, Fabiano Schivardi, and Michael Woywode, "On Industry Life-Cycles: Delay, Entry, and Shakeout in Beer Brewing," *International Journal of Industrial Organization* 19(7) (2001), 1023-1052.
- Jovanovic, Boyan, and Glenn MacDonald, "The Life Cycle of a Competitive Industry," *Journal of Political Economy* 102(2) (1994), 322-347.
- Kimes, Beverly Rae, and Henry Austin Clark, Jr., *Standard Catalog of American Cars 1805-1942*, 3rd ed. (Iola, Wis.: Krause Publications, 1996).
- Klepper, Steven, "Entry, Exit, Growth, and Innovation over the Product Life Cycle," *American Economic Review* 86(3) (1996), 562-583.
- Klepper, Steven, "Firm Survival and the Evolution of Oligopoly," *RAND Journal of Economics* (forthcoming [2001]).
- Klepper, Steven, and Elizabeth Graddy, "The Evolution of New Industries and the Determinants of Market Structure," *RAND Journal of Economics* 21(1) (1990), 27-44.

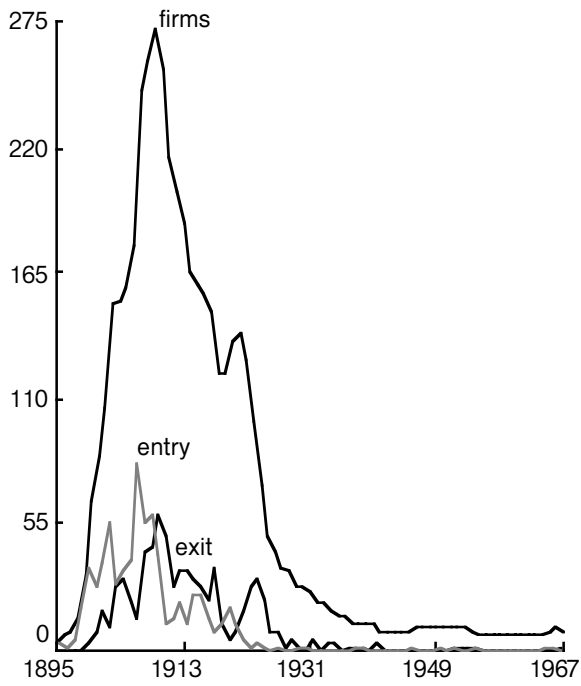


- Klepper, Steven, and Kenneth L. Simons, "Technological Extinctions of Industrial Firms: An Inquiry into their Nature and Causes," *Industrial and Corporate Change* 6(2) (1997), 379-460.
- Klepper, Steven, and Kenneth L. Simons, "The Making of an Oligopoly: Firm Survival and Technological Change in the Evolution of the U.S. Tire Industry," *Journal of Political Economy* 108(4) (2000a), 728-760.
- Klepper, Steven, and Kenneth L. Simons, "Dominance by Birthright: Entry of Prior Radio Producers and Competitive Ramifications in the U.S. Television Receiver Industry," *Strategic Management Journal* 21(10-11) (2000b), 997-1016.
- LaFrance, Vincent, *The United States Television Receiver Industry: United States Versus Japan, 1960-1980*, Ph.D. dissertation, Pennsylvania State University (1985).
- Levy, Jonathan, *Diffusion of Technology and Patterns of International Trade: The Case of Television Receivers*, Ph.D. dissertation, Yale University (1981).
- Loader, Clive, *Local Regression and Likelihood* (New York: Springer, 1999).
- Metcalf, J.S., and M. Gibbons, "Technology, Variety and Organisation: A Systematic Perspective on the Competitive Process," in Richard S. Rosenbloom and Robert A. Burgelman (eds.), *Research on Technological Innovation, Management, and Policy*, vol. 4 (Greenwich, Conn.: JAI Press, 1988), 153-93.
- Nelson, Richard R., and Sidney G. Winter, "Forces Generating and Limiting Concentration under Schumpeterian Competition," *Bell Journal of Economics* 9(2) (1978), 524-48.
- Petrakis, Emmanuel, Eric Rasmusen, and Santanu Roy, "The Learning Curve in a Competitive Industry," *RAND Journal of Economics* 28(2) (1997), 248-268.
- Reynolds, Lloyd G., "Competition in the Rubber-Tire Industry," *American Economic Review* 28(3) (1938), 459-468.
- Schwartzman, David, *Innovation in the Pharmaceutical Industry* (Baltimore: Johns Hopkins University Press, 1976).
- Shaked, Avner, and John Sutton, "Product Differentiation and Industry Structure," *Journal of Industrial Economics* 36(2) (1987), 131-146.
- Simons, Kenneth L., *Shakeouts: Firm Survival and Technological Change in New Manufacturing Industries*, Ph.D. dissertation, Carnegie Mellon University (1995).

