

Firm Capabilities and Industry Evolution: The Case of the U.S. Automobile Industry

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Abstract

In its first fifteen years the U.S. automobile industry was characterized by a great deal of entry and the number of firms exceeded 200. Despite robust growth in the market for automobiles, the industry subsequently sustained a prolonged shakeout in the number of producers and evolved to be an oligopoly dominated by three firms. The industry also evolved to be heavily concentrated around Detroit, Michigan, which not only was home to its top three firms but most of its other leaders. A model of industry evolution characterized by heterogeneous firm capabilities, increasing returns associated with R&D, and a birth and inheritance process governing entry is developed to explain these patterns. Predictions of the model concerning entry and firm survival are tested using data on the origin and years of production of every entrant into the industry. The shakeout is shown to result from a process imparting strong advantages to early entrants, and the geographic concentration of the industry is attributed to the success of four early entrants around Detroit, who in turn spawned a large number of successful firms in the Detroit area that together dominated the industry.

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Firm Capabilities and Industry Evolution: The Case of the U.S. Automobile Industry

Steven Klepper[†]

I. Introduction

The evolution of the U.S. automobile industry has long intrigued scholars from numerous disciplines. The enormity of the industry and its importance to the U.S. economy, epitomized by the saying, “What’s good for GM is good for the country,” has alone been sufficient to make the industry one of the most studied, if not the most studied, of any U.S. industry. Perhaps the most intriguing aspect of the industry has been the evolution of its market structure. When it began, the industry experienced a flood of entrants. So many firms entered that it was difficult to keep track of the comings and goings of firms, but nearly all sources reflect hundreds of entrants in the first 15 years of the industry spanning 1895 to 1910, with the annual number of firms peaking at well over 200 during this period. After 1910 the industry took off, and its output grew annually by over 10% for many years. In contrast to the first 15 years of the industry, however, entry fell off sharply and by the 1920s was negligible. The number of firms plummeted and the industry evolved to be an oligopoly dominated by three famous firms, General Motors, Ford, and Chrysler. The industry also became highly concentrated around Detroit, Michigan, which not only was home to its top three firms but most of the other leaders of the industry.

Unraveling the causes of these developments promises to shed light on two of the most important questions in industrial organization: Why do some industries evolve to be oligopolies and others remain atomistic, and why do a few industries become

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concentrated in narrow geographic areas for long periods whereas most are dispersed over many regions during their entire history? Numerous explanations have been offered for the particular developments that characterized the automobile industry, reflecting the absence of any consensus concerning the broader market structure questions. Indeed, the automobile industry is a kind of litmus test for theories of geographic concentration and market structure (cf. Tsai [1997]). The purpose of this paper is to exploit the wealth of information that has been collected about the industry and the heritage of its producers to gain new insight into the forces that shaped its evolution. Brief information on the origin of each entrant into the industry is used to identify the pre-entry experiences of each firm. Three types of firms with distinctive experiences that could be interpreted as the basis for firm “capabilities” are distinguished: preexisting firms diversifying from related industries, new firms founded by people who headed firms in these same related industries, and new firms founded by employees of incumbent automobile firms. The analysis focuses on how the background of firms and the timing of their entry affected their performance, which in turn is used to gain insight into the factors conditioning the evolution of the industry’s market structure and geographic distribution of activity.

A model of industry evolution developed in Klepper [1996, 2000] is used to structure the analysis of the data. The model has much in common with the modeling of industry evolution in Nelson and Winter [1982]. It features how heterogeneity in firm capabilities, increasing returns to firm size associated with research and development, and costly firm growth can account for a rise and then shakeout in the number of producers and the evolution of an oligopolistic market structure. A birth and heredity process is added to the model to analyze the entry of new firms started by employees of incumbent firms. It is shown that with this additional component, the model can not only explain the evolution of the industry’s market structure but also its concentration around Detroit, Michigan, attributing the latter development to the chance location around Detroit of four of the most successful early entrants into the industry. Numerous distinctive hypotheses are derived from the model that are used to test its explanation for the evolution of the industry’s horizontal and geographic market structure.

The paper is organized as follows. The history of the industry is first reviewed in Section II. The model of industry evolution developed in Klepper [1996, 2000], extended

to encompass a birth and heredity process for employee startups, is then presented in Section III. Various predictions are derived from the model concerning entry, firm location, and firm survival in Section IV. Firm entry and survival analyses are used to evaluate the predictions in Section V, and more formal econometric methods are used to test the predictions in Section VI. Implications of the findings are discussed in Section VII, which also includes concluding remarks.

II. History of the Industry

Smith [1968] compiled a list of every make of automobile produced commercially¹ in the United States from the start of the industry in 1895 through 1966. He lists the firms that manufactured each make, their location, the years they manufactured the make, and any reorganizations and ownership changes the firms underwent. Smith's list of makes was used to derive the annual number of entries, exits, and manufacturers of automobiles for the period 1895-1966, where entry and exit dates are based on the first and last year of production. These series are graphed in the bottom panel of Figure 1. The top panel plots the percentage of firms exiting the industry on an annual and five-year moving average basis.

The number of firms that entered the industry grew steadily from 1895 to 1907, peaking at 82 in 1907. Entry remained high for the next three years and then dropped sharply. It averaged 15 firms per year from 1911 to 1922 and became negligible after 1922, with only 16 firms entering from 1923 through 1966. After the first few years, the industry exit rate exceeded 10% for many years, and by 1909 the number of exits overtook the number of entries. Except for the two-year period 1919-1921, the number of firms fell steadily from 1909 to 1941, dropping from a peak of 275 in 1909 to 9 in 1941.

Not surprisingly given this drastic decline in the number of firms, the industry evolved to be a tight oligopoly dominated by three firms, General Motors, Ford, and Chrysler. General Motors was formed in 1908 as a merger of a number of firms, with its

¹ Smith [1968, p. 183] confines his list to makes that were manufactured and sold to the general public.

most prominent components, Buick, Cadillac, and Olds Motor Works, dating back respectively to 1903, 1902, and 1901. Ford Motor Company entered in 1903. Chrysler Corporation emerged in 1924 through the efforts of Walter Chrysler, ex-president of Buick, to reorganize two of the leading firms in the industry that had merged after falling on hard times, Maxwell Motor Corporation, which dated back to 1904, and Chalmers Motor Car Company, which dated back to 1908. In 1911, Ford and General Motors were the top two firms, accounting for 38% of the industry's output. By the 1920s their joint share had increased to over 60%, and after 1930 General Motors, Ford, and Chrysler jointly accounted for over 80% of the industry's output (FTC [1939, p. 20]).

General Motors, Ford, and Chrysler were all based in Detroit, Michigan, which for many years had been the geographic center of the industry. The industry was not, however, originally focused around Detroit. The annual number of firms and the percentage of all firms in the Detroit area² from 1895 to 1941, when the number of firms reached a trough of 9, is presented in the bottom two panels of Figure 2. In the first six years of the industry there were 69 entrants, none of which entered in the Detroit area. The first Detroit area entrant was Old Motor Works in 1901. Subsequently, the number of firms in the Detroit area rose, reaching a peak of 41 in 1913, four years after the peak in the number of firms in the industry. The number of Detroit area firms subsequently declined along with the decline in the total number of automobile producers. After the entry of Olds Motor Works in 1901, the percentage of firms in the Detroit area rose to 14% by 1905, then fell back some in the next four years after which it increased to almost 25% by 1916. It subsequently fell back again in the next eight years or so, after which it

² In addition to Detroit, the Detroit area was defined to include the following locations in Michigan, all of which are within approximately 100 miles of Detroit: Adrian, Chelsea, Flint, Jackson, Marysville, Oxford, Plymouth, Pontiac, Port Huron, Sibley, Wayne, and Ypsilanti. The boundaries of this region were chosen to reflect mobility of the firms within the region. For example, Olds Motor Works moved from Lansing to Detroit and back and Buick moved from Detroit to Flint, suggesting that Lansing and Flint, two of the further cities from Detroit in the defined region, were in the same geographic sphere as Detroit.

climbed to over 50% by 1935. Given the paucity of entrants after 1916, the rise in the percentage of firms based in the Detroit area after 1916 reflects the distinctive success of the Detroit area firms. Indeed, only 15% of the firm's in Smith's list were based in the Detroit area, so the concentration of activity around Detroit is largely a reflection of the distinctive longevity of the Detroit area firms.

The concentration of activity around Detroit was actually considerably greater than the percentage of firms based in the Detroit area. The editors of the magazine *Automobile Quarterly* compiled a list of the leading makes of American automobiles beginning in 1896 based upon production figures by make (Bailey [1971]). Through 1900 at most six total makes are listed, with 14 or 15 makes listed from 1905 to 1924 and 18 makes listed by 1928, after which nearly all the makes were manufactured by firms based in the Detroit area. The annual number of makes manufactured by Detroit area firms for 1896 to 1928 is plotted in the top panel of Figure 2. The one make listed for the Detroit area in 1896 and 1897 reflects one experimental car made by Ford and Olds respectively in these two years. The first listing of a Detroit area firm that produced more than one car was Olds Motor Works in 1901, when it was credited with the manufacture of 425 cars. Olds was the only firm in the Detroit area listed as one of the (nine) industry leaders in 1901. Subsequently, the number of makes manufactured by Detroit area firms increased steadily through 1914, when it reached 13 (out of 15 makes listed), and then reached 15 (out of 18) by the end of the period in 1928. Thus, by the mid-1910s the Detroit area firms were totally dominating the industry, with over 14 separate firms involved in the decade 1911-1920.³

In summary, the automobile industry experienced an initial rise and then sharp shakeout in the number of producers and evolved to be a tight oligopoly, with the leading three firms accounting for over 80% of the industry's output. Initially no firm entered in

³ Even these figures understate the dominance of Detroit, with two of the other three prominent non-Detroit firms having links to Detroit. One, Studebaker, entered initially by marketing the cars of a Detroit company, E-M-F, that it later acquired. The other, Nash, was a leading firm acquired by Charles Nash, the ex-president of General Motors, in 1916.

the Detroit area, but after the entry of Olds Motor Works in 1901, the percentage of firms based in the Detroit area and the percentage of leading makes manufactured in the Detroit area rose sharply. Since the mid 1910s firms based in the Detroit area have dominated the industry, and they subsequently maintained their dominance as the number of firms in the industry declined, with all three of the industry's leaders based in Detroit.

III. Model of Industry Evolution

The model is first specified, and then its implications for the evolution of industry market structure are discussed.

A. Specification of the Model

The model is specified in terms of discrete time intervals, where period 1 denotes the start of the industry. The driving force in the model is research and development (R&D). In each period, it is assumed that new opportunities for innovation arise, and incumbent firms conduct R&D to lower their average cost.⁴ Firms are assumed to differ in terms of the productivity of their R&D, and all innovations are assumed to be imitated one period after they are introduced. This is modeled as follows. The average cost of firm i in period t , c_{it} , is

$$c_{it} = c_t - a_i g(r_{it}) + \varepsilon_{it},$$

where c_t is a cost component common to all firms in period t , r_{it} is firm i 's spending on R&D in period t , $\varepsilon_{it} \geq 0$ is a random cost shock to firm i in period t , and a_i calibrates the productivity of the firm's R&D efforts. The reduction in the firm's average cost in period t is determined by the amount of R&D it conducts, r_{it} , and the productivity of its R&D, a_i . The function $g(r_{it})$ is assumed to be such that $g'(r_{it}) > 0$ and $g''(r_{it}) < 0$ for all $r_{it} > 0$ to reflect diminishing returns to R&D. All innovations are assumed to be costlessly imitated after one period, which is modeled as $c_t = c_{t-1} - \max_i \{a_i g(r_{it-1})\}$, where $\max_i \{a_i g(r_{it-1})\}$ is the largest cost decrease from R&D among all firms in period $t-1$. Last, ε_{it} is a random cost shock that causes the firm's average cost to exceed its minimum

⁴ R&D to improve product quality can be thought of as lowering the firm's average cost per unit of quality and thus can be accommodated.

possible value in period t . Cost shocks arise from factors such as difficulties in imitating the leading firm's innovations, unanticipated capital shortages, lax management, etc. It is assumed that cost shocks are independent across periods and thus last for only one period.

