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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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# The Evolution of the U.S. Automobile Industry and Detroit as its Capital

Steven Klepper

## I. Introduction

Between 1900 and 1930, Detroit experienced nearly unparalleled growth for a large city, growing six-fold from a population of 305,000 to 1,837,000. There was no secret formula behind this growth. It was fueled by the concentration around Detroit of the automobile industry, which by 1929 was the largest industry in the U.S. (Davis [1988, p. ix]). The industry was not initially concentrated around Detroit, with numerous firms entering through the eastern seaboard and the midwest. By 1909, when there were well over 200 producers, Detroit was a leading automobile center, but it was in the subsequent era that Detroit rose to preeminence. After 1909 the number of firms in the industry fell sharply and within ten years most of the leading makes of automobiles were produced by Detroit-area firms, with the industry evolving to be an oligopoly dominated by three famous Detroit firms, General Motors, Ford, and Chrysler.

While industries are typically agglomerated geographically, it is rare for industries to be as concentrated around one region as automobiles (Ellison and Glaeser [1997]). Unraveling the causes of the extreme shakeout and concentration of the auto industry around Detroit thus promises to shed light on one of the driving questions of the burgeoning literature on economic geography, namely what forces contribute to the agglomeration of industrial activity. Numerous explanations have been advanced for the concentration of the automobile industry around Detroit. Some emphasize Detroit's low-cost access by water to raw materials and major markets for autos and Detroit's many small machine shops and skilled laborers available to supply the industry (Rae [1980]). Coupled with increasing returns to scale, which is not much of a leap given the oligopolistic structure that emerged in the industry, one has the main ingredients of Krugman et al.'s (Krugman [1991], Futia, Krugman, and Venables [1999]) theory of agglomeration. Other explanations emphasize factors making Detroit's initial entrants especially capable competitors. Coupled with positive externalities associated with knowledge spillovers and more developed input markets (Tsai [1997], Rae [1980]), one has the main ingredients of agglomeration theories featuring externalities and path-

dependent processes (Arthur [1988]). Indeed, the auto industry has been a kind of litmus test of competing theories of agglomeration, but no consensus has emerged for the concentration of the industry around Detroit, reflecting deficiencies in all the proffered explanations (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. Using data on the location and years of production of every manufacturer of automobiles from 1895 to 1966 and on the annual production leaders, the evolution of the market structure and the concentration of the industry around Detroit is traced. Brief information on the origin of each entrant into the industry is also 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 version of the model of industry evolution developed in Klepper [1996, 2001b] is used to structure the analysis of the data. 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 and the many firms they spawned. 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, 2001b], 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 commercially<sup>1</sup> 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 commercial 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 15 firms entering from 1923 through 1966. After the first few years, the industry exit rate exceeded 10% for many years, and by 1910 the number of exits overtook the number of entries. Except for the two-year period 1919-1921, the number

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<sup>1</sup> Various lists of automobile producers have been compiled. The most inclusive is a list compiled by Carroll and Hannan [1995] from the *Standard Catalog of American Cars*, which attempts to list all firms ever mentioned as involved in the automobile industry. Smith [1968, pp. 183-184] confines his list to firms that manufactured and sold to the general public. He excludes the few companies that built and exhibited cars for the sole purpose of selling stock, the hundreds of companies that filed for incorporation but failed to advance beyond the paper stage, and the hundreds more that designed a car but never got into production. He also excludes firms that produced racing cars, taxicabs, and cycle cars. Although the compilations of Smith and Carroll and Hannan differ in terms of the number of producers, they have similar time patterns in terms of entry, exit, and the number of producers. Except for Epstein [1928], who

of firms fell steadily from 1909 to 1941, dropping from a peak of 272 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 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 Co., which dated back to 1906. 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 located in the Detroit area<sup>2</sup> 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, 1895-1900, there were 69 entrants. Packard Motor Car Co. (nee Ohio Auto Co.) entered in 1900 and moved to Detroit in 1903, but otherwise no manufacturer was located in Detroit until 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

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compiled a very selected list, most other lists exhibit similar time trends (cf. Klepper and Simons [1997, pp. 387-388]).

<sup>2</sup> 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. While most firms located in the Detroit area maintained this location over their entire period of automobile production, 11 firms moved into or out of the Detroit area. In the econometric analysis, the location of these firms was allowed to vary on annual basis, but in all compilations the 11 firms were assigned a single location based on where they were located for a majority of their years of automobile production.

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 15% by 1905, then fell back some in the next four years after which it increased to 24% by 1916. It subsequently fell back again in the next eight years or so, after which it climbed to over 50% by 1935.

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 through 1915, 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,<sup>3</sup> and the Detroit-area firms continued to dominate the industry for the next 45 years.

### **III. Model of Industry Evolution**

The model is the same as in Klepper [2001b], with a few extensions. It is first specified, and then its implications for the evolution of industry market structure are discussed.

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<sup>3</sup> Even these figures understate the dominance of Detroit, with two of the three other prominent non-Detroit firms having links to Detroit. One, Studebaker, entered initially by marketing the cars of a Detroit

## A. Specification of the Model

The model contains many simplifications and stylizations designed to isolate the role of R&D, where R&D encompasses all efforts devoted by firms to improving their technology. The model is specified in terms of discrete time intervals, where period 1 denotes the start of the industry. In each period, it is assumed that new opportunities for technological improvements arise, and incumbent firms conduct R&D to lower their average cost.<sup>4</sup> 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. For simplicity, unit transportation costs, which are embodied in  $c_t$ , are assumed not to vary across firms or units of output, reflecting the national character of the automobile industry. 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,  $\varepsilon_{it}$  is a random cost shock that causes the firm's average cost to exceed its minimum 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  $\Delta q_{it}$  is the

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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.

<sup>4</sup> 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.

growth in the firm's output and  $m'(\Delta q_{it}) \geq 0$  and  $m''(\Delta q_{it}) \geq 0$  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.<sup>5</sup> For simplicity, it is assumed that the industry demand curve is fixed over time and all firms are price takers, so that in each period the price  $p_t$  clears the market.<sup>6</sup>

Firms in the industry in period  $t$  choose  $r_{it}$  and  $\Delta q_{it}$  to maximize  $\Pi_{it}$ , their profits in period  $t$  before the realization of the cost shock  $\varepsilon_{it}$ :

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

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  $\Delta q_{it}$ .

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 denovo firms composed primarily of firms founded by capitalists and firms founded by lower-level employees in related industries. Let  $a_{\max}$  denote the maximum R&D productivity of any firm. It is assumed that some experienced firms, experienced entrepreneurs, and spinoffs attain  $a_{\max}$ , but all the inexperienced firms lack the pre-entry experience needed to attain  $a_{\max}$ . The inexperienced firms are also assumed to have a less favorable distribution of R&D productivities than the other three

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<sup>5</sup> Entrants in period  $t$  have no output prior to entry and thus enter at size  $\Delta q_{it}$ .

<sup>6</sup> Firms are also assumed to be sufficiently small that the exit of any one firm does not appreciably affect the total quantity supplied by all firms.

types of firms. This is specified as follows. Experienced firms, experienced entrepreneurs, and spinoff potential entrants are assumed to have the same distribution of R&D productivities, denoted as  $F(a)$ . The distribution of R&D productivities for the inexperienced firms,  $G(a)$ , is such that  $(F(a)-F(p))/(1-F(p)) < (G(a)-G(p))/(1-G(p))$  for all  $p \leq a < a_{\max}$ , which insures that for any cutoff  $p$ , the truncated distribution of R&D productivity above  $p$  for the experienced firms, experienced entrepreneurs, and spinoffs stochastically dominates that of the inexperienced firms.<sup>7</sup> Each firm is assumed to know 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 firms and experienced 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, knowledge, and risk preferences start spinoffs. It is assumed that better-performing firms have superior learning environments, which leads them to spawn more spinoffs and spinoffs with higher R&D productivity. For simplicity, it is assumed that as the industry expands and more employees are hired, the number of potential spinoff entrants rises proportionally. The fourth category is composed primarily of two types of firms. One type is founded by capitalists, who typically hire experienced employees of incumbents to direct their firms. It is assumed that the number of these potential entrants increases in proportion to the

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<sup>7</sup> Letting  $p=0$ , this implies  $F(a) < G(a)$ , which is the standard condition for stochastic dominance. If only R&D productivities above  $p$  are considered, the respective truncated distributions are  $(F(a)-F(p))/(1-F(p))$

number of employees in the industry, comparable to potential spinoff entrants. The other type of inexperienced firm is founded by lower-level employees in related industries. Comparable to the first two types of potential entrants, their number is assumed to decline over time as the ranks of employees in related industries willing and able to start their own firms gets depleted over time. Based on the time trends in these two types of potential entrants, the percentage growth in the number of potential inexperienced entrants should be less than the growth rate of the spinoff potential entrants but greater than the growth rates of the first two types of potential entrants.