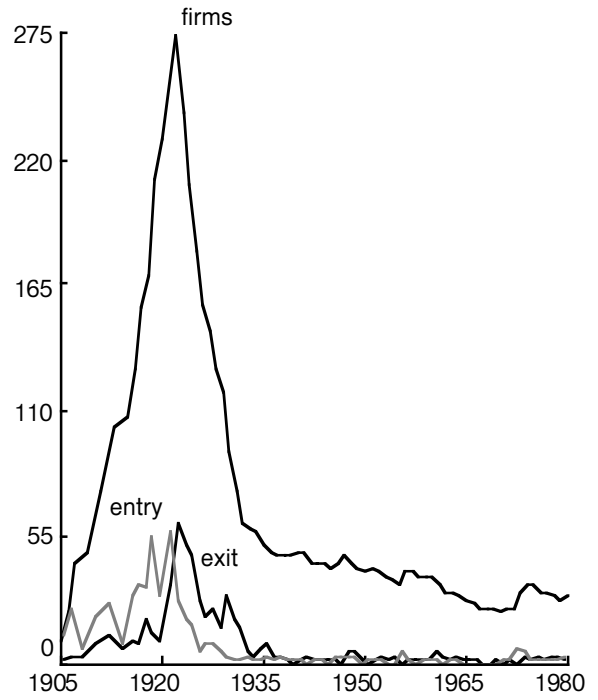
- Smith, Philip H., *Wheels within Wheels: A Short History of American Motor Car Manufacturing* (New York: Funk and Wagnalls, 1968).
- Suárez, Fernando, and James Utterback, "Dominant Designs and the Survival of Firms," *Strategic Management Journal* 16(5) (1995), 415-430.
- Sutton, John, *Technology and Market Structure* (Cambridge, Mass.: MIT Press, 1998).
- Teitelman, Robert, *Profits of Science* (New York: Basic Books, 1994).
- U.S. Tariff Commission (later U.S. International Trade Commission), *Synthetic Organic Chemicals* (Washington, D.C.: U.S. Government Printing Office, 1944-1992).
- Utterback, James, and Fernando Suárez, "Innovation, Competition, and Industry Structure," *Research Policy* 22 (1993), 1-21.
- Warner, Stanley L., *Innovation and Research in the Automobile Tire and Tire-Supporting Industries*, Ph.D. dissertation, Harvard University (1966).
- Willard, Gary E., *A Comparison of Survivors and Non-Survivors under Conditions of Large-Scale Withdrawal in the U.S. Color Television Set Industry*, Ph.D. dissertation, Purdue University (1982).