In each period, firms are assumed to retain their customers from the prior period, but if they want to expand they must incur a cost of growth of $m(\Delta q_{it})$, where Δq_{it} is the growth in the firm's output and $m'(\Delta q_{it}) \geq 0$ and $m''(\Delta q_{it}) \leq 0$ for all $\Delta q_{it} \geq 0$ to reflect increasing marginal costs of growth. This cost of growth applies to entrants as well as incumbents and thus determines their size at entry.⁵ For simplicity, it is assumed that the industry demand curve is fixed over time and that all firms are price takers, so that in each period the price p_t clears the market.

Firms in the industry in period t choose r_{it} and Δq_{it} to maximize Π_{it} , their profits in period t before the realization of the cost shock ε_{it} :

$$(1) \quad \Pi_{it} = [p_t - c_t + a_i g(r_{it})] (q_{it-1} + \Delta q_{it}) - r_{it} - m(\Delta q_{it}).$$

If these profits are less than zero then the firm exits the industry. Incumbent firms are also assumed to exit if they incur a sufficiently large cost shock. To simplify, in each period t the decision to exit after the realization of the cost shock is assumed to be based only on the firm's current profitability. If the firm's cost shock is such that $\varepsilon_{it} > p_t - c_t + a_i g(r_{it})$ then the firm would lose money by producing, in which case the firm is assumed to disband its R&D operation and permanently exit the industry. Otherwise, the firm remains in the industry and spends r_{it} on R&D and grows by Δq_{it} .

Entry is specified as follows. In each period there are a limited number of potential entrants with the requisite R&D productivity to enter the industry. Four types of entrants are distinguished: experienced firms, experienced entrepreneurs, spinoffs, and inexperienced firms. The first group diversify from related industries, the second group are de novo firms founded by heads of firms in related industries, the third group are de novo firms founded by employees of incumbent firms, and the fourth group is a residual category of inexperienced entrants. Each group j of entrants is assumed to have a

⁵ Entrants in period t have no output prior to entry and thus enter at size Δq_{it} .

distribution of R&D productivities $F_j(a)$, where a_{\max} denotes the maximum R&D productivity of any firm. It is assumed that by dint of their pre-entry experience, each of the first three groups has a more favorable distribution of R&D productivities than the fourth group of inexperienced entrants. This is specified as $F_j(a) \leq F_4(a)$ for all $a \leq a_{\max}$, $j=1,2,3$, with a strict inequality if the best inexperienced entrants cannot duplicate the R&D productivity of the best entrants in each of the other three categories. It is assumed that each firm knows its R&D productivity at its time of entry, and for now it is assumed that its R&D productivity remains fixed over time.

Potential entrants in each period enter if their maximum possible profits based on (1) (with $q_{it-1} = 0$) are positive. For simplicity, it is assumed that to take advantage of local knowledge and to avoid the costs of moving, entrants locate where they are based, which for de novo firms is where their founder(s) lives. The number of potential entrants of each type in each period is specified as follows. It is assumed that at the start of the new industry, there are a number of firms and entrepreneurs in related industries with sufficiently high R&D productivities to enter profitably. As these firms enter, their ranks get depleted, causing the number of potential entrants in the experienced firm and experienced entrepreneur categories to decline over time. The third category of entrants, spinoffs, is assumed to be governed by a birth and heredity process. Employees of incumbent firms are assumed to learn from their experiences, which they can exploit in their own firms. Only employees with the requisite organizational skills and risk preferences will start spinoffs. It is assumed that the better the learning environment in an incumbent firm then the greater the number of spinoffs it will spawn and the greater the R&D productivity of its spinoffs. For simplicity, it is assumed that as the industry expands and more employees are hired, the number of potential spinoff entrants in each period rises. The last group of entrants is a residual category, making it difficult to theorize about how the number of potential entrants in this category changes over time. It is simply assumed that the number of potential inexperienced entrants will not rise faster than the number of potential spinoff entrants.

B. Evolution of Market Structure

Klepper [2000] derives a number of implications of the model. In each period, larger firms invest more in R&D since the total profit from R&D, which equals the

reduction in average cost times the firm's output, is scaled by the firm's output. Furthermore, in every period firms expand until the marginal cost of growth equals their profit per unit of output. The firm's profit per unit of output is determined by its investment in R&D and its R&D productivity. Therefore, larger firms and firms with greater R&D productivity have greater profit margins and thus expand faster. Consequently, among firms that entered in the same period, firms with greater R&D productivity conduct more R&D and are always larger and more profitable than firms with lower R&D productivity. Furthermore, among firms with the same R&D productivity, firms that entered earlier start growing earlier and are thus always larger and more profitable than later entrants.

Expansion of incumbents over time and (initially) entry causes the total output of the industry to rise over time and $p_t - c_t$, the average price-cost margin of firms that do no R&D, to decline over time. When $p_t - c_t$ is high initially, the minimum R&D productivity required for entry to be profitable is low and a range of firms in terms of their R&D productivities enter. As $p_t - c_t$ falls over time, the minimum a_i needed for entry to be profitable rises, causing the percentage of potential entrants of each type that enter the industry to decline over time. Eventually entry becomes unprofitable even for firms with the greatest R&D productivity, at which point entry ceases altogether.

The decline in $p_t - c_t$ also causes the profits of incumbents to decline over time. This is partially offset by the rise in firm R&D over time that occurs as firms grow, which lowers firm average costs. In every period, incumbents that experience a sufficiently large cost shock exit. Incumbents also exit when $p_t - c_t$ falls sufficiently that they cannot earn positive profits even if they produce at their minimum possible cost. The latest entrants with the lowest R&D productivity are always the least profitable and thus the most vulnerable to exit. Thus, even after entry ceases, firms exit, with the latest entrants with the lowest R&D productivity expected to exit first. This causes the number of firms to decline steadily over time, resulting in a shakeout. It also causes the earliest entrants with the greatest R&D productivity to take over an increasing share of the industry's output, which contributes to the evolution of an oligopolistic market structure.

Thus, the model predicts that over time firm profit margins decline, entry eventually ceases and a shakeout occurs, and the industry evolves to be an oligopoly.

The market structure predictions of the model correspond to what occurred in the auto industry. Moreover, the rates of return on investment of the leading firms, which began at extremely high levels, also declined over time (Epstein [1928, p. 256]). Thus, the model passes an initial hurdle of being able to account for the way the market structure of the automobile industry and the profitability of the firms evolved over time. It remains to be shown that the model can also account for the increasing concentration of the industry in one region, around Detroit, Michigan. This is shown in the next section, where further predictions are derived from the model that are used subsequently to test its account of the evolution of the automobile industry.

IV. Further Predictions

The model has a number of additional implications concerning firm survival, entry, and the geographic distribution of activity that are reviewed in this section. The predictions regarding entry and regional activity follow straightforwardly from the model. The survival predictions are established in Klepper [2000].

A. Firm Survival

Suppose two firms with the same R&D productivity that entered at different times are compared at the same age. At every age, the earlier entrant faces a higher industry price-cost margin and thus conducts more R&D than the later entrant. Consequently, at every age the earlier entrant will be larger, hence will conduct more R&D and have a greater profit margin. This will make it less likely for the earlier entrant to draw a large enough cost shock to induce it to exit, hence at every age earlier entrants will have a lower hazard than later entrants with the same R&D productivity. However, on average earlier and later entrants, even of a particular type (such as inexperienced firms or spinoffs), will not have the same R&D productivities. The later entrants will enter when price-cost margins are more compressed, causing them on average to have higher R&D productivities. At young ages, this will offset the effect of earlier entry on the hazard, and it is conceivable that the earlier entrants will not have lower hazards than later entrants of the same type at young ages. Over time, though, as each cohort ages the lowest R&D productivity firms will disproportionately exit and the range of R&D productivities in both entry cohorts for entrants of a given type will narrow and approach

the maximum R&D productivity of firms of that type. Consequently, for each type of entrant, eventually the earlier entrants will have a lower hazard than the later entrants, and the later entry cohort will become extinct before the earlier entry cohort.

This prediction is summarized as hypothesis 1 in Table 1 and is illustrated in the cohort survival graph in the top panel of Figure 3. Anticipating the empirical analysis, three cohorts of entrants of a specific type are represented. The survival curves represent the fraction of entrants in each cohort surviving to each age. The vertical axis is scaled logarithmically so that the negative of the slope of each curve indicates the hazard of the cohort at the respective age. To simplify, it is assumed that the firms in cohort 3, the latest group of entrants, have a constant hazard rate up to the time that the cohort becomes extinct. The figure is (arbitrarily) constructed so that the entrants in the first two cohorts initially have the same hazards as the entrants in the last cohort. But eventually the earlier entry cohorts have lower hazards, with the first cohort having the lowest hazards at younger ages, which causes the survival curves of the first two cohorts to flatten out with age and diverge from the survival curve of the third cohort. These predictions are distinctive. Most other theories of shakeouts posit either a particular event, such as a major innovation or key innovative development (Utterback and Suarez [1993], Jovanovic and MacDonald [1994]), or an overshooting of an equilibrium number of firms (cf. Klepper and Miller [1995], Horvath et al. [2001]), as the cause of shakeouts. These theories imply that at young ages later entrants will have a higher hazard than earlier entrants, but over time the hazards of firms in different cohorts will converge, which is the opposite of hypothesis 1 (Klepper and Simons [2000c]).

Consider next firms that entered at the same time that have different backgrounds. The inexperienced firms were assumed to have lower R&D productivities on average than the other three categories of firms. This implies that at young ages, the inexperienced firms will have a higher hazard than the other three types of entrants. Over time, the entrants of each type with the lowest R&D productivities will disproportionately exit, causing the average productivity of the survivors of each type to rise with age. But if the maximum R&D productivity of the inexperienced entrants is below that of the other three types of entrants, the average R&D productivity of the inexperienced entrants will remain below that of the other three groups as they age. Therefore, the inexperienced

entrants will have higher hazards at every age than entrants of the other three types that entered at the same time. This is summarized in Table 1 as hypothesis 2 and is illustrated in the cohort survival graph in the bottom panel of Figure 3 for the arbitrary case of constant hazards. Hypothesis 2 is also distinctive. Many theories can accommodate more experienced firms having lower hazards at young ages than less experienced firms, but their logic generally implies that such differences will decline with age (Klepper [2000]).⁶

Hypotheses 1 and 2 are stated in terms of the four classes of entrants that are distinguished, but finer gradations of entrants, such the quality of the parents of spinoffs and the industries in which experienced firms and entrepreneurs participated, will be introduced in the empirical analysis. The model implies that spinoffs from firms with better learning environments will have higher R&D productivities, hence the hazard of spinoffs at every age should be a decreasing function of the quality of the learning environments of their parents. The premise behind experienced firms and entrepreneurs having lower hazards than inexperienced firms is that they can draw on their experiences in related industries to enhance the productivity of their R&D. It would be expected that the more related their industries are to automobiles, the more valuable will be their experience and thus the lower will be their hazards at every age. These propositions are summarized as hypothesis 3 in Table 1.