## **B. Evolution of Market Structure**

Klepper [2001b] derives a number of results that apply directly to the proposed 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 is assumed to cause 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.

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and  $(G(a)-G(p))/(1-G(p))$ , so the assumed condition is the analogous condition for stochastic dominance for

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, 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. Furthermore, 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 based on comparable predictions established in Klepper [2001b].

##### **A. Firm Survival**

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the truncated distributions.

The survival rates of firms will be examined empirically based on their time of entry and background. The model provides some intuition regarding how both factors affect survival rates.

Consider first two cohorts of entrants that entered at different times. Suppose the entrants in each cohort had the same distribution of R&D productivities. At each age, the earlier entrants would face a higher industry price-cost margin than the later entrants. Thus, if two entrants had the same R&D productivity, at every age the earlier entrant would do more R&D and grow more. Hence it would have a higher profit margin and thus a lower hazard because it would take a greater cost shock to induce it to exit than the later entrant. Therefore, if the early and late entry cohorts had the same distribution of R&D productivities, the earlier entry cohort would have a lower hazard and higher survival rate at every age. However, the two entry cohorts will not have the same distribution of R&D productivities—the composition of potential entrants changes over time, and more importantly, the minimum R&D productivity needed for profitable entry is greater for the later entry cohort. Consequently, the earlier entry cohort will have a set of lower R&D productivity firms with no counterpart in the later entry cohort. These firms will pull up the initial hazard of the early entry cohort and could conceivably cause the hazard of the early entry cohort at young ages not to be less than that of the later entry cohort. Over time, the lowest productivity firms from each cohort would be expected to exit first, causing the R&D productivities of the firms in each cohort to converge toward  $a_{\max}$ . The early entrants with R&D productivity of  $a_{\max}$  will have the lowest hazards of all firms. Consequently, as the R&D productivities of the early and late entry cohorts converge toward  $a_{\max}$ , the earlier entrants would be expected eventually to have lower hazards and higher survival rates, with the later entry cohort expected to become extinct first.

Thus, the model admits the possibility of the earlier entrants not having lower hazards and higher survival rates at young ages, but eventually having lower hazards and higher survival rates at older ages. This possibility is listed 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 are represented. The survival curves represent the percentage of firms surviving to each age. The vertical axis in each graph is

scaled logarithmically so that the negative of the slope of each curve indicates the hazard of the firms 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. Eventually the earlier entry cohorts have lower hazards, with the first cohort having the lowest hazards at older 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 patterns are distinctive. Many theories attribute shakeouts to a particular event, such as an innovation or an information cascade (Utterback and Suárez [1993], Jovanovic and MacDonald [1994], Horvath, Schivardi, and Woywode [2001]). Such theories imply that early entrants have a lower hazard at young but not older ages (Klepper and Simons [2001]), which is the opposite of the illustrated pattern.

The model also has distinctive implications regarding how survival rates differ across firms with different backgrounds. Among firms that entered at the same time, the assumptions regarding the R&D productivity distributions of the four types of firms imply that inexperienced firms will have lower average R&D productivities at every age than the other three firm types. Consequently, in each entry cohort, the inexperienced firms will have higher hazards at every age than the other three types of firms. This is summarized as hypothesis 2 in Table 1 and is illustrated in the bottom panel of Figure 3 for inexperienced and experienced firms for the arbitrary case of constant hazards. Hypothesis 2 is also distinctive. Many theories can accommodate more experienced firms having higher hazards than inexperienced firms at young ages, but their logic generally implies that such differences decline with age (Klepper [2001b]).<sup>8</sup>

Hypotheses 1 and 2 are stated in terms of the four classes of entrants that are distinguished. Finer gradations of the spinoffs and the experienced firms and experienced entrepreneurs will be introduced in the empirical analysis. The model

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<sup>8</sup> 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 toward a common value as firms age, then at any given age firms that entered with a greater R&D productivity would still be larger. Therefore, they would conduct more R&D and hence 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.

assumes that spinoffs from better-performing firms will have higher R&D productivities, hence the hazard of spinoffs at every age should be a decreasing function of the performance of their parents. The premise behind experienced firms and experienced 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**

Over time, the minimum R&D productivity required for profitable entry rises, which causes the fraction of each type of potential entrant that enters the industry to fall. This fraction will be equal for the experienced firms, experienced entrepreneurs, and spinoff potential entrants since they have the same R&D productivity distribution. But the number of potential spinoff entrants was assumed to rise over time while the number of potential experienced firm and experienced entrepreneur entrants was assumed to decline over time. Consequently, the ratio of spinoffs to experienced firm and experienced entrepreneur entrants should rise over time. Alternatively, the fraction of potential entrants that enter must always be less for the inexperienced firms than the other three types of firms and must go to zero before the other three types of firms. Consequently, eventually the ratio of spinoff entrants, experienced firm entrants, and experienced entrepreneur entrants relative to inexperienced entrants should rise. It was assumed that the R&D productivity of spinoff entrants was related to the performance of their parents. Consequently, with the minimum R&D productivity required for profitable entry rising over time, the model implies that over time the performance of the parents of spinoff entrants should improve. At any point in time, the model also implies (by assumption) that better-performing firms will spawn more spinoffs. These predictions are summarized as hypotheses 4a-4d in Table 1. Hypotheses 4b and 4c concerning the eventual relative decline in the number of inexperienced entrants and the improvement in the performance of the parents of spinoff entrants are distinctive; they follow only if potential entrants know their R&D productivity prior to entry, whereas many theories

assume that entrants can learn about their capabilities only by entering (e.g., Jovanovic [1982], Horvath et al. [2001]).

### **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 were distinctively successful.

The model implies that the early entrants will be 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. Since the inexperienced firms are not expected to be as successful as the spinoff entrants, it would then have to be the spinoff entrants that fueled the growing concentration of activity in the Detroit area if the model is to explain this pattern. This could occur if the earliest entrants in the Detroit area were unusually successful. According to the model, better-performing firms will have more and better spinoffs, and spinoffs will generally locate close to their parents. Hence if the earliest entrants in the Detroit area were unusually successful, this could start a cascading spinoff process in the Detroit area contributing to a growing concentration of the industry around Detroit.

This explanation is dependent on a number of assumptions and has a number of testable implications. First, if spinoffs locate close to their parents, then spinoffs of Detroit-area firms should generally have located in the Detroit area and spinoffs located in the Detroit area should generally have had parents located in the Detroit area. Second, if a few unusually successful early entrants fueled a cascading spinoff process, then the percentage of entrants that were spinoffs should have been higher in the Detroit area than elsewhere. Third, if better-performing firms spawn better-performing spinoffs, then the parents of Detroit-area spinoffs should have performed better than the parents of spinoffs elsewhere. Fourth, if a few unusually successful early entrants in the Detroit area spawned a cascading spinoff process, then it should be possible to directly and indirectly trace back many of the spinoffs in the Detroit area to a few very successful early entrants. Fifth, relatedly the spinoffs in the Detroit area should have had lower hazards of exit at every age than the spinoffs elsewhere. Sixth, the model assumes that better-performing

firms spawn better-performing spinoffs because the founders of the spinoffs learn from their parents. Learning is assumed to occur only between a firm and its spinoffs, and no benefits are assumed to accrue to any other firms. Moreover, there are no other mechanisms hypothesized in the model that would allow firms to learn from or benefit from other firms. Therefore, inexperienced entrants that located in the Detroit area would not share in any of the benefits experienced by the spinoffs because of the absence of any kind of agglomeration economy in the model. This implies that in contrast to the spinoff entrants, inexperienced entrants located in the Detroit area should not have had lower hazards than inexperienced entrants located elsewhere. These predictions are summarized as hypothesess 5a-5f in Table 1.