Figure 1.—Number of Producers, Entry, and Exit in the Four Products

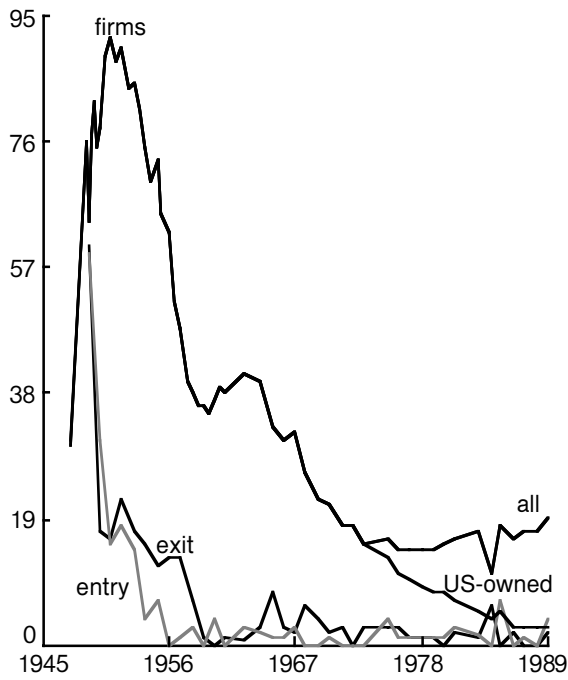
Automobiles



Tires



Televisions



Penicillin

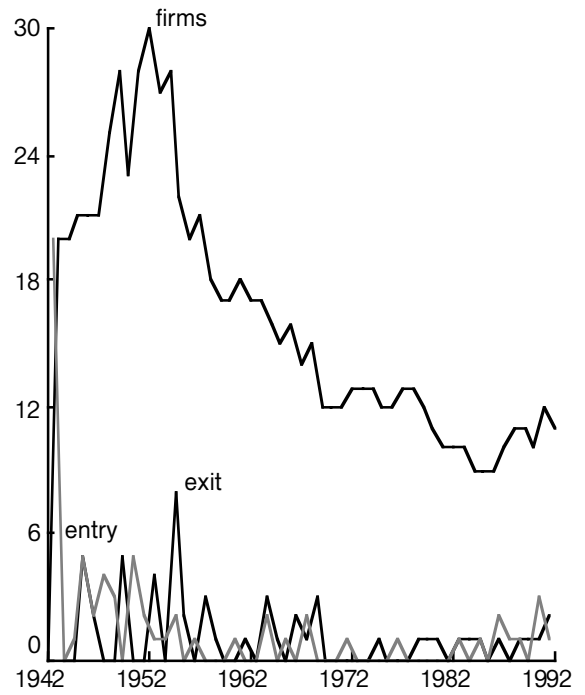