B. Entry

Consider first the implications of the model concerning the composition of entrants over time. It was assumed that the number of potential entrants in the categories of experienced firms and experienced entrepreneurs declines over time, the number of potential spinoff entrants increases over time, and the number of potential inexperienced

⁶ It was assumed that firm R&D productivities do not change over time, but this is not necessary for hypothesis 2. If firm R&D productivities revert towards a common value as firms age, it would still be true that at any given age firms that started with greater R&D productivities would be larger. Therefore, they would conduct more R&D, hence would have greater profit margins and lower hazards than firms that entered at the same time with lower R&D productivities, and hypothesis 2 would continue to hold.

entrants does not rise faster than the number of potential spinoff entrants. The former assumption implies that the number of entrants that are experienced firms and experienced entrepreneurs will fall over time. Consider the other two groups of entrants, spinoffs and inexperienced firms. Over time, the minimum R&D productivity required for profitable entry rises. If the maximum R&D productivity of inexperienced firms is less than that of spinoffs, then eventually the ratio of the number of spinoff entrants to inexperienced entrants must rise, causing the fraction of these two types of entrants accounted for by spinoffs eventually to rise. Last, if firms with better learning environments spawn spinoffs with higher R&D productivities, then over time the quality of the parents of spinoff entrants, in terms of their learning environments, should improve. These predictions are summarized as hypothesis 4 in Table 1. The last parts of hypothesis 4 are distinctive. Many theories assume that entrants can learn about their capabilities only by entering (e.g., Jovanovic [1982], Horvath et al. [2001]), in which case the characteristics of entrants will not change over time, as predicted in hypothesis 4.

The model also has a cross sectional implication regarding entry. It predicts that in every period firms with better learning environments will spawn more spinoffs (as well as ones with higher R&D productivities). This is summarized as hypothesis 5.

C. Regional Activity

Recall that in the first six years of the automobile industry, no firms entered in the Detroit area, and subsequently the percentage of firms in the Detroit area increased sharply and the firms around Detroit were distinctively successful.

The model predicts that the early entrants are disproportionately experienced firms and experienced entrepreneurs. If the Detroit area attracted few early entrants, then the model implies that the percentage of entrants accounted for by experienced firms and entrepreneurs should be lower in the Detroit area than elsewhere. More importantly, the only way the model can account for the growing concentration of activity around Detroit is through the spinoff entrants. This could occur if by chance the earliest entrants in the Detroit area were unusually successful, which could lead to a cascading spinoff process in which the early successful entrants spawned more and stronger spinoffs in the Detroit area than in other regions, which in turn spawned more and stronger later generation spinoffs in the Detroit area than elsewhere.

This explanation for the concentration of activity around Detroit has a number of implications. First, the spinoffs of Detroit area firms will locate in the Detroit area and the spinoffs located in the Detroit area will have parents located in the Detroit area. Second, the percentage of entrants that are spinoffs should be higher in the Detroit area than elsewhere. Third, the quality of the parents of the spinoffs, in terms of their learning environments, should be greater in the Detroit area than elsewhere. Fourth, by dint of their better learning environments, the spinoffs in the Detroit area should have lower hazards at every age than the spinoffs elsewhere. Fifth, a few early Detroit area entrants should rank high on the list of firms with the greatest number of spinoffs. It should also be possible to trace back the most successful spinoffs in the Detroit area, either directly or through their spinoffs, to these firms. Sixth, the model implies that the distinctive success of the Detroit spinoffs should not be duplicated by the inexperienced firms that entered in Detroit. These firms do not share the advantage of the Detroit spinoffs, which stems from their parents rather than any advantage per se of locating around Detroit. Expressed alternatively, no agglomeration economies are specified in the model that could benefit the inexperienced entrants around Detroit. Consequently, in contrast to the spinoffs that entered in Detroit, the inexperienced firms that entered in Detroit should not have lower hazards at each age than the inexperienced firms that entered elsewhere. These predictions are summarized as hypothesis 6 in Table 1.

V. General Patterns

To test the various predictions, the firms are divided according to their time of entry and prior experience. Firms are grouped into three entry cohorts of roughly equal size to probe the importance of time of entry. The first cohort includes the 220 firms that entered between 1895 and 1904, the second cohort includes the 269 firms that entered between 1905 and 1909, and the third cohort includes the remaining 236 firms that entered between 1910 and 1966. Firms that were reorganized or acquired by nonautomobile producers were considered to be continuing producers. Mergers and acquisitions were treated as continuations of the firm whose name was retained, or in the case of mergers the largest firm involved, with the other firms treated as censored exits.

Approximately 6% of the firms exited by being acquired by another automobile firm or through a merger.

The classification of firms according to their prior experience is based on Smith [1968] and the brief histories of the firms in the *Standard Catalog of American Automobiles* (Kimes [1996]), which contains an entry for every make of automobile on Smith's list. Smith categorized firms according to whether they entered automobiles from another business. Those that did were classified in the category of experienced firms. Twenty-three additional firms on Smith's list were identified from the *Standard Catalog* as entering from another business, most often from carriages/wagons. These firms were also classified as experienced firms, yielding a total of 121 experienced firms. Firms were classified into the category of experienced entrepreneurs if in the *Standard Catalog* at least one of their founders was identified as the head of a named firm that was active or had recently been sold. This yielded a total of 103 experienced entrepreneurs. The *Standard Catalog* was used to identify the main product produced by each experienced firm and experienced entrepreneur. Firms were classified as spinoffs if at least one of their founders had worked for and/or founded an automobile firm in Smith's list, yielding a total of 127 spinoffs.⁷ The latest firm worked for by the founder was designated as the parent of the spinoff.⁸ In a small number of cases it was indicated that the impetus for the spinoff was the failure of the parent firm or a dispute in the parent

⁷ In the case of some spinoffs it was difficult to tell from the brief history in the *Standard Catalog* whether a person who was mentioned as having worked for another automobile firm was a founder of the spinoff. These firms generally did not survive very long. To be conservative, they were included as spinoffs. One firm, Dodge Brothers, was a major supplier to Ford Motor Company from its inception and the Dodge brothers themselves were major stockholders of Ford. Based on their experience with Ford, they were classified as a spinoff rather than an experienced firm.

⁸ In most cases, only one firm was mentioned for spinoff founders. In some spinoffs there were multiple founders that had worked for different automobile firms. In these cases, the parent of the spinoff was determined based on the founder(s) that were described as the most instrumental in the spinoff.

firm involving the spinoff's founder, and this was recorded. For most of the spinoffs the founder's prior position was also identified, and this was also recorded. The 324 firms that were not classified as experienced firms, experienced entrepreneurs, or spinoffs were included in the residual category of inexperienced firms.

The first hypothesis in Table 1 deals with how time of entry affects firm survival. It is tested using the survival graphs in Figure 4. Cohort 1 refers to the 1895-1904 entrants, cohort 2 to the 1905-1909 entrants, and cohort 3 to the 1910-1966 entrants. The top graph includes all the firms and the other four graphs look separately at the four categories of entrants. The graphs are analogous to Figure 3, indicating the fraction of firms in a cohort surviving to each age, plotted on a logarithmic scale so that minus the slope of the curve at any age is the hazard rate for the cohort.⁹ A curve drops to the horizontal axis at a particular age when the survival rate of the cohort at that age is less than or equal to 1%. If the last firm in a cohort exited by being acquired and the survival rate to that age exceeded 1%, the cohort survival graph ends at the age of the acquired firm but does not drop to the horizontal axis. Curves that continue to the far right of each graph indicate that more than 1% of the firms in the cohort were still surviving at the end of the data period in 1966.

The three survival curves for all the firms in the top panel initially overlap until approximately age seven, when they diverge, with cohort 1 having the highest survival rate at older ages, followed by cohort 2 and then cohort 3. Correspondingly, the survival curve of the third cohort drops to the horizontal axis at the earliest age, followed by the second cohort, with the first cohort having well over a 1% survival rate through 1966. This conforms to the predicted pattern, as reflected in the top panel of Figure 3. The graphs for each type of entrant are similar. With the exception of the first cohort of experienced firms, the three cohort survival curves in each graph overlap at young ages and don't diverge until around age seven, at which point the survival curves are ordered by time of entry as in the top graph. Thus, as the industry evolved, the hazard rates of the

⁹ The percentage of firms surviving to age x was estimated as the product of the percentage of nonacquired firms surviving through each one-year age interval through age x .

entrants in the different cohorts diverged, with cohort hazard rates ordered by time of entry.

Figure 5 compares the survival rates of the inexperienced firms with each of the other three categories of entrants. Only the first two cohorts of each group of entrants are graphed to keep the graphs uncluttered (the patterns are similar for the third cohort as well). The first cohort is represented in pink and the second in yellow, with the thinner curves used to represent the inexperienced firms. The graph in the upper panel compares the inexperienced firms and the experienced firms. The (pink) survival curves of the experienced and inexperienced firms in the first cohort of entrants diverge from the youngest ages and their slopes do not change greatly with age, indicating that the difference in their hazards persists with age. A similar pattern holds for the experienced and inexperienced firms that entered in the second cohort (the yellow curves). The other two graphs pertaining to the experienced entrepreneurs and spinoffs are similar. The curves overlap more at the youngest ages, but at older ages the experienced entrepreneurs and spinoffs have considerably higher survival rates than the inexperienced firms in the same entry cohort. The curves for the less experienced firms also have steeper slopes at the older ages, indicating that the hazards of the inexperienced firms remain higher than the other two groups at older ages (cf. Carroll, Bigelow, Seidel, and Tsai [1996]). This conforms with hypothesis 2 in Table 1 and with the predicted patterns in the bottom panel of Figure 3.

Hypothesis 3 pertains to how the particular backgrounds of the experienced firms, experienced entrepreneurs, and spinoffs affect their survival rates. Further breakdowns of the survival curves for these groups according to their backgrounds would result in some very small samples, making comparisons difficult. The analysis of the role of the backgrounds of these firms is deferred until the econometric analysis, where a parsimonious specification can be used to cope with the small samples.

The next set of predictions concern entry. These are tested using the tabulations in Tables 2 and 3. Table 2 reports the number of each type of entrant in the three periods 1895-1904, 1905-1909, and 1910-1966. Consistent with hypothesis 4a, both the number of experienced firms and experienced entrepreneurs decline over the three time periods. Table 3 provides a further breakdown of these two groups of entrants according to their

industry background. Five different backgrounds are distinguished—bicycles, engines, carriages/wagons, metal manufactured products (including machinery), and a residual, other category. Table 3 indicates that for both groups of entrants, the firms with a bicycle background all entered in the first period. The bicycle industry was experiencing a sharp downturn and consolidation during this period, which no doubt greatly lowered the opportunity cost of automobile entry for firms and entrepreneurs with bicycle experience. The engine and metal manufactured products firms also tended to enter predominantly in the earlier period. The carriage/wagon firms stand out because of their late entry, which was lowest in the first period and then peaked in the second period. Carriages were the product most directly challenged by automobiles. At first, it was unclear how serious the challenge would be, and many carriage firms waited for this uncertainty to resolve before entering. Mitchell [1989] found a similar pattern for incumbent diagnostic imaging firms, which delayed entering new diagnostic imaging products until the uncertainty surrounding their market prospects was resolved. The number of firms in the residual category was similar in the three time periods, reflecting perhaps the absence of a strong connection between their backgrounds and automobile technology.