## **V. General Patterns**

To test the various predictions, the firms are divided according to their time of entry and prior experience. To probe the importance of time of entry, firms are grouped into three entry cohorts. Each cohort is constrained to span at least five years, and the cohorts are defined to have comparable numbers of firms. The first cohort contains the 219 firms that entered from 1895 to 1904, the second cohort includes the 271 firms that entered between 1905 and 1909, and the third cohort contains the remaining 235 firms that entered between 1910 and 1966. Firms that were reorganized or acquired by nonautomobile producers were treated as 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.<sup>9</sup> 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 primarily on Smith [1968] and the brief histories of the firms in the *Standard Catalog of American*

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<sup>9</sup> These standards were generally straightforward to implement. The principal exception concerned Chrysler Corporation. Chrysler evolved out of Maxwell Motor Co. and Chalmers Motor Co. when Walter Chrysler, formerly the president of Buick, was called in to reorganize Maxwell, which had recently merged with Chalmers. Maxwell was descended from Maxwell-Briscoe, which was a very successful 1904 entrant that was the centerpiece of the unsuccessful 1910 United States Motor Co. merger organized by one of the founders of Maxwell-Briscoe. Maxwell emerged from the ruins of United States Motor Co., regaining a leading position in the industry until it floundered before Walter Chrysler was brought in to reorganize it. Accordingly, Chrysler Corporation was treated as the lineal descendant of Maxwell-Briscoe.

*Automobiles* (Kimes [1996]), which contains an entry for every make of automobile on Smith's list.<sup>10</sup> Smith categorized firms according to whether they entered automobiles from another business. Those that did were classified in the category of experienced firms. Twenty-five 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,<sup>11</sup> yielding a total of 120 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.<sup>12</sup> This yielded a total of 108 experienced entrepreneurs. The *Standard Catalog* was used to identify the main prior 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 145 spinoffs.<sup>13</sup> The latest firm worked for by the founder was designated as the parent of the spinoff and prior firms worked by the founder were designated as secondary parents.<sup>14</sup> In about 30% of the spinoffs, the motivation for

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<sup>10</sup> Also consulted were the compilations of Detroit firms in Szudarek [1996] and world-wide producers in Baldwin et al. [1987] and the histories of Ransom Olds' automobile ventures (May [1977]) and the Franklin Automobile Company (Powell [1999]).

<sup>11</sup> Only firms that produced automobiles and earlier products under (exactly) the same name were included in this category.

<sup>12</sup> It was sometimes difficult to distinguish firms in this category from experienced firms because some firms entered with names very similar to, but not exactly the same, as preexisting firms in related industries. Some of these cases represent instances when the head/leading stockholder of a preexisting firm could not convince the other stockholders to enter autos, in which case a new firm with the same head and similar stockholders was formed to enter autos. Whenever there was any uncertainty about such cases, they were classified as experienced entrepreneurs rather than experienced firms, no doubt blurring the distinction between these two categories. Furthermore, some of the firms Smith classified as preexisting producers were suspicious based on their descriptions in the *Standard Catalog*, which may have further blurred the distinction between these two firm categories.

<sup>13</sup> 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. In a few instances it appeared that an incumbent firm sponsored a separate entrant. These firms, which tended to be short-lived, were also classified as spinoffs.

<sup>14</sup> 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, with the prior employers of the other founders classified as secondary parents.

the spinoff could be discerned from the firm's description in the *Standard Catalog* and the circumstances of the firm's founding, and this was recorded. The 352 firms that were not classified as experienced firms, experienced entrepreneurs, or spinoffs were included in the residual category of inexperienced firms.<sup>15</sup>

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 percentage 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.<sup>16</sup> 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%.<sup>17</sup> 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. With the exception of the intertwining of the survival curves of the last two cohorts of experienced firm entrants, the graphs for each type of entrant are similar.

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<sup>15</sup> Some of the candidates for this category were also difficult to classify. Some firms produced engines or trucks for a few years or less before autos, and it was difficult to tell if these firms were started with the purpose of producing autos or whether they should be classified as experienced firms. Apart from the few instances where the *Standard Catalog* indicated the firm was started to produce engines or trucks and not autos, these firms were classified as inexperienced entrants. It was also difficult to classify firms that had financiers with lengthy business histories. Unless the financiers appeared to have been instrumental in the formation of the firm, they were not considered to have been founders and their firms were classified as inexperienced firms. Some firms had founders that were noted as owning an unnamed machine shop, repair shop, or similar kind of business. Apart from a few instances in which it was clear the prior business was substantial, these firms were classified as inexperienced entrants because their generic businesses were not considered sufficiently significant to warrant their classification as experienced entrepreneurs. Last, for some firms no information was provided about their founders or only their initial officers were listed with little information provided about their backgrounds. These firms were all classified as inexperienced firms, but no doubt some of them deserved to be in one of the other categories.

<sup>16</sup> 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  $x$ .

The survival curves of the three entry cohorts overlap at young ages and tend to diverge at older ages according to the time of entry. Thus, as the industry evolved, the hazard rates of the various types of entrants tended to diverge based on their 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 inexperienced firms also tend to 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 in hypotheses 4a-4c concerning the composition of entrants is evaluated using Table 2, which breaks down the entrants in each cohort by

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<sup>17</sup> If the last firm in a cohort exited by being acquired and the survival rate to that age exceeded 1%, the

background. Table 2 also reports various ratios regarding the number of entrants of each type, with experienced firms and experienced entrepreneurs combined into one category due to their similar entry patterns over time. Regarding hypothesis 4a, the ratio of spinoffs to the sum of experienced firms and experienced entrepreneurs rises over the three entry cohorts, as predicted. Regarding hypothesis 4b, the ratio of spinoffs to inexperienced firms rises over the three entry cohorts while the ratio of the sum of experienced firms and experienced entrepreneurs to inexperienced firms falls from cohort 1 to cohort 2 and then rises to cohort 3. Thus, consistent with hypothesis 4b, eventually both ratios rise. To test hypothesis 4c regarding the performance of the parents of spinoff entrants, the total years of production of parents was used as a measure of their performance. Parents were crudely divided according to whether they produced for ten years or more, with parents that were acquired within ten years of entry excluded from the comparison. The percentage of parents that produced ten or more years was 50% (5 of 10) for the parents of spinoffs in cohort 1, 37% (13 of 35) for the parents of spinoffs in cohort 2, and 62% (46 of 75) for the parents of spinoffs in cohort 3. Although the percentage of parents that produced for ten or more years initially dropped from cohort 1 to cohort 2, once entry became more difficult after 1909 the percentage of parents that produced for ten or more years increased markedly and was higher in cohort 3 than in either of the two earlier entry cohorts, consistent with hypothesis 4c. Hypothesis 4d concerning the incidence of spinoffs across firms is tested econometrically in the next section.

The last set of predictions in hypothesis 5 pertain to the concentration of the industry around Detroit. Hypothesis 5a 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. Fifty-four spinoffs located initially in the Detroit area, and 50 of them had parents located in the Detroit area. Eleven spinoffs with parents in the Detroit area located elsewhere, so 50 of the 61 spinoffs with parents in the Detroit area located there.<sup>18</sup> Thus, spinoffs with parents in the Detroit did not locate

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cohort survival graph ends at the age of the acquired firm but does not drop to the horizontal axis.

<sup>18</sup> One of the 11 spinoffs that did not initially locate in the Detroit area moved there soon after its founding, and two of the others were founded in their home cities by sales agents based outside of the Detroit area.

far from their parents, and few spinoffs without parents in the Detroit area located there, as conjectured.<sup>19</sup>

Hypothesis 5b predicts there would be a disproportionate number of spinoffs in the Detroit area. In total, 15% of the entrants located in the Detroit area. The Detroit area was actually underrepresented in terms of experienced firms, experienced entrepreneurs, and inexperienced firms. Only 9% of the experienced firms and experienced entrepreneurs and 11% of the inexperienced firms located in the Detroit area. What distinguished the Detroit area was spinoffs, with 37% of all spinoffs entering in the Detroit area. More spinoffs entered in the Detroit area than any other type of entrant, accounting for 48% of the firms located in the Detroit area versus only 15% of the firms located elsewhere. Thus, apart from the spinoffs, the Detroit area did not attract a large number of entrants into the industry.

Hypothesis 5c predicts that spinoffs in the Detroit area would have better-performing parents than spinoffs elsewhere. Parents were again compared according to whether they produced for ten or more years. Among parents that were not acquired within ten years of entry, the percentage of parents that produced ten or more years was 66% (25 of 38) for the parents of the Detroit-area spinoffs and 48% (39 of 82) for the parents of the spinoffs elsewhere. Thus, consistent with hypothesis 5c, the spinoffs in the Detroit area came from longer-lived parents.