Figure 2a.—Smoothed Hazard Plot for Automobiles

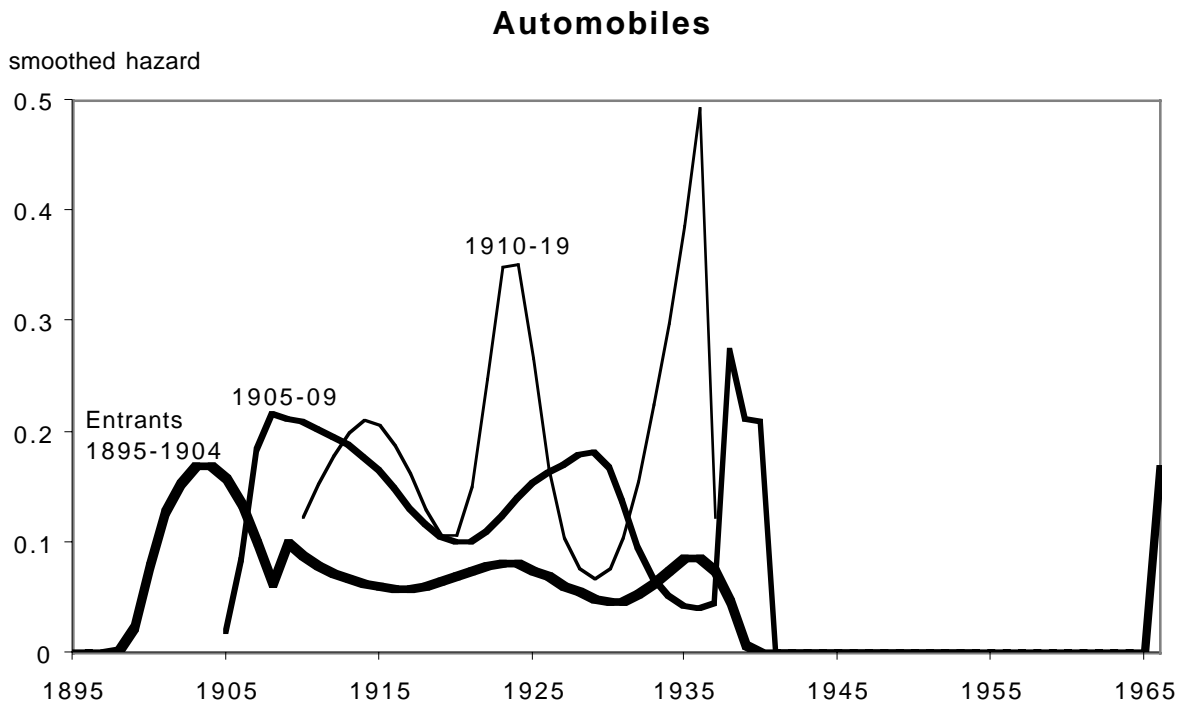


Figure 2b.—Smoothed Hazard Plot for Tires

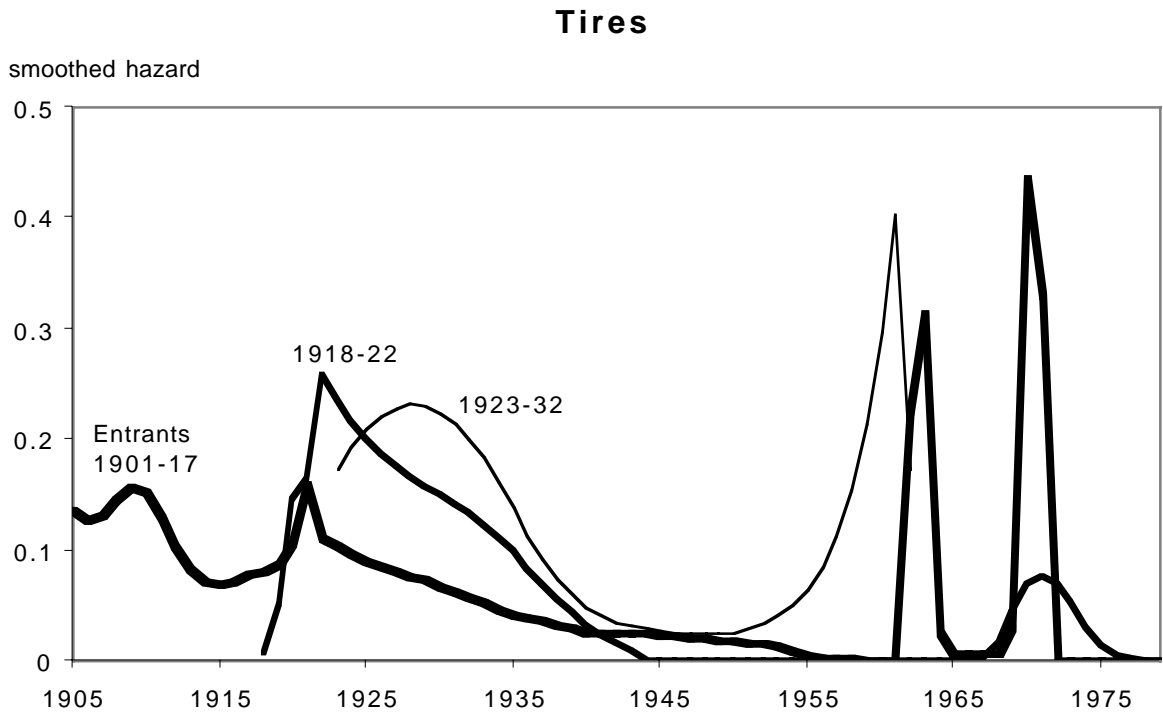


Figure 2c.—Smoothed Hazard Plot for Televisions