Hypothesis 4b predicts that among the spinoffs and inexperienced firms, eventually the spinoffs will account for a greater percentage of these entrants. Using the figures in Table 2, the percentage of these firms that were spinoffs was 11% in the first period, 20% in the second, and 42% in the third, indicating a substantial rise in the relative number of spinoffs, as predicted. Hypothesis 4c predicts that over time the spinoffs will come from better learning environments. A crude proxy for the learning environments of the spinoffs is the number of years their parents remained in the industry, which is a conventional performance measure. The last two columns of Table 3 report the number of spinoffs in each entry cohort whose parents survived less than 10 years and greater than or equal to 10 years. In the first entry cohort composed of 14 spinoffs, 35% had parents that survived 10 or more years. In the second entry cohort of 39 spinoffs, this percentage fell to 26%, and then it rose sharply to 59% of the 74 spinoffs in the third entry cohort. Thus, at first the quality of the spinoffs' parents did not increase, but after 1909 when entry declined the quality of the parents of the spinoffs increased sharply. This is consistent with the idea that as entry became more difficult,

spinoffs required a better background in order to enter profitably. Hypothesis 5 delves further into the background of the parents of the spinoffs, and this is tested econometrically in the next section.

The last set of hypotheses in Table 1 pertain to the concentration of the industry around Detroit. Hypothesis 6a concerns whether the spinoffs that located in the Detroit area had parents in the Detroit area and whether the parents in the Detroit area had spinoffs that located in the Detroit area. Forty-nine spinoffs located initially in the Detroit area, and 45 of them had parents located in the Detroit area. There were ten spinoffs that located outside of the Detroit area that had parents in the Detroit area. One moved to Detroit soon after its entry and two of the others were founded in their home cities by New York and Atlanta sales agents for their Detroit area parent firms. Thus, the spinoffs in the Detroit area and from firms located in the Detroit area did not generally move far from where their founders were employed, as conjectured.¹⁰

Hypothesis 6b pertains to the composition of entrants in the Detroit area and elsewhere. It is tested using Table 4, which breaks down the entrants into whether they entered in the Detroit area or elsewhere.¹¹ The experienced firms and entrepreneurs are combined into one category and the last entry cohort is subdivided into two cohorts, the first spanning 1910-1916 and the second 1917-1966. Table 4 indicates that 15% of all the firms entered in the Detroit area. Detroit was not blessed by entry of firms or

¹⁰ The other 68 spinoffs that entered outside the Detroit area that did not have Detroit area parents were somewhat less prone to locate close to their parents. Forty-nine of them, or 72%, located within a 100 miles of where they were working. A number of the other 19 involved founders who had already left their employers before starting their own firms and seemingly had moved on to other locations. This may have been more prevalent among the spinoffs not connected to the Detroit area, perhaps reflecting the lesser success of their parents relative to those of spinoffs connected to the Detroit area, as discussed below.

¹¹ Maxwell-Briscoe, which had a Detroit parent and eventually moved to Detroit after entering elsewhere and evolved into Chrysler, was included with the Detroit area entrants.

entrepreneurs with experience in related industries, with only 9% of the entrants in the experienced firm and experienced entrepreneur categories entering in the Detroit area. Only 11% of the less experienced entrants also entered in the Detroit area. As predicted in hypothesis 6b, Detroit was distinguished by a relatively large number of spinoff entrants, with 39% of all the spinoffs entering in the Detroit area. More spinoffs entered the Detroit area than any other type of entrant, accounting for 45% of the entrants in the Detroit area versus only 13% of the entrants elsewhere. Thus, apart from the spinoffs, the Detroit area did not attract a large number of entrants into the industry.

It was also predicted that the quality of the learning environments of the Detroit area spinoffs would be greater than the quality of the learning environments of spinoffs elsewhere. Among the 45 spinoffs in the Detroit area with a Detroit area parent, 17 had parents that were acquired within ten years of their entry, five had parents that survived less than 10 years, and the other 23 had parents that survived 10 years or longer. In contrast, among the 68 spinoffs outside the Detroit area with a parent located outside of the Detroit area, three had parents that were acquired within 10 years of their entry, 33 had parents that survived less than 10 years, and 32 had parents that survived 10 years or longer. Thus, nearly half of the spinoffs outside the Detroit area had parents that survived less than ten years and were not acquired, whereas few spinoffs in the Detroit area had parents that survived less than 10 years unless they were attractive enough to be acquired within their first ten years. These patterns are strongly consistent with hypothesis 6c.

The large number of Detroit area spinoffs with parents that were acquired at a young age is attributable to the large number of spinoffs from Olds Motor Works and Cadillac, both of which were acquired by General Motors. These firms had 6 and 5 spinoffs respectively. The only other firm with more spinoffs, 7, was Buick/General Motors (Buick was the largest component of General Motors and thus General Motors was defined as the continuation of Buick, and all the spinoffs from Buick and subsequently General Motors were assigned to Buick/General Motors). Olds, Cadillac, and Buick were three of the earliest entrants in the Detroit area, entering respectively in 1901, 1902, and 1903. All three were immensely successful soon after their entry. Olds was the number two producer in the industry in 1901 and 1902 and then number one from

1903 to 1905, Cadillac was the number three producer by 1903 and then number two from 1904 to 1906, and Buick was the number five producer in 1905, number eight in 1906, and then number two in 1907 and 1908 (Bailey [1971]). After its formation in 1908, General Motors, which acquired Olds, Cadillac, and Buick, was the number two producer in the industry for many years. The other very successful early entrant in the Detroit area was Ford in 1903, and Ford had three spinoffs, which was surpassed by only one other firm, Hupp Motor Car Company, which itself was a 1909 Detroit area spinoff traceable back to Olds and Ford.

To convey further the spinoff juggernaut started by Olds, Cadillac, Buick/General Motors, and Ford, the heritage of the 17 spinoffs that survived over ten years was examined. Surviving over 10 years was a significant accomplishment achieved by only 14% of the entrants into the industry. Of the 17 spinoffs that survived this long, 11 were located in the Detroit area, and eight of the 11 had founders that worked for Olds, Cadillac, Ford, or General Motors, with a ninth having a founder that worked for a spinoff from one of these four firms. Among the eight spinoffs with founders that worked for one of the four firms, seven were ranked among the industry's sales leaders in one or more years. Four other successful spinoffs in the Detroit area with founders that worked at one of these same four firms were acquired before they were ten years old, and three of the four played an important role in leading firms in the industry.¹²

¹² This includes: Chevrolet, which was a spinoff from General Motors that General Motors later used to take over the number one position in the industry; E-M-F, which had founders that worked for Ford and Cadillac and was used by Studebaker to launch its entry into the leading automobile firms; and Lincoln, a spinoff from General Motors that became an important component of Ford. The fourth acquired firm was Brush, which was very successful until it was acquired as part of the unsuccessful United States Motor Company merger in 1910. Three of the spinoffs that survived over ten years, Maxwell-Briscoe (in its later incarnation as Maxwell Motor Company), Chalmers, and Dodge, were also key components of Chrysler. Thus, spinoffs with founders that worked for one of the four early successful Detroit area firms played a key role in the top firms in the industry as well as themselves constituted many of the leaders of the industry.

Thus, consistent with hypothesis 6e, most of the successful spinoffs in the Detroit area can be traced back to four very successful early entrants in the Detroit area. Having four such successful early entrants locate in one small area is an extremely unlikely event, particularly in the Detroit area given the paucity of experienced firms and entrepreneurs that entered there. But these firms were blessed by very talented leaders, three of whom were very successful businessmen in the Detroit area even before the advent of the automobile. They not only guided their own firms so ably but seemingly played a key role in establishing the Detroit area as the automotive capital of the United States.

The remaining two parts of hypothesis 6, parts d and f, pertain to the survival experiences of spinoffs and inexperienced firms in the Detroit area versus elsewhere. These hypotheses are evaluated using the survival graphs in Figure 6. The top two graphs present the survival curves for the three cohorts of spinoff entrants in the Detroit area and elsewhere. They further establish the extraordinary performance of the Detroit spinoffs, particularly the first two cohorts of spinoff entrants in the Detroit area. These firms had much higher survival rates to older ages than spinoffs outside the Detroit area. The other two survival graphs in Figure 6 pertain to the inexperienced entrants in the Detroit area and elsewhere. These patterns are quite different. The cohort survival curves for the Detroit area inexperienced firms resemble those of the inexperienced firms outside the Detroit area at young ages, but they all end by 10 years of age, reflecting that no Detroit area inexperienced firm survived over 10 years (one was acquired at age 10). In contrast, a nonnegligible percentage of inexperienced firms that located outside of the Detroit area survived over 10 years.

The failure of the Detroit area firms to survive to older ages suggests that at some point the Detroit area became a difficult place for the inexperienced firms to compete. Consistent with this, Table 4 indicates that after 1916 very few inexperienced firms entered the Detroit area. Before 1916, the percentage of inexperienced entrants that located in the Detroit area had been steadily rising, reaching 21% in the 1910-1916 period. But after 1916 it dropped to 3%, with only 1 of 33 inexperienced entrants locating in the Detroit area. The percentage of spinoffs entering in the Detroit area after 1916 also was much lower than in earlier periods. Although the percentage of all entrants

that located in the Detroit area had been steadily rising, from 10% in 1895-1904 to 14% in 1905-1909 to 29% in 1910-1916, it declined to 12% after 1916, reflecting the fall off in the entry rate of spinoffs and inexperienced firms. All this suggests that the success of the Detroit area firms was mainly attributable to their pedigree and not their location, which may actually have been disadvantageous as competition in the industry intensified, particularly among the Detroit area firms that were the leaders of the industry.

VI. Econometric Analysis

In this section, econometric methods are used to test the various hypotheses. First, the hypotheses concerning the effect of various types of pre-entry experience on firm hazards are tested. Second, the factors affecting the rate at which firms spawn spinoffs are explored to test the hypotheses concerning firm spinoff rates.

The first set of hypotheses about firm hazard rates are tested using the following specification. The hazard of firm exit at age t , $h(t)$, is modeled according to the Gompertz specification:

$$h(t) = \exp\{(\alpha_0 + \alpha_1 C_1 + \alpha_2 C_2)t\} \exp\{\beta_0 + \beta' \underline{x}\},$$

where C_1 and C_2 are 1-0 dummies equal to 1 for firms that entered in the first and second cohorts respectively, \underline{x} is a vector of covariates, and the other terms are coefficients. The first exponential term allows the age of the firm to affect its hazard rate. It also includes the two time of entry dummies to test the hypothesis that as firms age, the hazards of entrants diverge according to their time of entry. The second exponential term allows for factors that affect the hazard proportionally at all ages.

The theory predicts that firm hazard rates may not be ordered by time of entry at young ages but will be ordered by time of entry at older ages. To test for the former possibility, C_1 and C_2 are included in the vector of covariates \underline{x} in the second exponential term. If time of entry does not affect the hazard at young ages, as the analysis of the survival graphs suggested, then the coefficients of C_1 and C_2 in the second exponential term will equal zero. If firm hazards by time of entry diverge at older ages, then the coefficients of C_1 and C_2 in the first exponential term, α_1 and α_2 , will both be negative, with $\alpha_1 < \alpha_2$.

The analysis of the survival graphs suggested that firm backgrounds affected the hazard similarly at all ages. Accordingly, the firm background variables are included in the vector of covariates \underline{x} . A 1-0 dummy equal to 1 for experienced firms and a 1-0 dummy equal to 1 for experienced entrepreneurs are included in \underline{x} . Each of these dummies is in turn multiplied by a 1-0 dummy equal to 1 if the firm or its head had a background in bicycles, engines, wagons/carriages, or metal manufactured products, which were considered to be the industrial backgrounds most closely related to automobiles. The coefficients of all four of these variables are expected to be negative.