Hypothesis 5d predicts that it should be possible to trace a large number of spinoffs in the Detroit area to a few very successful early entrants in the Detroit area. This is evaluated using Table 3, which identifies the five firms with the most spinoffs and reports information about the firms and their spinoffs. The first four firms, Olds, Buick/General Motors, Cadillac, and Ford, were all early entrants that located in the Detroit area. The fifth firm, Maxwell-Briscoe, which was a spinoff descended from Olds, did not initially enter in the Detroit area but moved there later, where it spawned all but

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<sup>19</sup> The other 80 spinoffs (which did not have parents in the Detroit area and located outside of the Detroit area) also tended to locate close to their parents. Sixty of them, or 75%, located within a 100 miles of where they were working. Some of the other 20 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.

one of its spinoffs. Olds, Buick, Cadillac, and Ford quickly reached the ranks of the production leaders of the industry, attaining the number one or two rank within five years of entry. Given the paucity of experienced firms and experienced entrepreneurs, the Detroit area was an extremely unlikely place for the entry of four such successful firms. But they were led by extremely able men, three of whom had headed engine and carriage firms in the Detroit area before the industry began in 1895. The four firms collectively spawned 22 spinoffs, and 19 additional firms descended from these 22 spinoffs, for a total of 41 descendants. Their descendants were extremely successful, accounting for all but two of the subsequent twelve entrants in the Detroit area that made it into the ranks of the production leaders. Their descendants also played an important role, as acquisitions, in the success of General Motors, Ford, and Chrysler.<sup>20</sup> Even the three principal industry leaders outside the Detroit area were influenced by employees of the four firms.<sup>21</sup> Thus, not only were most of the leading firms in the Detroit area descended from Olds, Buick/General Motors, Cadillac, and Ford, but in one way or another employees of the four firms influenced nearly all the leading firms in the industry.

The remaining two parts of hypothesis 5, parts e 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

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<sup>20</sup> General Motors acquired Chevrolet, itself a spinoff from General Motors, which it used to displace Ford as the industry leader. Ford acquired Lincoln, another General Motors spinoff, which provided it with a high quality line. Three of the descendants, Maxwell-Briscoe (in the form of its successor, Maxwell Motors), Chalmers, and Dodge, formed the core of Chrysler.

<sup>21</sup> The three main industry leaders outside the Detroit area were Studebaker, Nash Motors Co., and Willys-Overland Co. Studebaker was a leading carriage producer. It rose to prominence in the automobile industry by acquiring E-M-F, a Detroit firm that which was descended from an Olds spinoff and was cofounded by two prior employees of Ford and Cadillac. Charles Nash, the head of Nash Motors, was the president of General Motors before acquiring Thomas B. Jeffrey & Co., the producer of the Rambler, and

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 inexperienced firms to survive to older ages suggests that at some point the Detroit area may have become a difficult place for the inexperienced firms, and possibly all firms, to compete. Indeed, after 1916 entry rates in the Detroit area fell off sharply. Prior to 1916 the percentage of entrants that located in the Detroit area had been steadily rising, increasing from 10% in 1895-1904 to 14% in 1905-1909 and 29% in 1910-1916, but after 1916 it was only 12%. While the entry of all four types of firms declined, the decline was particularly severe for the inexperienced firms. In 1910 to 1916, the Detroit area attracted 19% of the inexperienced entrants, but after 1916 it attracted only 1 of 28, or 4%, of the inexperienced entrants. 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.

## **VI. Econometric Analysis**

The various hypotheses can be tested using econometric methods, which facilitates a more detailed investigation and allows for the relevant factors to be analyzed together. The hypotheses concerning firm hazards are tested first, followed by tests of the hypotheses concerning firm spinoff rates.

### **A. Firm Hazards**

The 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:

$$h(t) = \exp\{(\alpha_0 + \underline{\alpha}' \underline{x})t\} \exp\{\beta_0 + \underline{\beta}' \underline{z}\},$$

where  $\underline{x}$  and  $\underline{z}$  are vectors of covariates and the other terms are coefficients. The first exponential term allows the age of firms to affect (monotonically) their hazard rates. It

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changing its name to Nash Motors. Willys-Overland was reorganized by Walter Chrysler, who had headed

also allows for the variables in  $\underline{x}$  to condition how age affects the hazard. In particular, 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, which implies that time of entry should condition the effect of age on the hazard. The second exponential term allows the variables in  $\underline{z}$  to affect the hazard proportionally at all ages. Included in  $\underline{z}$  are the firm background variables that distinguish the experienced firms, experienced entrepreneurs, and spinoffs from the inexperienced firms. Also included in  $\underline{z}$  are variables pertaining to whether firms were located in the Detroit area.

A series of models that control for successively more factors are estimated. Model 1 tests whether firms located in the Detroit area survived longer. It includes age,  $t$ , as the only variable in the first exponential term and one covariate in the vector  $\underline{z}$  in the second exponential term, a 1-0 dummy variable equal to 1 for firms located in the Detroit area. The estimates of this model are presented in the first column of Table 4, with standard errors in parentheses and significance levels based on one-tailed tests. As expected, the coefficient estimate of the Detroit variable is negative and significant, implying a 31% lower annual hazard for firms in the Detroit area than elsewhere.<sup>22</sup> The estimate of the constant term  $\alpha_0$ , which is the coefficient estimate of  $t$ , is negative and significant, implying that firm hazards decreased with age. The negative age dependence of the hazard could be due to unobserved heterogeneity in firm capabilities; if more capable firms have lower hazards, then the average capabilities of survivors will increase with age, causing their hazard to decline. This will be tested by adding controls for firm backgrounds and time of entry, which should diminish the negative age dependence of the hazard if it is due to unobserved heterogeneity in firm capabilities.

Model 2 adds controls for the backgrounds of entrants. Three 1-0 dummies equal to 1 for experienced firms, experienced entrepreneurs, and spinoffs are added to the vector  $\underline{z}$ , with inexperienced firms the omitted reference group. The coefficient estimates of the three variables in Table 4 are all negative and significant, consistent with figure 5. The experienced firms and experienced entrepreneurs have almost identical coefficient

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Buick and later organized the Chrysler Corporation.

<sup>22</sup> The percentage reduction in the hazard from being located in the Detroit area is computed as  $100*(1 - \exp\{-.36740\}) = 31\%$ .

estimates, implying a 46% lower annual hazard for both groups than inexperienced firms. The coefficient estimate for the spinoffs implies a 29% lower annual hazard than inexperienced firms. The coefficient estimate for the Detroit variable is similar to Model 1 while the estimate of  $\alpha_0$ , the coefficient of  $t$ , is about a third less negative than in model 1, consistent with the negative age dependence of the hazard being attributable to unobserved heterogeneity in firm capabilities.

Model 3 adds controls for time of entry in  $\underline{z}$ , allowing time of entry to affect the hazard proportionally at all ages. Two 1-0 dummy variables, denoted C1 and C2, are added for firms that entered in cohort 1 and cohort 2 respectively, with cohort 3 the omitted reference group. The coefficient estimates of both variables are negative and significant, consistent with figure 4, implying respectively a 44% and 14% lower hazard for entrants in cohorts 1 and 2 than cohort 3. The addition of C1 and C2 makes the spinoff coefficient estimate about 50% more negative, bringing the implied annual hazard of spinoffs down closer to the hazards of the experienced firms and experienced entrepreneurs. Spinoffs enter after their parents and thus tend to enter later. Since later entry raises the hazard, controlling for the time of entry increases the negative effect of a spinoff background on the hazard. The coefficient estimate of  $t$  is about half of its value for Model 3, further suggesting that the negative age dependence of the hazard is due to unobserved heterogeneity in firm capabilities

In Model 4 C1 and C2 are also added to the vector  $\underline{x}$ , which effectively adds the variables  $C1*t$  and  $C2*t$  to the first exponential term. This allows the effect of time of entry on the hazard to depend on firm age. The coefficient estimates of  $C1*t$  and  $C2*t$  are negative and significant while the coefficient estimates of C1 and C2 in  $\underline{z}$  both become small and insignificant. This implies that at young ages different entry cohorts have similar hazards, but the hazards of the cohorts diverge with age according to the time of entry, as predicted by the theoretical model. For example, the estimates imply that cohorts 1 and 2 have 76% and 48% lower hazards at age 15 and 90% and 67% lower hazards at age 25 than entrants in cohort 3. The estimates also imply that the hazard declines with age only for cohort 1 (the effect of age for cohort 1 equals the sum of the coefficients of  $t$  and  $C1*t$ ), and significantly, whereas it increases with age for cohorts 2 and 3, with the latter effect significant. If the negative age dependence of the hazard

reflects unobserved heterogeneity in firm capabilities, then these results are consistent with the theory, which predicted that earlier entry cohorts are more heterogeneous in terms of firm capabilities because the firms entered when conditions were less demanding. The other estimates of Model 4 are similar to Model 3.