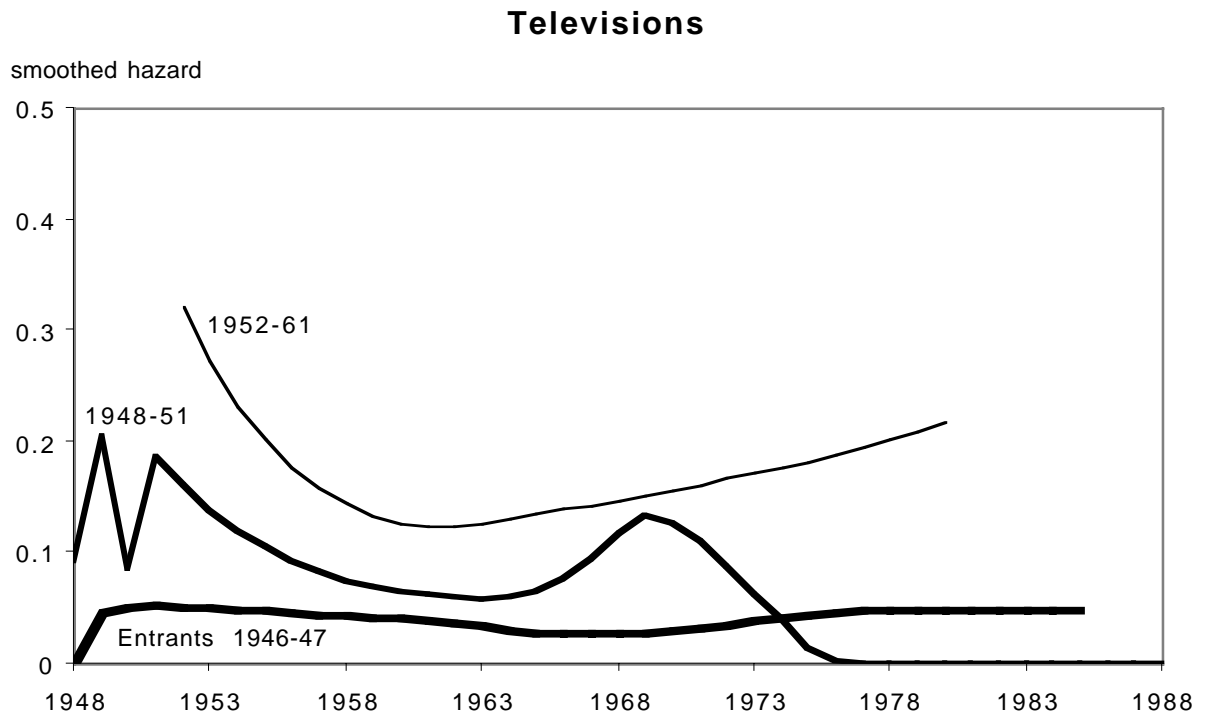


Figure 2d.—Smoothed Hazard Plot for Penicillin

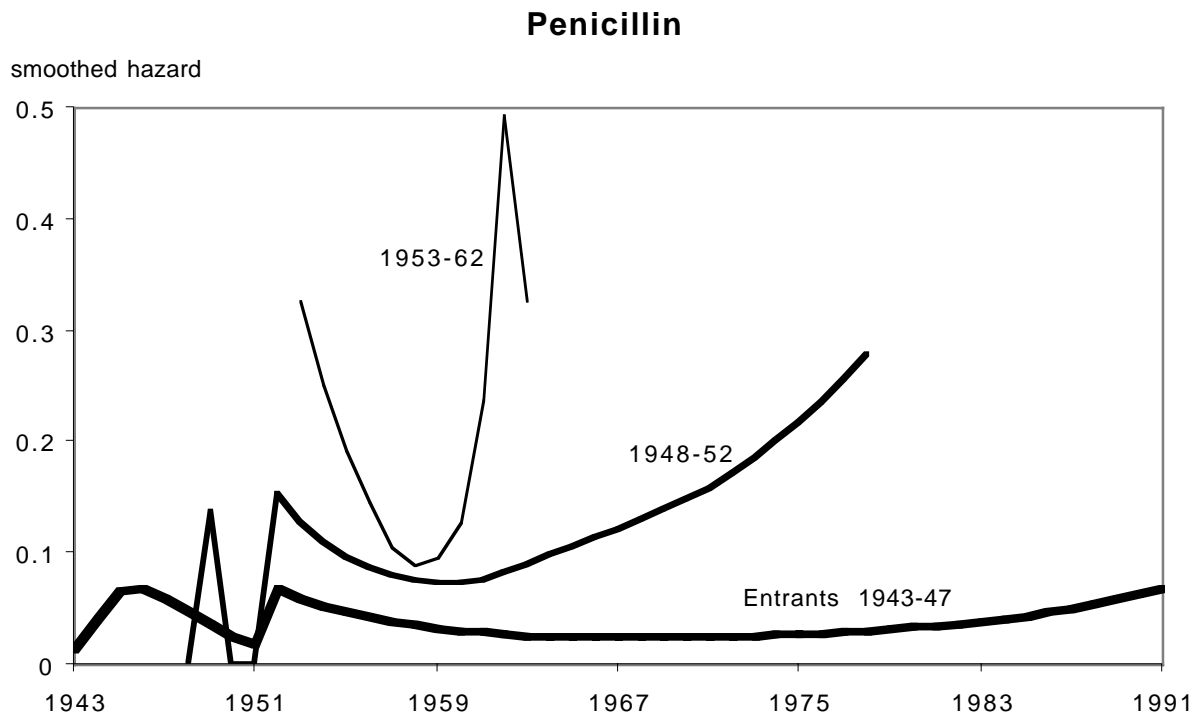


Table 1.—Predictions of the Three Theories for Equation (1)