Variables representing the backgrounds of the spinoff entrants are also included in \underline{x} . To control for the environments in which the spinoffs were reared, two variables are included for the parents of the spinoffs: the total number of years the parents survived in the industry,¹³ and a 1-0 dummy equal to 1 for parents that were the sales leader of the industry (based on Bailey [1971]) in the entry year of the spinoff or any of the preceding five years. The coefficients of both variables are expected to be negative. A separate variable was also included for whether the impetus for the spinoff was the failure of its parent. This variable was not significant on its own but was significant when interacted with a 1-0 dummy equal to 1 for spinoffs located in the Detroit area, and the interacted form of the variable is included in the analysis, with its coefficient expected to be positive. For most spinoffs information was available on the position of the spinoff's founder in its parent firm. After some experimentation, a 1-0 dummy for founders who worked as engineers in the design of their parent's car was included.

A 1-0 dummy equal to 1 for all spinoffs and the 1-0 dummy equal to 1 for spinoffs located in the Detroit area were included, but only the latter was significant and retained. If being located in the Detroit area was beneficial, the coefficient of this variable will be negative. Alternatively, given the better performance of the parents of the Detroit area spinoffs noted in the prior section, if the parent survival and sales leader variables do not fully control for the spinoff's learning environment then the coefficient

¹³ Acquired firms that played an important role in their acquirer were assigned the same number of years of survival as their acquirer in the construction of this variable.

of the Detroit area spinoff variable will be negative even if being located in the Detroit area was not beneficial. To probe this further, a 1-0 dummy equal to 1 for inexperienced firms located in the Detroit area is included. The analysis in the prior section suggested that it may have been disadvantageous for inexperienced firms to be located in the Detroit area, in which case the coefficient of this variable will be positive. If the coefficient is not negative, it suggests that whatever possible benefit there was to locating in the Detroit area did not extend to all firms.

The estimates of the coefficients of the hazard model are reported in Table 5, with all significance tests one-tailed. Consider first the estimates of the coefficients on the cohort dummies C_1 and C_2 . The coefficient estimates of C_1 and C_2 when not interacted with age are trivial and insignificant, implying little difference in cohort hazard rates at young ages. In contrast, the coefficients estimates of C_1*t and C_2*t are both negative and significant at the .01 and .10 levels respectively, implying that at older ages the cohort hazards diverge with age according to the time of entry. Thus, consistent with hypothesis 1, time of entry affects the hazard only at older ages. To illustrate the magnitude of these effects, at age 15 the estimates imply a 73% and 33% lower hazard of entrants in cohorts 1 and 2 than cohort 3, with the analogous reductions equal to 89% and 49% at age 25.

Consider next the coefficient estimates for the experienced firm and experienced entrepreneur variables. The coefficient estimates of the experienced firm and experienced entrepreneur dummies are both negative and significant at the .05 and .10 levels respectively. They are very close in magnitude, implying a reduction of approximately 26% in the hazard at every age of experienced firms and experienced entrepreneurs relative to inexperienced firms. For both groups of experienced firms, the coefficient estimates for experience in bicycles, engines, carriages/wagons, or metal manufactured products are also negative and significant at the .05 and .01 levels. The coefficient estimates are also similar in magnitude, implying that more closely related experience further lowered the hazard at every age by 37% for experienced firms and 42% for experienced entrepreneurs. Thus, consistent with hypothesis 2, entrants with experience in related industries had lower hazards, and consistent with hypothesis 3, the closer their experience to automobiles then the lower their hazard.

Consider next the coefficient estimates for the spinoff variables. The coefficient estimate for the number of years of survival of the parent is negative and significant at the .05 level, implying a reduction in the spinoff's hazard at every age of .7% for each additional year of survival of the parent. The coefficient estimate for the sales leadership variable is also negative and significant at the .05 level, implying a further reduction in the spinoff's hazard at every age of 73%. The coefficient estimate of the impetus for the spinoff being a failing parent and the spinoff located in the Detroit area is positive and significant at the .05 level, implying a 225% higher hazard at every age. Thus, consistent with hypothesis 3, the better the performance of the spinoff's parent then the lower the hazard of the spinoff. The coefficient estimate for founders that worked as engineers designing their parent's cars is also negative and significant at the .01 level, implying that this background further lowered the spinoff's hazard at every age by 38%.

The coefficient estimate for spinoffs located in the Detroit area is negative and significant at the .01 level, implying a reduction in the hazard at every age of 45%. As noted, this could be due to an advantage of being located in the Detroit area or to the crudeness of the controls for the parental environments of the spinoffs coupled with the superior performance of the parents of the spinoffs in the Detroit area. To probe the potential magnitude of the latter effect, the variables pertaining to the spinoff's parent were first omitted from the analysis, followed by the omission of the dummy for the founder's prior position. Dropping the first set of variables caused the coefficient estimate for the Detroit area spinoff dummy to rise absolutely from -0.5889 to $-.9680$ and dropping the founder variable caused the coefficient estimate to rise further absolutely to -1.2017 . Thus, even crudely measured these variables account for much of the greater longevity of the spinoffs located in the Detroit area, and it may well be that if better measured they would account for all their greater longevity. Consistent with the analysis of the survival graphs, the coefficient estimate for the inexperienced firms located in the Detroit area is positive and significant at the .10 level, implying a 24% higher hazard for these firms at every age. Thus, if there were advantages to being located in the Detroit area, they were not shared by the inexperienced firms.

The econometric analysis thus provides strong support for the model's predictions concerning firm performance. Its other key prediction, which lies at the heart of its

explanation for the concentration of the industry around Detroit, is that firms with better learning environments spawn more spinoffs (hypothesis 5 in Table 1). This is tested econometrically by examining the rate at which firms spawned spinoffs between 1899 and 1924, which is when most of the spinoffs entered. Each firm's history is broken into annual intervals from its date of entry (or 1899 if it entered earlier) through 1924. Pooling the observations for each firm, a logit model was estimated of the factors influencing the annual probability of a firm having one or more spinoffs. The explanatory variables for each firm-year t include: a 1-0 dummy equal to 1 for firms that were no longer producing in year t ; a 1-0 dummy equal to 1 for firms not producing in year t that had ceased producing less than five years earlier; the number of years of production through year t for firms still producing in year t ; the total years the firm survived over its lifetime;¹⁴ a 1-0 dummy equal to 1 if the firm had been among the sales leaders of the industry (based on Bailey [1971]) in year t or the preceding five years; a 1-0 dummy equal to 1 for firms located in the Detroit area; and a variable equal to the number of nonspinoff entrants divided by the number of firms averaged over years $t-2$, $t-1$, and t .

By focusing on the annual probability of a firm spawning a spinoff, it is possible to explore not just the factors affecting the total number of spinoffs from a firm but its rate of spinoffs during the time it produced and after it ceased producing (or was acquired). The firm spinoff rate is allowed to vary according to the firm's history of production under the expectation that firms no longer producing, especially ones that had not produced for over five years, would have lower spinoff rates,¹⁵ and older firms still producing might have more knowledge for employees to draw upon and thus higher spinoff rates. The nonspinoff entry variable was included to allow the spinoff rate to vary

¹⁴ As in the hazard analysis, acquired firms that played an important role in their acquirer were assigned the same number of years of survival as their acquirer.

¹⁵ If employees started firms after the exit of their parents, which occurred in some cases, then firms would have spinoffs after they ceased producing, but this was not expected to be the norm.

according to the attractiveness of entry generally.¹⁶ The years of survival and sales leadership variables were included to test whether a firm's performance affected its spinoff rate, as the model presumes. These variables control crudely for firm performance. Thus, analogous to the hazard estimates, the Detroit area dummy could play a role because of the crudeness of these measures and the above average performance of the Detroit area firms or because of factors in the Detroit area that might have been conducive to spinoffs.

The estimates of the coefficients of the model are reported in Table 6. All the estimates conform with expectations. The probability of a spinoff was significantly lower (at the .01 level) if the firm was no longer producing. It was significantly higher (at the .01 level) if it had ceased producing within the last five years, but still lower (as reflected in the sum of the coefficient estimates of the production dummy and the dummy for exiting less than five years earlier) than for firms still producing. For firms still producing, the probability of a spinoff was greater the older the firm, although this effect was not significant. The probability of a spinoff was significantly greater (at the .05 level) the higher the nonspinoff entry rate. In terms of the critical variables for the theory, the probability of a spinoff each year was significantly greater (at the .01 level) for firms that survived longer and significantly greater (at the .05 level) for firms that were among the sales leaders in the prior five years. Detroit area firms also had significantly higher (at the .01 level) spinoff rates, which could reflect conditions around Detroit conducive to spinoffs or simply the crudeness of the measures of firm performance. Thus, consistent with hypothesis 3, firms that performed better had higher annual spinoff rates, and firms located in the Detroit area, which on average were superior performers, had higher spinoff rates.

VII. Discussion

The findings are first summarized, and then the implications of the findings are considered.

¹⁶ This was alternatively controlled using year dummies, which had little effect on the estimates

The performance of firms in terms of the hazard of exit was strongly related to their time of entry and the firms' pre-entry backgrounds. Entry cohorts had similar hazards at young ages but at older ages their hazards diverged sharply according to their time of entry. Firms with experience in related industries or firms founded by heads of firms in these industries had lower hazards at every age, particularly if the industries in which they participated were more closely related to automobiles. Better performing firms and firms located in the Detroit area, perhaps by dint of their superior performance, had higher spinoff rates and spinoffs with lower hazards at every age. Spinoffs did not venture far from their parents, and many of the Detroit area spinoffs, especially the most successful ones, could be traced back to Olds, Cadillac, Buick/General Motors, and Ford, four of the most successful early entrants into the industry that all happened to locate in the Detroit area.

The Detroit area was not characterized by a large number of entrants with experience in related industries, and the success of Detroit was largely driven by its spinoffs, which constituted a much higher fraction of the entrants in the Detroit area than elsewhere. As the industry evolved and the intensity of competition in the industry increased, especially in the Detroit area, the nature and location of entrants changed. The experienced firms and experienced entrepreneurs entered earliest with the exception of the carriage/wagon firms, whose market was directly challenged by the automobile. Few of these firms located in the Detroit area. Over time they were replaced by spinoffs, who accounted for an increasing percentage of the entrants into the industry, with the quality of the parents spawning the spinoffs eventually improving markedly. Partly fueled by the growing importance of spinoffs, entry increased faster in the Detroit area than elsewhere. After 1916, however, entry in the Detroit area turned down sharply, especially for inexperienced firms, whose hazards were higher in the Detroit area than elsewhere.

These patterns are revealing about the forces that shaped the evolution of the industry. Consider first the findings about how firm hazards were related to the time of entry. It appears that early entrants had substantial competitive advantages that surfaced as the industry evolved. A few later firms, such as Chrysler, that built on the efforts of earlier entrants were successful, but later entrants that started from scratch were rarely

able to compete very long in the industry.¹⁷ Strong advantages to early entry would help explain the eventual falloff in the rate of entry that occurred in the industry. With entry eventually becoming negligible, a shakeout in the number of producers was inevitable, with earlier entrants taking over an increasing share of the industry's output. Alternative theories of shakeouts have been proposed in which shakeouts are triggered by particular events, either technological in nature or due to factors such as information cascades. Such theories imply that the industry hazard rate will rise around the start of the shakeout, causing later entrants to have higher hazards than experienced by the earlier entrants at comparably young ages. The hazards of entry cohorts may also differ at the start of the shakeout according to their time of entry, but over time firm hazard rates will decline and cohort hazard rates will converge. This is not what occurred in automobiles, suggesting that the shakeout was not triggered by a particular event but was a natural part of the evolution of the industry.