The theoretical model assumed that location in Detroit does not provide any competitive advantages and that the superior performance of Detroit-area firms should be confined to spinoffs in the Detroit area. To test this, a 1-0 dummy for spinoffs located in the Detroit area was added to Model 4. The coefficient estimate of this variable in Model 5 is negative and significant, as predicted. More important, the coefficient estimate of the Detroit-area dummy is trivial and insignificant, suggesting that the lower hazard of Detroit-area firms was in fact confined to the spinoffs in the Detroit area. In terms of the ranking of firms regarding their hazards, the estimates imply that the Detroit-area spinoffs had the lowest hazards, followed by the experienced firms and experienced entrepreneurs, the non-Detroit-area spinoffs, and the inexperienced firms.

In Model 6 the Detroit-area dummy is dropped and the experienced firms and experienced entrepreneurs are distinguished according to whether their pre-entry experience was in the carriage and wagon, engine, or bicycle industries, with 1-0 dummies added for each group of firms with such a background. These are the three backgrounds most closely related to autos technically and in terms of marketing, and firms with such backgrounds were expected to have superior capabilities. The coefficient estimates of both of the added dummies are negative, with the one for the experienced firms significant, suggesting that firms with backgrounds in the three industries did in fact have lower hazards. The main experienced firm and experienced entrepreneur variables continue to have significant coefficient estimates, suggesting that any kind of pre-entry industry experience was valuable. In terms of the ranking of firms according to their hazards, the Detroit-area spinoffs still have lower implied hazards than any other group of entrants, including the experienced firms and experienced entrepreneurs from the carriage and wagon, engine, and bicycle industries, which have comparable hazards. The other coefficient estimates are similar to Model 5.

The advantage of the Detroit-area spinoffs is probed further in Models 7 and 8. If the lower hazard of the Detroit-area spinoffs is attributable to their superior heritage, then

the hazards of the spinoffs should vary according to their heritage and controlling for their heritage should reduce the coefficient estimates of the spinoff and Detroit-area spinoff dummies. Spinoffs were assumed to be influenced by their parents, with better-performing parents spawning better-performing spinoffs. The only variable that could be constructed for the performance of all the parents is the total number of years they produced autos. This measure does not distinguish the performance of the parents before the entry of their spinoffs when the founders of the spinoffs worked for their parents, but it would be expected to be correlated with the parents' performance during this period. It is added to the vector of covariates  $\underline{z}$  in Model 7. Parents that were acquired and played an important role in their acquirer were assigned the same total years of production as their parents.<sup>23</sup> The coefficient estimate of the parent's years of production is negative and significant, consistent with the theoretical model. It implies a 1.34% lower spinoff hazard for each additional year of production of the parent. Furthermore, the coefficient estimates of both the spinoff and Detroit-area spinoff dummies are less negative than in Model 6. The former coefficient estimate is small and insignificant while the latter remains significant but is about 30% less negative than in model 6.

Model 8 adds some measures of the performance of the parents prior to the entry of their spinoffs and a variable for the impetus of the spinoffs. It was expected that parents that were among the production leaders of the industry in the five years preceding and including the year of entry of their spinoff would have better-performing spinoffs.<sup>24</sup> To test this, three 1-0 dummy variables were created. The first equals 1 for spinoffs whose parent was ranked among the production leaders in the year of the spinoff or the preceding five years. The second equals 1 for spinoffs whose parent was the number one producer in the industry in the year of the spinoff or the preceding five years. The third equals 1 for spinoffs whose secondary parent (i.e., the firm the spinoff's founder worked

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<sup>23</sup> This includes Olds Motor Works, Cadillac, and Chevrolet, all of which were acquired by General Motors, Overman Auto, which was acquired by Locomobile, and Rauch & Lang, which was acquired by Baker.

<sup>24</sup> The dates when the founders of spinoffs worked at their parents were not generally known, but judging from the dates of entry of the parents and other information, most of the founders worked for their parents within five years of the formation of their spinoffs.

for immediately before the parent of the spinoff if the founder had worked for at least two auto firms) was the number one producer in the industry in the year of the spinoff or the preceding five years. The first dummy added little explanatory power to Model 7 due to its high correlation with the years of production of the parent, but the other two dummies had greater explanatory power and were included as covariates in  $\underline{z}$ .<sup>25</sup>

The other covariate added to  $\underline{z}$  in Model 8 was a 1-0 dummy pertaining to the impetus for the founding of the spinoffs. It equals 1 for spinoffs that arose due to a disagreement in the parent firm about strategy or innovation, the failure or imminent failure of the parent firm (or its automobile business), or the desire of the parent firm to market a new car through a separate organization in order to preserve its image. The distinctive quality of these spinoffs is that they generally built directly on the expertise of their parents while at the same time differentiated themselves from their parents. Descriptions of the origins of the other spinoffs suggest they were not so closely linked to their parents, although no doubt the brevity of the historical record for some obscured their connection to their parents. It was expected that the spinoffs that built in discernible ways on the expertise of their parent would have lower hazards, *ceteris paribus*.<sup>26</sup>

The coefficient estimates of all three of the added variables are negative, as predicted, with only the dummy for the spinoff's secondary parent not significant. Furthermore, the coefficient estimate of the Detroit spinoff dummy is approximately 55% less negative than in model 7 and is insignificant, making both it and the coefficient estimate of the spinoff dummy insignificant. Thus, crude controls for the heritage of the spinoffs largely explain the superior performance of the Detroit-area firms, suggesting further that there were no particular advantages to locating in Detroit. The controls also

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<sup>25</sup> When the two included dummies were broadened to encompass parents who were the number two producer, their explanatory power declined considerably. The production leaders of the industry, in particular Olds and Ford, were the first to mass produce automobiles and apparently provided novel challenges to their employees. Indeed, Ransom Olds, the founder of Olds Motor Works, was known as the "Schoolmaster of Motordom" (Doolittle, [1916, p. 44]).

<sup>26</sup> Note that many of these spinoffs, especially the ones whose parents' failure was imminent, did not produce very long. Not surprisingly, their parents did not generally produce long either. All that is predicted is that after controlling for the years of production of their parent and the other variables in the model, these firms survived longer, *ceteris paribus*. Efforts to break down the 1-0 dummy according to the particular motivation of the spinoffs were not productive.

suggest that the superior performance of spinoffs generally was restricted to those with distinctive heritages.

The absence of a Detroit-area effect is probed further by estimating Model 9, which drops the the spinoff and Detroit-area spinoff dummies and adds two covariates to  $z$  that interact the 1-0 dummy for location in the Detroit area with the years of production of the spinoff's parent and the 1-0 dummy for the spinoff having a discernible reason for its formation.<sup>27</sup> This makes it possible to test if the spinoff background variables had similar effects for Detroit-area and non-Detroit-area spinoffs. The estimates of the interacted variables are negative but insignificant, while the coefficient estimates of the main variables continue to be negative and significant. This implies that background similarly affected the hazard of spinoffs everywhere. To gauge the effects of all the background variables, one last model, Model 10, was estimated without the two interactive variables added to Model 9. The coefficient estimates of all four variables for the backgrounds of the spinoffs are negative and significant, along with nearly all the other background variables, confirming further the importance of the pre-entry experience of firms on their performance.

## **B. Firm Fertility**

The other key prediction of the theoretical model, which lies at the heart of its explanation for the concentration of the industry around Detroit, is that better-performing firms spawn more spinoffs (hypothesis 4d in Table 1). It was shown earlier that Olds, Buick/General Motors, Cadillac, and Ford, which were all located in the Detroit area, had the most spinoffs among all firms and that the Detroit area was characterized by a disproportionate number of spinoff entrants. A host of factors other than better performance, such as the Detroit-area firms producing longer, could account for their greater number of spinoffs. To test this, an ordered logit model was estimated of the annual rate of spinoffs of each firm in the industry. Nearly all the spinoffs entered between 1899 and 1924, and so the analysis is restricted to this period. Each firm's

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<sup>27</sup> The two dummies for the spinoff's parent and secondary parent being the number one producer were not interacted with the Detroit-area dummy because all the spinoffs with primary or secondary parents that

history is broken into annual intervals from the year before its date of entry<sup>28</sup> (or 1899 if it entered earlier) through 1924. The observations of all firms are pooled and an ordered logit is estimated of the factors influencing the annual probability of a firm having one, two, or three spinoffs.<sup>29</sup>

To control for all possible determinants of the spinoff rate, a specification similar to the one used by Klepper and Sleeper [2000] to analyze spinoffs in the laser industry is employed. The explanatory variables for each firm-year  $t$  include: a 1-0 dummy equal to 1 for firms that produced in year  $t$ ; a 1-0 dummy equal to 1 for firms that did not produce in year  $t$  but had ceased producing less than five years earlier; the number of years of production through year  $t$  and the number of years of production squared for firms that produced in year  $t$ ; the total number of years the firm produced autos;<sup>30</sup> a 1-0 dummy equal to 1 if the firm had been among the production leaders of the industry in year  $t$  or the preceding five years and a 1-0 dummy equal to 1 if the firm had been the number one or two producer in year  $t$  or the preceding five years;<sup>31</sup> a 1-0 dummy equal to 1 for firms that were acquired by another auto firm between year  $t-1$  and  $t+2$  and a comparable 1-0 dummy equal to 1 for firms acquired by nonauto firms between year  $t-1$  and  $t+2$ , both of which were based on listings of ownership changes in Smith [1968]; a variable equal to the number of nonspinoff entrants divided by the number of firms averaged over years  $t-2$ ,  $t-1$ , and  $t$ ; and two 1-0 dummies for firms located in the Detroit area, with the first dummy equal to 1 for firms located in the Detroit area in year  $t$  and the second equal to 1 for firms located in the Detroit area in year  $t$  for years greater than 1916.