Parameter	Event theory 1 (radical invention)	Event Theory 2 (dominant design)	Competitive Advantage Theory
$\beta_1$	+	+	0
$\beta_2$	$+, < \beta_3$	- or $< \beta_3$	$+, < \beta_3$
$\beta_3$	+	+	+
$\beta_1 + \beta_2$	+	+ or ambiguous	+
$\beta_1 + \beta_3$	+	+	+
$\beta_4$	-	-	0
$\beta_5$	$-, > \beta_6$	$-, > \beta_6$ or +	$\geq 0$
$\beta_6$	-	-	$\geq 0$
$\beta_4 + \beta_5$	-	-	$\geq 0$
$\beta_4 + \beta_6$	-	-	$\geq 0$

Table 2.—Years (Number of Firms) in the Three Entry Cohorts

Product	Cohort 1	Cohort 2	Cohort 3
Autos	1895-1904 (219)	1905-1909 (272)	1910-1919 (182)
Tires	1901-1917 (239)	1918-1922 (224)	1923-1932 (84)
Televisions	1946-1947 (22)	1948-1951 (113)	1952-1961 (28)
Penicillin	1943-1947 (28)	1948-1952 (13)	1953-1962 (4)

Table 3.—Hazard of Exit: Entry Time and Shakeout

		Exponential Model							
		Automobiles		Tires		Televisions		Penicillin	
Constant	c	-2.08	(0.06)	-2.66	(0.07)	-2.37	(0.14)	-3.09	(0.23)
$S_t$	$\beta_1$	-0.32	(0.26)	0.47*	(0.22)	-0.52	(0.59)	0.31	(0.63)
Cohort2; $S_t$	$\beta_2$	0.92***	(0.27)	0.83***	(0.23)	1.23*	(0.60)	0.72	(0.79)
Cohort3; $S_t$	$\beta_3$	0.51	(0.32)	0.71*	(0.32)	1.75**	(0.68)	0.46	(1.56)
$S_t$ (t-S)	$\beta_4$	-0.05	(0.04)	-0.06†	(0.03)	-0.03	(0.08)	-0.07	(0.09)
Cohort2; $S_t$ (t-S)	$\beta_5$	-0.01	(0.04)	0.00	(0.04)	-0.09	(0.09)	0.02	(0.12)
Cohort3; $S_t$ (t-S)	$\beta_6$	0.07	(0.04)	0.05	(0.05)	-0.06	(0.10)	0.18	(0.21)
	$\beta_1 + \beta_2$	0.60***	(0.13)	1.30***	(0.13)	0.71**	(0.24)	1.03†	(0.58)
	$\beta_1 + \beta_3$	0.19	(0.21)	1.18***	(0.25)	1.23**	(0.39)	0.78	(1.46)
	$\beta_4 + \beta_5$	-0.06**	(0.02)	-0.06*	(0.02)	-0.11**	(0.04)	-0.05	(0.08)
	$\beta_4 + \beta_6$	0.02	(0.02)	-0.01	(0.03)	-0.09	(0.06)	0.11	(0.19)
Log Likelihood		-945.19		-1587.39		-456.46		-151.06	
		Cox Model							
		Automobiles		Tires		Televisions		Penicillin	
$S_t$	$\beta_1$	-0.34	(0.30)	0.37	(0.26)	-0.32	(0.69)	1.74	(1.04)
Cohort2; $S_t$	$\beta_2$	0.66*	(0.32)	0.48	(0.30)	1.37*	(0.66)	-0.42	(1.12)
Cohort3; $S_t$	$\beta_3$	0.37	(0.38)	0.35	(0.39)	1.28	(0.79)	-1.80	(2.04)
$S_t$ (t-S)	$\beta_4$	-0.04	(0.04)	0.00	(0.04)	-0.07	(0.09)	-0.28*	(0.11)
Cohort2; $S_t$ (t-S)	$\beta_5$	0.01	(0.05)	-0.02	(0.05)	-0.09	(0.10)	0.23	(0.15)
Cohort3; $S_t$ (t-S)	$\beta_6$	0.06	(0.05)	0.00	(0.06)	0.01	(0.11)	0.50*	(0.26)
	$\beta_1 + \beta_2$	0.32*	(0.14)	0.85***	(0.15)	1.05***	(0.32)	1.31*	(0.63)
	$\beta_1 + \beta_3$	0.03	(0.23)	0.72**	(0.28)	0.96*	(0.41)	-0.07	(1.68)
	$\beta_4 + \beta_5$	-0.03	(0.03)	-0.01	(0.03)	-0.16*	(0.06)	-0.05	(0.11)
	$\beta_4 + \beta_6$	0.02	(0.02)	0.00	(0.04)	-0.06	(0.06)	0.23	(0.22)
Log Partial Likelihood		-3498.59		-2783.02		-613.40		-116.64	
		Sample Characteristics							
		Automobiles		Tires		Televisions		Penicillin	
Number of firms		673		547		163		45	
Number of exits		620		511		144		40	
Number of firm-years		4469		4848		1394		730	