The fact that entry cohort rates diverged with age suggests that earlier entrants possessed a competitive advantage that did not dissipate as they and the other firms in the industry grew over time. There are not many factors that could account for this. Production scale economies eventually were prominent in the industry, but competitive advantages associated with production scale economies might be expected to diminish in importance as firms grow. Similar reasoning applies to learning by doing. The most obvious candidate driving the persistent advantage of the earlier entrants were the dramatic technological advances achieved in the industry, especially in the production process. Such advances required costly efforts, and the larger the firm then the greater the output over which it could amortize these efforts (cf. Klepper and Simons [1997]). Klepper [2000] finds that other industries that experienced extreme shakeouts, including tires, televisions, and penicillin, had similar firm survival patterns to automobiles, and these industries were also characterized by rapid rates of technological advance in both their products and production processes, similar to automobiles. Moreover, detailed analyses of firm survival and innovation suggested that in both tires and televisions early

¹⁷ In the analysis, firms like Chrysler are not counted as entrants but as continuations of other firms and thus do not influence the hazard rates of the later entry cohorts.

entrants and firms with greater related pre-entry experience were in the vanguard of innovation, and this was key to their greater longevity and superior performance (Klepper and Simons [2000a, 2000b]).

The superior performance of de novo entrants whose founders headed related firms or who worked for successful automobile firms suggests that firms critically drew their capabilities from the prior experiences of their founders (cf. Holbrook, Cohen, Hounshell, and Klepper [2000]). De novo entrants founded by individuals who headed related firms had very similar longevity to firms diversifying from the same industries, suggesting that having a preexisting organization with internal sources of capital was not per se the key advantage of firms diversifying from related industries. The persistent effect on the hazard of the pre-entry experiences of firms and their founders is noteworthy. Many theories could explain the superior initial performance of firms with distinctive types of pre-entry experience, but few could explain why pre-entry experience continued to affect firm hazards for many years. The findings suggest that having pre-entry experience in a related industry, including a successful incumbent firm, was virtually necessary to be a long-term, successful automobile producer. This is consistent with pre-entry experience imparting an initial advantage to firms via R&D and related efforts, which can have long-lasting effects in an industry characterized by increasing returns to firm size associated with R&D.

The extraordinary success of many of the spinoffs in the Detroit area and the connection between the performance of spinoffs and their parents suggests that successful incumbent firms can be powerful incubators of significant later entrants. The automobile industry was characterized by a kind of seeding process that later flowered in the form of many very successful firms, a great many of which were located in the Detroit area. Indeed, the concentration of the industry around Detroit seems to be largely attributable to this process and the chance location of four very successful entrants in the Detroit area, which fueled a kind of spinoff juggernaut. Such concentrations of firms are almost always associated with agglomeration economies that involve positive spillovers across firms, either directly through innovation or indirectly through such factors as specialized input markets. While the firms in the Detroit area on average performed better than those located elsewhere, this did not extend to the less experienced Detroit firms, of which

there were many. The benefits that accrued to Detroit firms appear to have come not so much through spillovers across firms but spillovers within firms, from the firms to their employees. It remains to be determined whether there were any advantages at all to being based in Detroit for the spinoffs or for any other type of firm.

The strong relationship between the performance of firms and the rate at which they spawned spinoffs and the performance of their spinoffs suggests an important continuity between new and old firms. The evolutionary metaphor of firms being born and inheriting characteristics from their parents seems apt to describe this process (Klepper [2001]). Little is known about this process, but judging from the automobile industry it can be a critical element of regional economic development. Other industries where the spinoff process also has been prominent include semiconductors (Brittain and Freeman [1986]), lasers (Klepper and Sleeper [2000]), and disk drives (Franco and Filson [2000]), all of which have helped fuel Silicon Valley. On the surface it would appear that spinoffs play an important role in regional economic growth, but exactly how this occurs and whether in fact spinoffs are socially beneficial is an unresolved question. If indeed spinoffs are an important element of the growth process, then the law on covenants not-to-compete and trade secrets may need to be shaped to harness spinoffs for the social good (cf. Hyde [2000], Klepper [2001]). Nations may even want to take steps to reduce any stigma associated with employees leaving to start their own firms and the inevitable failures that will result from more employee startups.

In many ways the model used to analyze the evolution of the automobile industry embodied many restrictive assumptions regarding firm behavior. Firms were assumed to use little discretion in where they located and when they entered, with the latter based largely on when they acquired the capabilities to enter. These capabilities were assumed to be based on the firms' pre-entry experiences and as such were heterogeneous and not easily duplicated by less experienced firms. Firms were assumed not to be able to grow quickly without incurring substantial costs and to make decisions based on near-term considerations. All told, these assumptions greatly circumscribed firm behavior, thereby simplifying the analysis of competition and making it possible to derive a number of distinctive predictions that guided the empirical analysis. Nelson and Winter [1982] pioneered this kind of modeling, and the detailed analysis of the origins of the automobile

firms and the evolution of the automobile industry illustrates the kind of insights it can generate.

Table 1: Hypotheses

1. Among entrants of each type and among all firms, the hazards of early and later entrants cannot be ordered at young ages, but at older ages the earlier entry cohorts will have lower hazards and the later entry cohorts will become extinct before the earlier entry cohorts.
2. Experienced firms, experienced entrepreneurs, and spinoffs will have lower hazards at every age than inexperienced entrants.
3. The better the learning environment of spinoffs and the more related to automobiles the industries in which experienced firms and entrepreneurs participated in, then the lower their hazards at every age.
4.
 - a.. The number of experienced firms and entrepreneurs that enter will decline over time
 - b. The ratio of spinoff entrants to spinoff plus inexperienced entrants will eventually rise as the industry evolves.
 - c. The quality of the parents of spinoff entrants, in terms of their learning environments, will improve over time.
5. Firms with better learning environments will spawn more spinoffs.
6.
 - a. The spinoffs of Detroit area firms will locate in the Detroit area and the spinoffs located in the Detroit area will have parents located in the Detroit area.
 - b. The percentage of entrants that are spinoffs will be higher in the Detroit area than elsewhere.
 - c. The quality of the learning environment will be greater for parents of spinoffs in the Detroit area than elsewhere.
 - d. Spinoffs located in the Detroit area will have lower hazards at every age than spinoffs located elsewhere.
 - e. A few early Detroit area entrants should rank high on the list of firms with the greatest number of spinoffs, and the most successful spinoffs in the Detroit area should be related, either directly or through their spinoffs, to these firms.
 - f. Inexperienced firms located in the Detroit area should have no lower hazards at every age than inexperienced firms located elsewhere.

Table 2: Number of Entrants by Background and Time of Entry

Period	Total	Experienced Firms	Experienced Entrepreneurs	Spinoffs	Inexperienced Firms
1895-1904	220	49	41	14	116
1905-1909	269	43	33	39	154
1910-1966	236	29	29	74	104

Table 3: Number of Experienced Firms (EF), Experienced Entrepreneurs (EE), and Spinoffs by Background and Time of Entry

Period	EF Bicy cle	EF Engi ne	EF Carr iage	EF Met Mfg	EF Oth er	EE Bicy cle	EE Engi ne	EE Carr iage	EE Met Mfg	EE Oth er	Spin Par. <10 Yrs	Spin Par. ≥ 10 Yrs
1895- 1904	11	8	4	15	11	14	3	4	9	11	9	5
1905- 1909	0	3	19	6	15	0	4	13	6	10	29	10
1910- 1966	0	0	11	2	16	0	3	10	3	13	30	44

Table 4: Entry Patterns By Region

Period	All Firms			Exp F&E			Spin offs			Inexp Firms		
	Det	Non Det	% Det	Det	Non Det	% Det	Det	Non Det	% Det	Det	Non Det	% Det
1895-1904	22	198	10	8	82	9	5	9	36	9	107	8
1905-1909	37	232	14	4	72	5	17	22	44	16	138	10
1910-1966	53	183	22	9	49	16	28	46	38	16	88	15
1910-1916	42	104	29	7	25	22	20	23	47	15	56	21
1917-1966	11	79	12	2	24	8	8	23	26	1	32	3
1895-1966	112	613	15	21	203	9	50	77	39	41	333	11

Table 5: Coefficient Estimates of the Hazard Model (Standard Errors in Parentheses)

<u>Variable</u>	<u>Coefficient Estimate</u>
Constant	-1.6371 (.1031) ***
C ₁ (Cohort 1)	-0.0268 (.1350)
C ₂ (Cohort 2)	-0.0065 (.1309)
Constant*t	-0.0661 (.0143) ***
C ₁ *t	-0.0903 (.0160) ***
C ₂ *t	-0.0271 (.0180)*
Exp. Firm	-0.2973 (.1710)**
Exp. Firm, bicycles et al.	-0.4594 (.2017)**
Exp. Entr.	-0.2990 (.1868)*
Exp. Entr., bicycles et al.	-0.5418 (.2198) ***
Yrs. Spin parent survival	-0.0070 (.0041)**
Spin parent sales leader	-1.3095 (.5805)**
Failing parent & Det.	-1.1852 (.6222)**
Founder eng./designer	-0.4731 (.1760) ***
Spinoff in Det. area	-0.5889 (.2339) ***
Inexp. Firm in Det.	0.2167 (.1692)*

*** significant at the .01 level (one-tailed)

** significant at the .05 level (one-tailed)

* significant at the .10 level (one-tailed)

Table 6: Coefficient Estimates of the Logit Model (Standard Errors in Parentheses)

<u>Variable</u>	<u>Coefficient Estimate</u>
Constant	5.0671(.3318) ***
Dummy—not producing	-1.9221 (.4402) ***
Dummy--≤5yrs.notprod.	1.3908 (.4230) ***
Yrs. Prod. if producer	0.0143 (.0239)
Nonspin. entry rate	2.0889 (1.0747) **
Yrs. survived	0.0227 (.0058) ***
Sales leader	0.5755 (.3319)**
Detroit area	0.9115 (.2298)***

*** significant at the .01 level (one-tailed)

** significant at the .05 level (one-tailed)

* significant at the .10 level (one-tailed)