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were the number one producer either entered in the Detroit area or, in the case of one spinoff, moved there after it entered.

<sup>28</sup> The firm's entry date is its initial year of commercial production in Smith [1968]. Some firms were organized before this date, and in two instances spinoffs entered in the year prior to the first year of commercial production of the parent firm. To accommodate this, the analysis was started in the year prior to each firm's initial year of commercial production.

<sup>29</sup> While 130 of the spinoffs occurred in years in which firms had only one spinoff, an ordered logit was used because there were six years in which firms had two spinoffs and one year in which one firm had three spinoffs.

<sup>30</sup> As in the hazard analysis, acquired firms that played an important role in their acquirer were assigned the same number of years of production as their acquirer. In addition to Olds, Cadillac, Chevrolet, Overman, and Rauch & Lang, the firms affected included Oakland, Edwards, Lincoln, Dodge, and Motorcar.

<sup>31</sup> In contrast to the hazard analysis, including the number two producer increased the explanatory power of this variable. This largely reflects the comparable spinoff rates of Cadillac and Buick/General Motors to Olds and Ford.

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.<sup>32</sup> The number of years of production through year  $t$  (for producers in year  $t$ ) was included to allow more experienced firms to have more knowledge for employees to draw upon, increasing the spinoff rate. It was entered quadratically to allow for the possibility of a firm's knowledge becoming more embodied in the production process as it aged and grew, with such knowledge possibly more difficult for employees to access, thus lowering the spinoff rate. The years of production and production leadership variables were included to test whether a firm's performance affected its spinoff rate, as the theoretical model presumes. The acquisition variables were included to allow for the possibility of acquisitions causing changes in firm strategies, which could provide greater opportunities for spinoffs to exploit expertise gleaned from their parent. The nonspinoff entry variable was included to allow the spinoff rate to vary according to the attractiveness of entry generally.<sup>33</sup> Last, the Detroit-area dummies were included to test whether the Detroit-area firms had higher spinoff rates even after controlling for their greater success. A separate dummy for years after 1916 was included to test whether the spinoff rate of Detroit-area firms was lower in later years, with 1916 chosen as the cutoff based on the fall in the entry of all firms in the Detroit area after 1916.

The estimates of the coefficients of the variables and three constant terms quantifying the thresholds for one, two, and three spinoffs are reported in Table 5. The estimates largely conform with expectations. The probability of a spinoff is significantly greater in years firms were producing. It is also significantly greater for firms that had ceased producing within the last five years (relative to firms that had ceased producing over five years ago, the omitted reference category). For producers, the probability of a spinoff increases significantly through approximately age 14, after which it declines significantly. Klepper and Sleeper [2000] found a similar relationship for laser spinoffs. The probability of a spinoff is significantly greater around times that firms were acquired

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<sup>32</sup> 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.

<sup>33</sup> This was alternatively controlled using year dummies, which had little effect on the estimates

by either auto or nonauto firms. It is also significantly greater in years with a higher nonspinoff entry rate. In terms of the critical variables for the theory, the probability of a spinoff each year is significantly greater for firms that produced longer. It is also significantly greater for firms that were among the production leaders in the contemporaneous or prior five years, and significantly greater still for firms that were the number one or two producer in this same time period. Thus, consistent with hypothesis 3, firms that performed better had higher annual spinoff rates.

The coefficient estimate for the Detroit dummy is positive and significant. It is almost completely offset by the negative coefficient estimate for the Detroit dummy after 1916, which is also significant. Thus, after 1916 the Detroit-area firms were not especially fertile, but before that Detroit-area firms spawned more spinoffs than expected based on their performance. The effect is quite large—the coefficient estimate of the Detroit-area dummy implies that through 1916 Detroit-area firms were about three times as likely to spawn one or more spinoffs than firms of comparable performance located elsewhere.<sup>34</sup> Thus, a substantial part of the greater fertility of the Detroit-area firms appears to have been attributable to circumstances peculiar to the Detroit area. In contrast, the hazard analysis suggested that the greater longevity of the Detroit-area firms, and in particular the Detroit-area spinoffs, was not primarily due to circumstances peculiar to the Detroit area but could largely be traced back to four very successful early entrants.

## **VII. Discussion**

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

Initially a large number of firms entered the automobile industry and the number of producers peaked at 272 in 1909. Subsequently entry fell sharply and became negligible by the 1920s and the industry experienced a sharp and prolonged shakeout.

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<sup>34</sup> The coefficient estimates can be interpreted in the conventional way as the derivative of the log odds ratio with respect to the explanatory variables, where the log odds ratio is the log of the probability of one or more spinoffs divided by one minus this probability (cf. Cox and Snell [1989, p. 159]). Thus,  $\exp(1.2079) = 3.346$  quantifies how much greater the odds ratio is for Detroit-area firms than firms located elsewhere. Since the annual probability of firms spawning one or more spinoffs is quite low, the denominator in the odds ratio is close to one, implying that the annual probability of a spinoff through 1916 was around three times greater for Detroit-area firms than firms located elsewhere.

Diversifying firms in related industries and firms founded by the heads of such firms tended to enter early, but few entered in the Detroit area. Consequently, there was little initial entry in the Detroit area, and in total the Detroit area only attracted 15% of all the entrants to the industry. But fueled by spinoffs, which accounted for a disproportionate share of entrants in the Detroit area, the percentage of producers in the Detroit area rose over time. By the late 1910s most of the leading makes of automobiles were produced by Detroit-area firms, and Detroit was home to the three firms that by the 1930s produced over 80% of the industry's output.

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 and 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 had higher spinoff rates, and better-performing firms had 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, Buick/General Motors, Cadillac, and Ford, four of the most successful early entrants into the industry that all happened to locate in the Detroit area.

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.<sup>35</sup> 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. Once the

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<sup>35</sup> 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.

window of opportunity for entry closed, there was also little chance of entry overturning the established geographic distribution of activity around Detroit that had already arisen.

The fact that entry cohort hazard 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. Such a pattern suggests that shakeouts were not triggered by particular technological developments, whose effects would be expected to dissipate over time, but were part of a broader process of industry evolution (cf. Klepper and Simons [2001]). Not many factors could account for the persistently lower hazards of earlier entrants. 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 grew. 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. Consistent with the model, Klepper and Simons [1997, 2001] found that early automobile entrants were in the vanguard of innovation, particularly process innovation, and innovators had markedly lower hazards.<sup>36</sup>

The importance of technological change provides a way of explaining the long-term effects of pre-entry experience on firm hazards, linking the productivity of firms' R&D efforts to their pre-entry experience (cf. Holbrook, Cohen, Hounshell, and Klepper [2000]). The similar hazards of experienced firms and experienced entrepreneurs and the low hazards of spinoffs, especially ones descended from more successful firms, suggests that in autos key capabilities resided as much in people as organizations. Olds, Buick/General Motors, Cadillac, and Ford exemplify this. Each had a famous leader with distinctive pre-entry experience in engines, carriages, or autos. In turn, these firms

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<sup>36</sup> Klepper [2001b] found 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. Moreover, detailed analyses of firm survival and innovation in both tires and televisions suggested that early 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]).

proved to be fertile training grounds for many other great auto men who started nearly all the other firms in the Detroit area that made it into the ranks of the industry leaders. Indeed, two of the leading historians of the auto industry attributed its concentration around Detroit to the preponderance of great men located there (Rae [1980], May [1977]). They did not explain, though, why so many great men were located in the Detroit area. The theoretical model can't explain why four of the most successful early firms arose in the Detroit area, which was an unlikely place for this to occur given the paucity of early entrants around Detroit. But given the chance occurrence of four such firms around Detroit, the theory can explain the subsequent concentration of great men around Detroit that propelled Detroit to become the capital of the U.S. automobile industry, attributing it to the birth and heredity process governing spinoffs.