Standard errors are in parentheses. †  $p < .10$ , \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$  (two-tailed).

Table 4.—Hazard of Exit: Entry Time and Innovation

		Exponential Model							
		Automobiles		Tires		Televisions		Penicillin	
Constant	c	-2.32	(0.11)	-2.10	(0.28)	-2.43	(0.30)	-2.42	(0.50)
Innovator 1	$\beta_1$	-2.19***	(0.46)	-1.11**	(0.36)	-2.41*	(1.04)	-1.78*	(0.87)
Innovator 2-3	$\beta_2$	-1.32*	(0.59)	-0.12	(0.33)	-0.71	(0.65)		
Noninnovator 2-3	$\beta_3$	0.64***	(0.13)	0.39	(0.34)	0.22	(0.33)		
	$\beta_1 - \beta_2$	-0.87	(0.73)	-0.99***	(0.28)	-1.71	(1.15)		
	$\beta_2 - \beta_3$	-1.97***	(0.58)	-0.51†	(0.27)	-0.92	(0.59)		
Log Likelihood		-197.43		-131.88		-74.58		-3.06	

		Cox Model							
		Automobiles		Tires		Televisions		Penicillin	
Innovator 1	$\beta_1$	-1.98***	(0.47)	-1.00**	(0.37)	-2.44*	(1.05)	-1.69†	(0.89)
Innovator 2-3	$\beta_2$	-1.30*	(0.59)	0.41	(0.42)	-0.82	(0.65)		
Noninnovator 2-3	$\beta_3$	0.55***	(0.14)	0.89*	(0.44)	0.12	(0.35)		
	$\beta_1 - \beta_2$	-0.68	(0.74)	-1.41***	(0.41)	-1.62	(1.16)		
	$\beta_2 - \beta_3$	-1.85**	(0.59)	-0.49†	(0.27)	-0.94	(0.60)		
Log Partial Likelihood		-1247.57		-354.00		-269.29		-9.06	

		Sample Characteristics			
		Automobiles	Tires	Televisions	Penicillin
Number of firms		299	154	91	9
Number of exits		265	91	73	6
Number of firm-years		2351	1048	852	179

Standard errors are in parentheses. † p < .10, \* p < .05, \*\* p < .01, \*\*\* p < .001 (two-tailed).

Table 5.—Innovation Rate by Entry Time

Product	Innovation type	Cohort 1	Cohort 2	Cohort 3	Fisher's Exact p
Automobiles	Product	.09	.02	.01	p < .001
Automobiles	Process	.03	.0	.001	p = .036 (.070)
Tires	Cord 1917	.36   .08			p = .023
Tires	Cord 1920	1.00   .73	.62		p = .036 (.033)
Tires	Balloon 1923	.63   .16	.07		p < .001
Tires	Product	.01	.0	.0	p = .002 (.001)
Televisions	Product	.02	.01	.0	p = .058 (.064)
Televisions	Process	.63	.07	.0	p < .001
Penicillin	Process	.05	.0	.0	p = .124 (.049)

Notes: The two sets of numbers for cohort 1 for the cord 1917, cord 1920, and balloon 1923 tire entries refer to the subdivision of cohort 1 into cohorts 1a and 1b as described in footnote 17. The Fisher's exact test column reports the probability of observing inter-cohort differences at least as large as occurred under the null hypothesis that all cohorts share identical probabilities of innovating at least once. Where p-values are greater than .001, results are reported in parentheses for a further Fisher's exact test comparing firms in the earliest cohort versus those in both later cohorts combined.