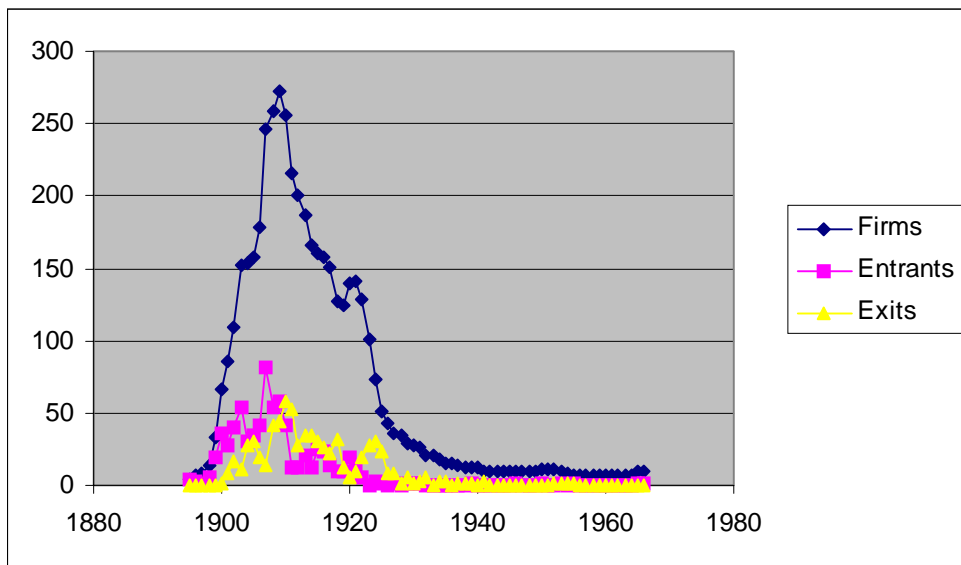
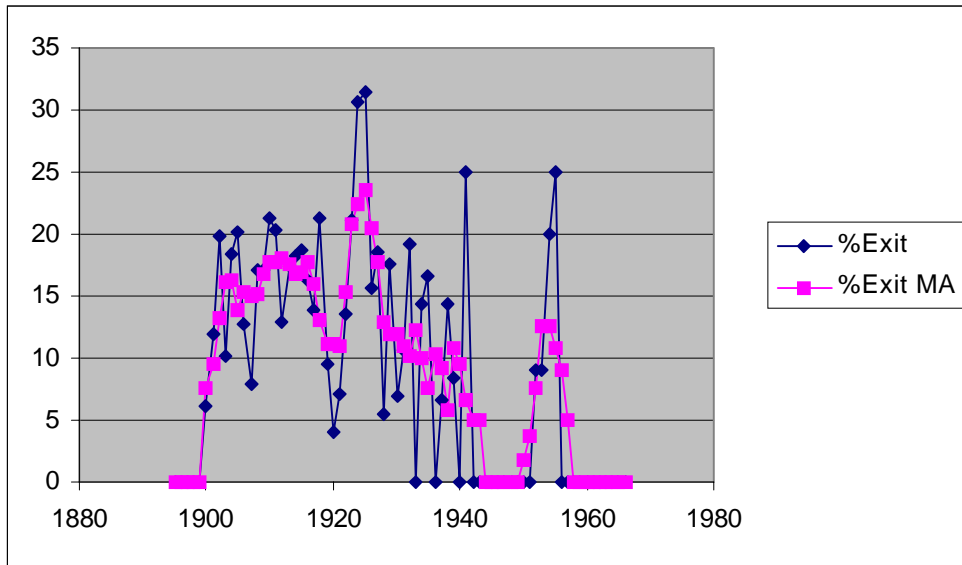