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. Indeed, the success of firms in the Detroit area was largely confined to the Detroit-area spinoffs. If agglomerations result from positive spillovers associated with R&D and/or input markets, as Alfred Marshall and others have conjectured, or from having producers and their suppliers locate close to each other and to buyers, as in Krugman et al.'s model, then the benefits of locating in the Detroit area should have been experienced by all types of firms. Moreover, it is not clear that there were any benefits from locating in the Detroit area. The success of the Detroit-area spinoffs can largely be explained by the superior performance of their parents and their greater proclivity to build on the expertise of their parents.

The theoretical model contains a number of elements that are needed to generate the extreme agglomeration of activity that characterized the auto industry. One is the ability of de novo firms founded by people with distinctive experience to compete with organizations diversifying from related industries. This does not occur in all industries. For example, the television industry evolved in a very similar way to autos (Klepper [2001b]), but the industry was dominated by firms diversifying from the radio industry. Consequently, the geographic distribution of activity did not concentrate in any one place, but largely reflected the geographic distribution of the radio producers. A second

aspect of the model contributing to the agglomeration of activity is the advantage of early entrants associated with technological change. This eventually causes entry to dry up, which not only contributes to a shakeout of producers but also limits the extent to which agglomerations can be overturned once they occur. While many technologically progressive industries eventually experience a drying up of entry and greater longevity of earlier entrants (cf. Klepper [2001b]), some, such as lasers, do not. Although spinoffs were also prominent in the laser industry, the industry has experienced a continual turnover of firms that seems to have limited its geographic concentration (Klepper and Sleeper [2000]). Last, in the model agglomeration depends on the chance location of a few successful firms in one narrow region. This is certainly a rare event. If all three conditions of the model are required to produce the kind of agglomeration that characterized autos, it would explain why such extreme agglomerations are rare (Ellison and Glaeser [1997]).<sup>37</sup>

The model implies that a region, including a nation, will not naturally develop a presence in a new industry unless it has firms in related industries that could successfully diversify into the new industry and subsequently spawn other entrants. It does not rule out, though, that a region could generate qualified entrants through a government-supported seeding process. The model is less informative about whether nations would find it beneficial to promote geographic agglomeration of evolving industries. There are no social advantages to agglomerations in the model. But judging from the experience of Silicon Valley, which appears to have been fueled by spinoffs in semiconductors (Brittain and Freeman [1986]) and other industries such as disk drives (Franco and Filson [2000]) and lasers (Klepper and Sleeper [2000]), agglomerations driven by spinoffs may well promote economic growth. Exactly how this occurs and whether in fact spinoffs are socially beneficial is an unresolved question. The rate of spinoffs was much higher in the Detroit area than expected based on the explanatory variables of the order logit model, suggesting that agglomerations may promote spinoffs, which would be socially beneficial

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<sup>37</sup> Once agglomerations occur, though, the model predicts they will tend to be self-reinforcing, which could explain Sorenson and Audia's [2000] finding for the footwear industry that firms entered disproportionately in agglomerated areas even though firms in those areas had *shorter* lifetimes, *ceteris paribus*.

if spinoffs are an important element of the growth process. If spinoffs are socially beneficial, then promoting spinoffs through such policies as restricting noncompete covenants and trade secrets may be warranted (cf. Hyde [2000], Klepper [2001a], Stuart and Sorenson [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 all firms and each type of entrant, the hazards of early and late entrants cannot be ordered at young ages, but at older ages the early entry cohorts will have lower hazards and will become extinct later than the late entry cohorts.
2. Experienced firms, experienced entrepreneurs, and spinoffs will have lower hazards at every age than inexperienced firms.
3. Spinoffs from better-performing parents and experienced firms and experienced entrepreneurs with experience in industries more related to automobiles will have lower hazards at every age.
4.
  - a. The number of spinoff entrants relative to the number of experienced firm and experienced entrepreneur entrants will steadily rise over time.
  - b. The number of experienced firm, experienced entrepreneur, and spinoff entrants relative to the number of inexperienced firm entrants will eventually rise as the industry evolves.
  - c. The performance of the parents of spinoff entrants will improve over time.
  - d. Better-performing firms will spawn more spinoffs.
5.
  - 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. Parents of Detroit-area spinoffs will perform better than parents of spinoffs elsewhere.
  - d. 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.
  - e. Spinoffs located in the Detroit area will have lower hazards at every age than spinoffs located elsewhere.
  - f. Inexperienced firms located in the Detroit area will not have lower hazards at every age than inexperienced firms located elsewhere.

Table 2: Entrants by Background and Time of Entry

Period	Total	# of Experienced Firms (EF)	# of Experienced Entrepreneurs (EE)	# of Spinoffs (S)	# of Inexperienced Firms (IF)	S/(EF + EE)	S/IF	(EF + EE)/IF
1895-1904	219	46	45	16	112	.18	.14	.81
1905-1909	271	43	32	47	149	.63	.32	.50
1910-1966	235	31	31	82	91	1.32	.90	.68
Total	725	120	108	145	352	.64	.45	.70

Table 3: Firms with the Most Spinoffs

Firm	Number of Spinoffs	Number of Descendants	Number of Descendants Among Production Leaders	Year of Entry	Rank Among Production Leaders w/in 5 Years of Entry	Leader & Prior Background
Olds	7	13*	5	1901	#2 1901-02 #1 1903-05	Ransom Olds, head, engine firm
Buick/GM	7	9	2	1903	#9 1905 #8 1906 #2 1907	William Durant, head, carriage firm
Cadillac	4	5**	3**	1902	#3 1903 #2 1904-06	Henry Leland, head, engine firm
Ford	4	9	1	1903	#2 1903 #4 1904-05 #1 1906-07	Henry Ford, auto founder
Maxwell-Briscoe	4	5	0	1904	#8 1905 #5 1906 #4 1907-08	Jonathan Maxwell, auto employee & founder

\* Includes Maxwell-Briscoe but not Maxwell-Briscoe's descendants

\*\* Includes Ford but not Ford's descendants

Table 4: Coefficient Estimates of the Hazard Model  
(Standard Errors in Parentheses)

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Constant	-1.6971*** (0.0504)	-1.4640*** (0.058)	-1.2487*** (0.0831)	-1.5024*** (0.0145)	-1.5251*** (0.0145)
t	-0.0287*** (0.0052)	-0.0191*** (0.0053)	-0.0097** (0.0055)	0.0555*** (0.0142)	0.0543*** (0.0140)
Detroit	-0.3674*** (0.1183)	-0.3435*** (0.1281)	-0.3431*** (0.1279)	-0.2946** (0.1295)	0.0121 (0.1528)
Exp. firms		-0.6190*** (0.1121)	-0.5891*** (0.1124)	-0.6298*** (0.1129)	-0.6308*** (0.1129)
Exp. entrep.		-0.6153*** (0.1186)	-0.5976*** (0.1193)	-0.6166*** (0.1187)	-0.6473*** (0.1196)
Spinoffs		-0.3380*** (0.1146)	-0.4786*** (0.1184)	-0.5509*** (0.1212)	-0.3806*** (0.1282)
C1			-0.5821*** (0.1075)	-0.1520 (0.1356)	-0.1537 (0.1349)
C2			-0.1459* (0.0951)	0.0234 (0.1291)	0.0058 (0.1292)
C1*t				-0.0844** (0.0161)	-0.0820** (0.0159)
C2*t				-0.0457*** (0.0174)	-0.0384** (0.0176)
Det. spins					-0.7752*** (0.2584)
C,b,e firms					
C,b,e entrep.					
Yrs par.prod					
Parent #1					
Sec.par #1					
Spin reason					
Yrs prod*D					
Sp. Reas*D					
Log Likel.	-1929.36	-1905.87	-1889.32	-1875.07	-1870.53

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

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

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

Table 4 cont'd: Coefficient Estimates of the Hazard Model  
(Standard Errors in Parentheses)