Figure 1: Entry, Exit, and Number of Firms

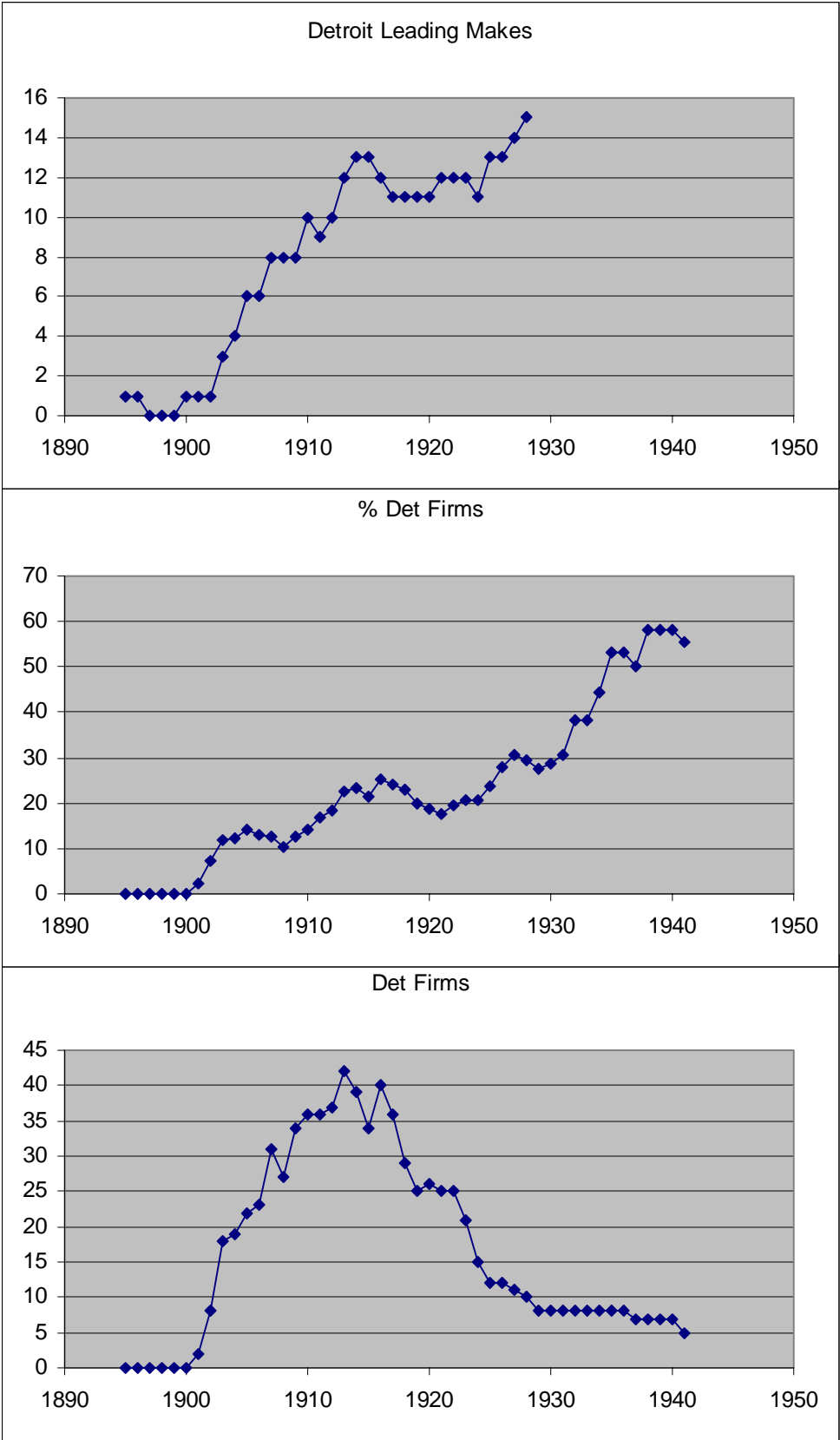


Figure 2: Location of Firms Around Detroit

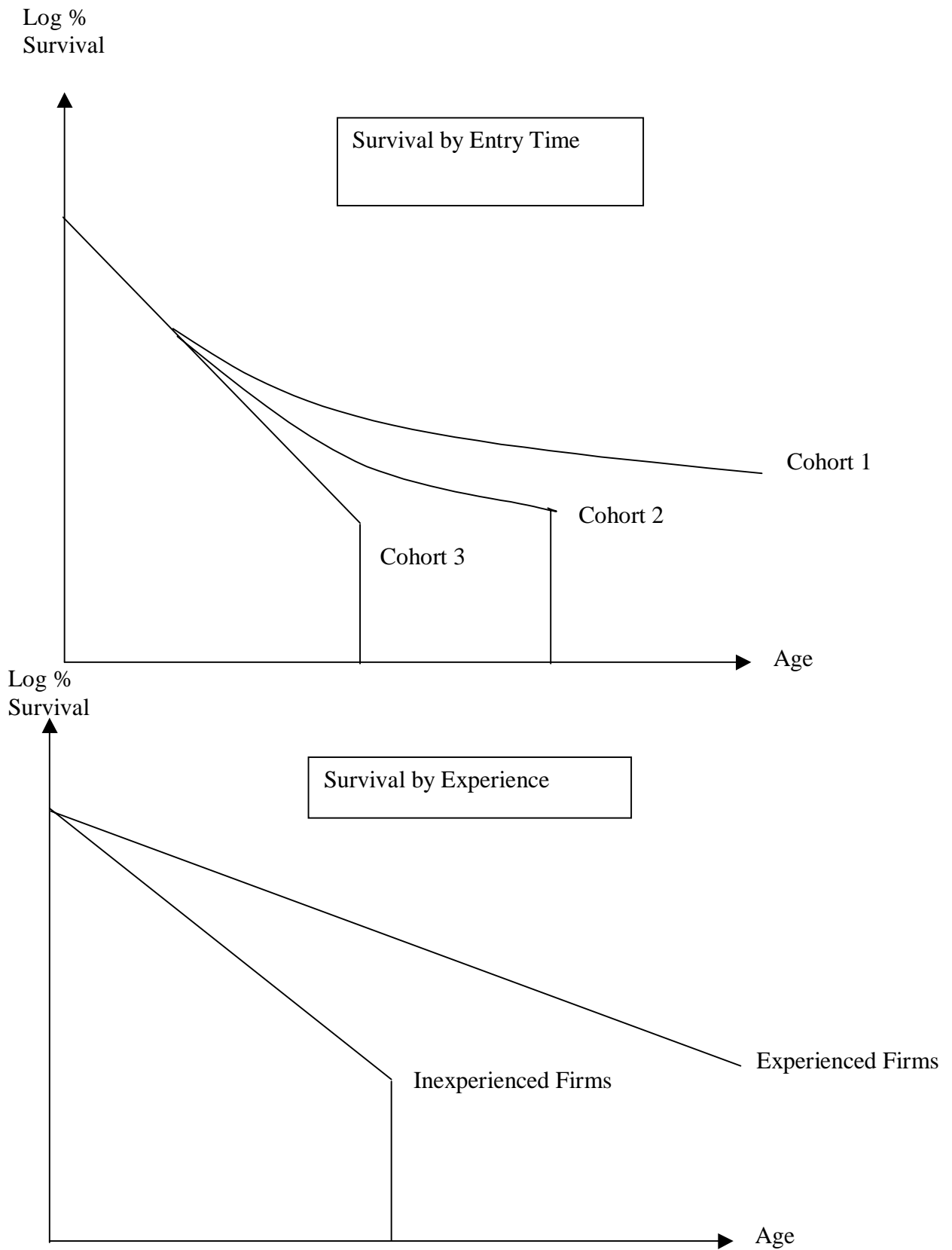


Figure 3: Survival Graphs

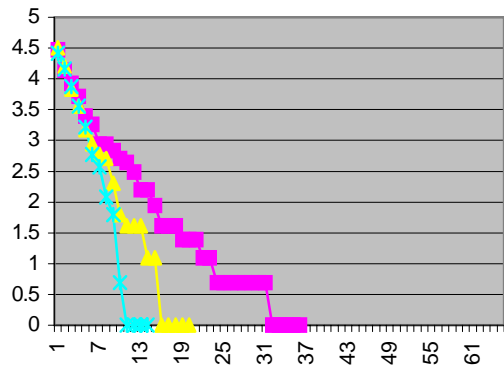
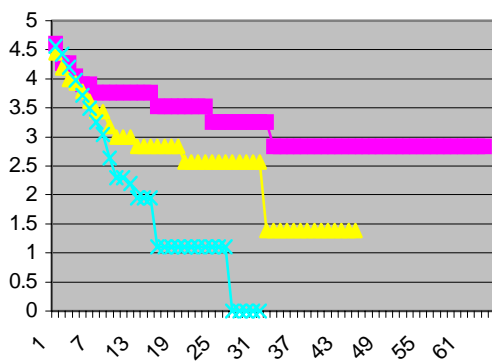
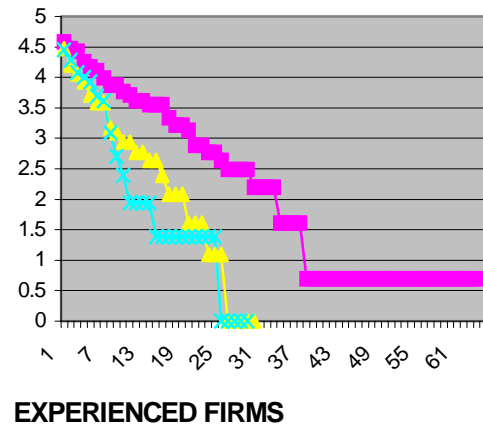
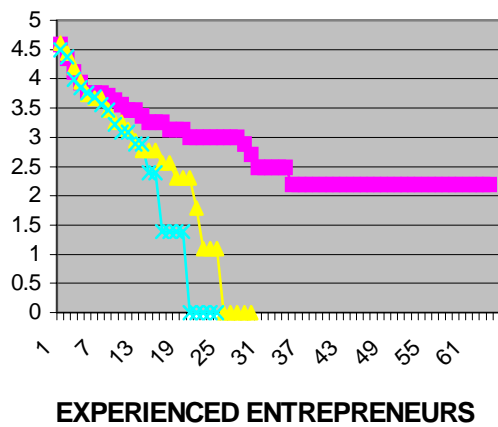
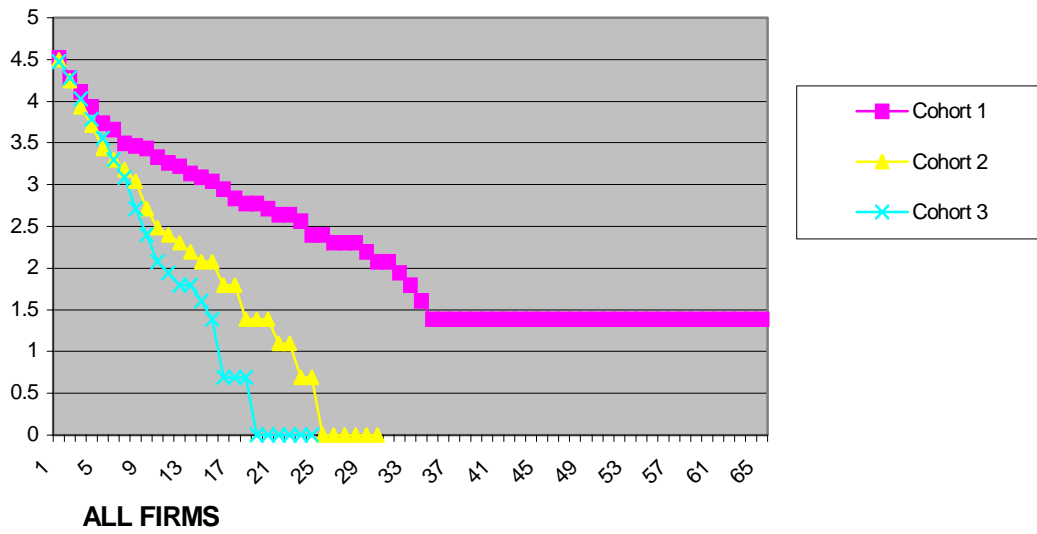
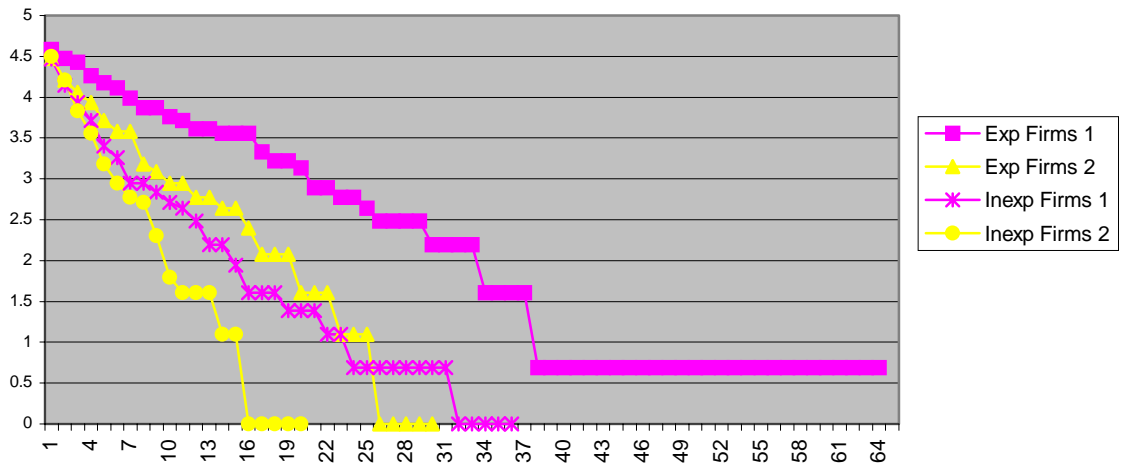
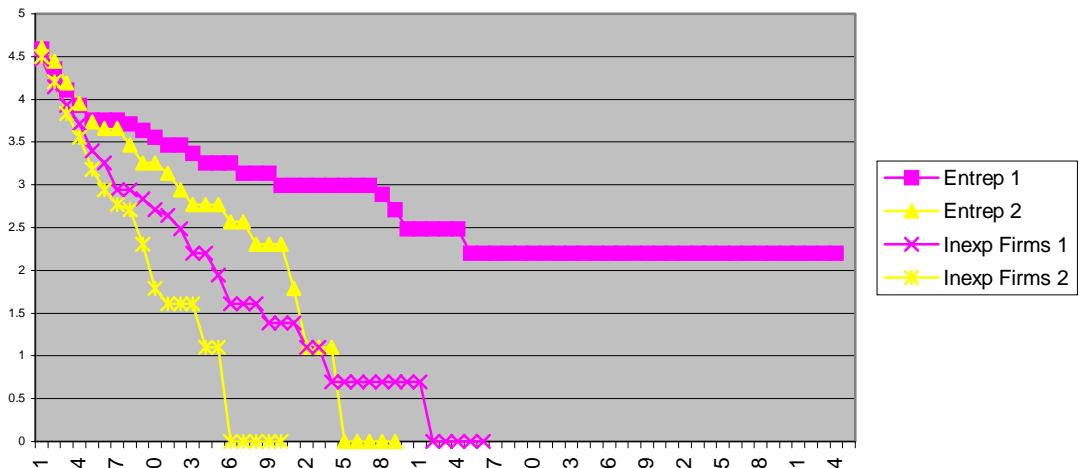


Figure 4: Survival Curves by Time of Entry



EXPERIENCED FIRMS VS. INEXPERIENCED FIRMS



EXPERIENCED ENTREPRENEURS VS. INEXPERIENCED FIRMS

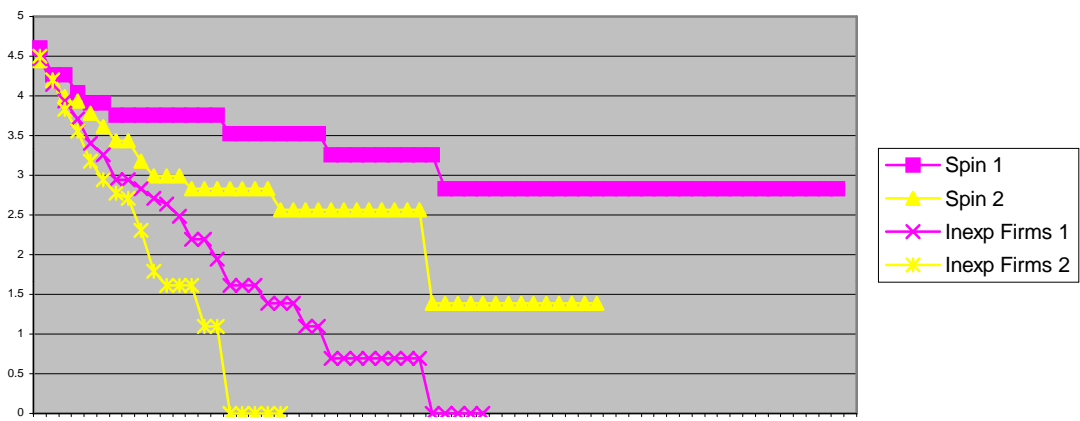


Figure 5: Survival Curves of Inexperienced Firms vs. the Other Three Groups of Firms

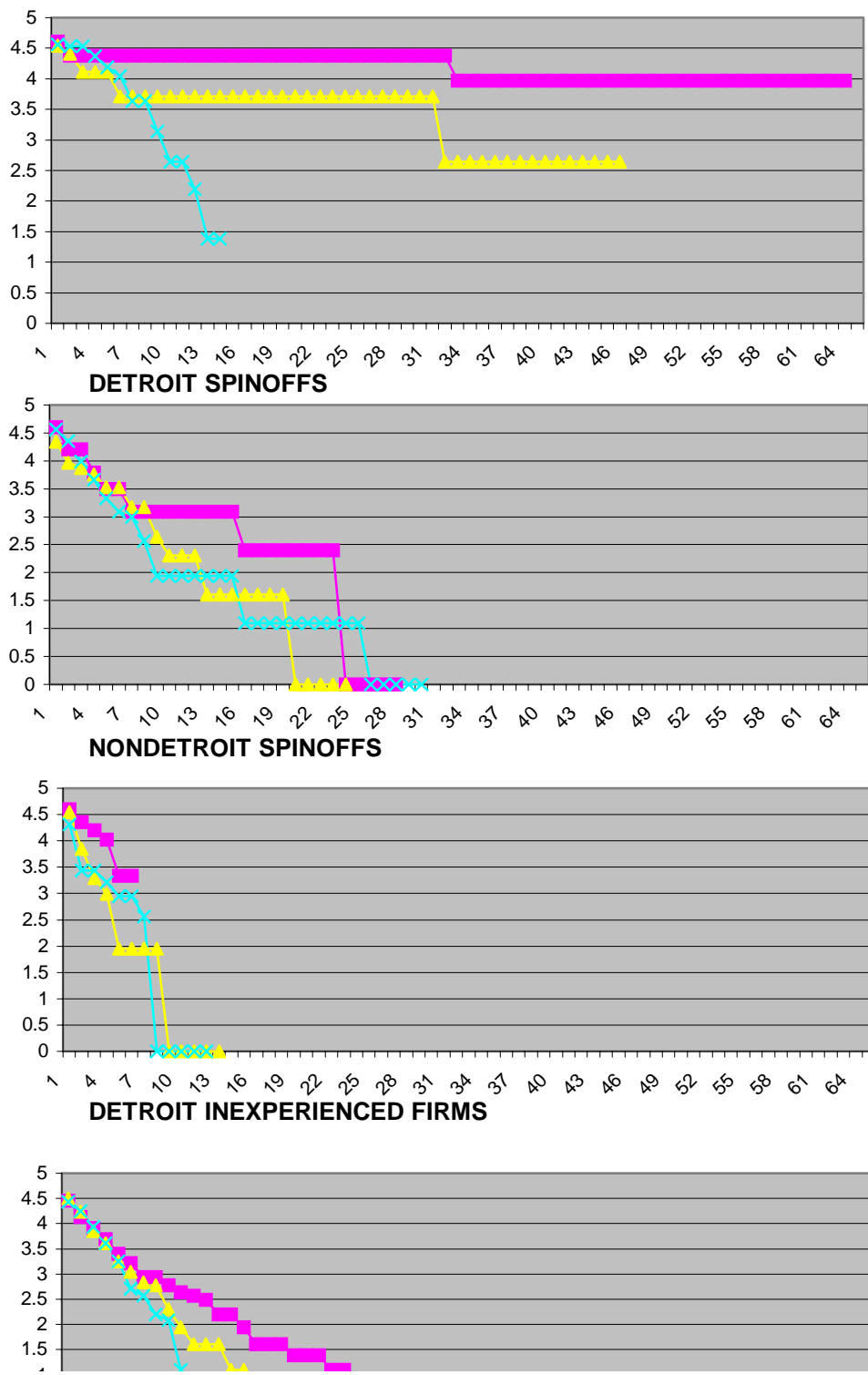


Figure 6: Survival Curves of Detroit and Non-Detroit Spinoffs and Inexperienced Firms

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