Variable	Model 6	Model 7	Model 8	Model 9	Model 10
Constant	-1.5359*** (0.1033)	-1.5355*** (0.1029)	-1.5537*** (0.1036)	-1.5969*** (0.1009)	-1.5926*** (0.1003)
t	0.0586*** (0.0141)	0.0585*** (0.0139)	0.0581*** (0.0139)	0.0558*** (0.0136)	0.0569*** (0.0136)
Detroit					
Exp. firms	-0.4103*** (0.1467)	-0.4124*** (0.1467)	-0.4112*** (0.1467)	-0.3872*** (0.1457)	-0.3914*** (0.1456)
Exp. entrep.	-0.5345*** (0.1525)	-0.5404*** (0.1526)	-0.5496*** (0.1528)	-0.5170*** (0.1514)	-0.5222*** (0.1512)
Spinoffs	-0.3928*** (0.1282)	-0.1515 (0.1459)	-0.1410 (0.1588)		
C1	-0.1528 (0.1349)	-0.1496 (0.1345)	-0.1272 (0.1350)	-0.0971 (0.1342)	-0.0976 (0.1339)
C2	0.0147 (0.1291)	-0.0022 (0.1293)	-0.0035 (0.1306)	0.0254 (0.1294)	0.0260 (0.1292)
C1*t	-0.0851*** (0.0160)	-0.0847*** (0.0158)	-0.0839*** (0.0159)	-0.0817*** (0.0157)	-0.0832*** (0.0156)
C2*t	-0.0412*** (0.0176)	-0.0376** (0.0176)	-0.0306** (0.0179)	-0.0310** (0.0177)	-0.0316** (0.0176)
Det. spins	-0.7663*** (0.2095)	-0.5377*** (0.2177)	-0.2515 (0.2323)		
C,b,e firms	-0.4141** (0.1927)	-0.4186** (0.1928)	-0.4290** (0.1930)	-0.4172** (0.1927)	-0.4199** (0.1927)
C,b,e entrep.	-0.2342 (0.2023)	-0.2325 (0.2023)	-0.2273 (0.2023)	-0.2262 (0.2023)	-0.2260 (0.2022)
Yrs par.prod		-0.0135*** (0.0045)	-0.0086** (0.0048)	-0.0093** (0.0041)	-0.0121*** (0.0041)
Parent #1			-0.9541** (0.5482)	-0.6246 (0.6249)	-0.9183** (0.5288)
Sec.par #1			-0.5571 (0.4837)	-0.7759** (0.4716)	-0.7774** (0.4616)
Spin reason			-0.3413* (0.2190)	-0.4031** (0.2406)	-0.4982*** (0.1944)
Yrs prod*D				-0.0055 (0.0082)	
Sp. Reas*D				-0.0039 (0.0092)	
Log Likel.	-1867.58	-1862.63	-1858.82	-1859.62	-1860.08

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

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

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

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

<u>Variable</u>	<u>Coefficient Estimate</u>
Constant1	-6.6851 (.3615) ***
Constant2	-9.7128 (.5174) **
Constant3	-11.6736 (1.0608) ***
Dummy—producing	1.1763 (.4652) ***
Dummy--≤5yrs.notprod.	1.3865 (.4131) ***
Yrs. Prod. if producer	0.1772 (.0648) ***
Yrs. Prod. <sup>2</sup> if producer	-0.0065 (.0030) **
Yrs. survived	0.0133 (.0077) **
Production leader	0.7605 (.3343) **
#1 or #2 producer	0.6789 (.3951) **
Acquired by auto firm	0.9551 (.3440) ***
Acquired by nonauto firm	0.8468 (.2616) ***
Nonspin. entry rate	0.9258 (.5239) **
Detroit area	1.2079 (.2279) ***
Detroit area after 1916	-1.1251 (.4008) ***

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

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

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

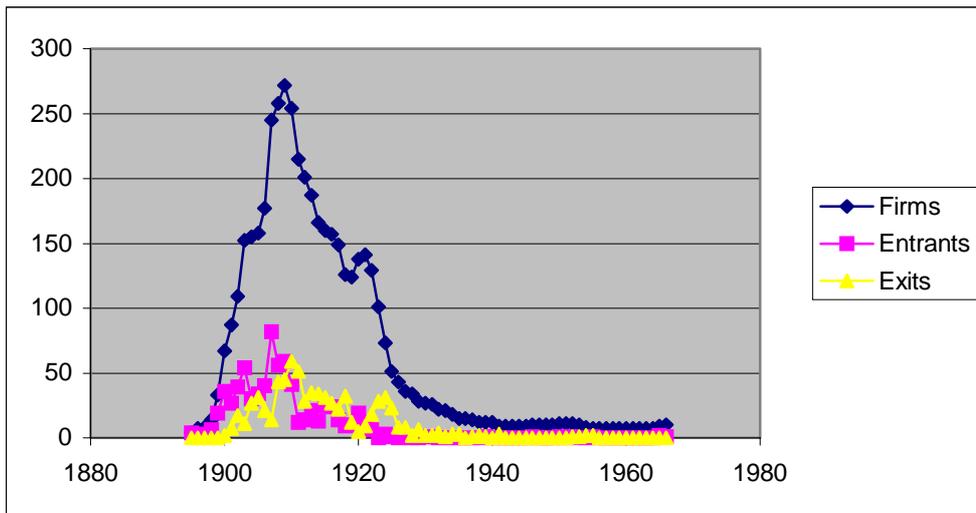
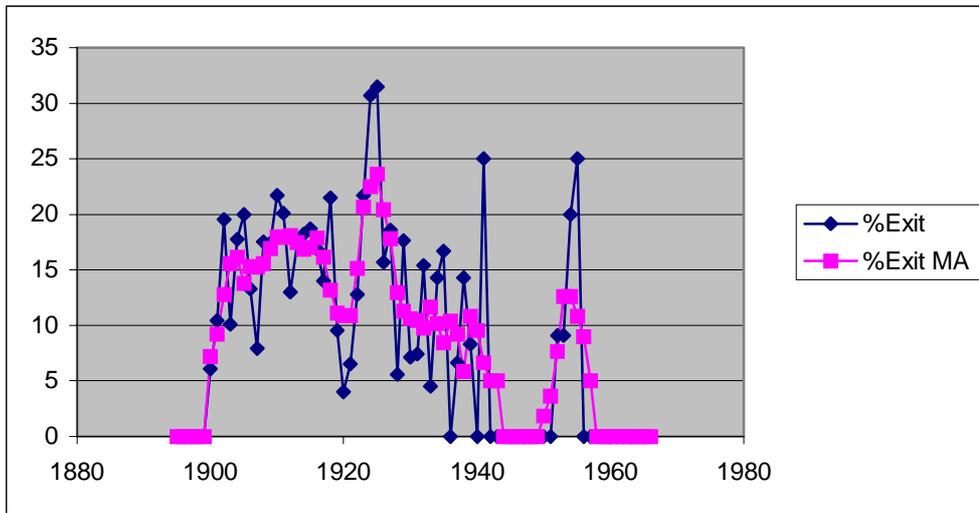


Figure 1: Entry, Exit, and Number of Firms

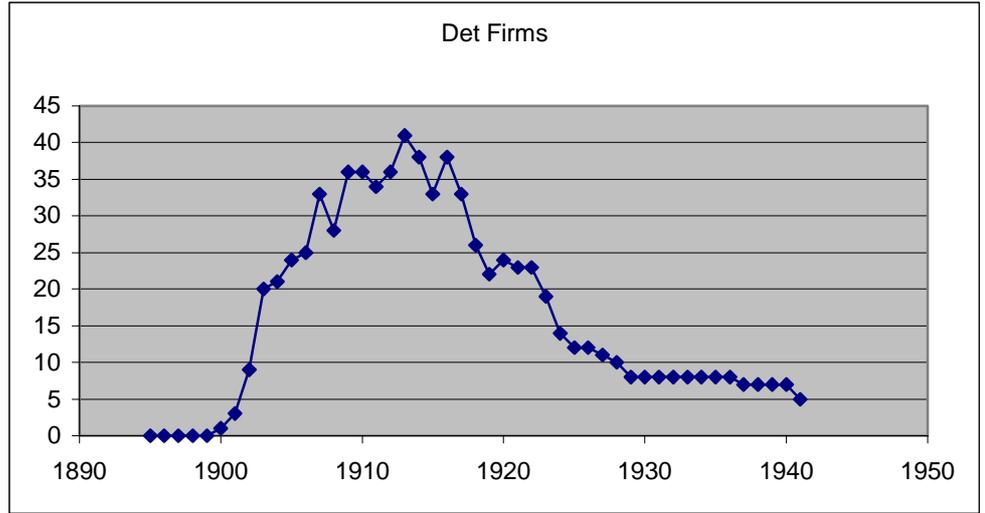
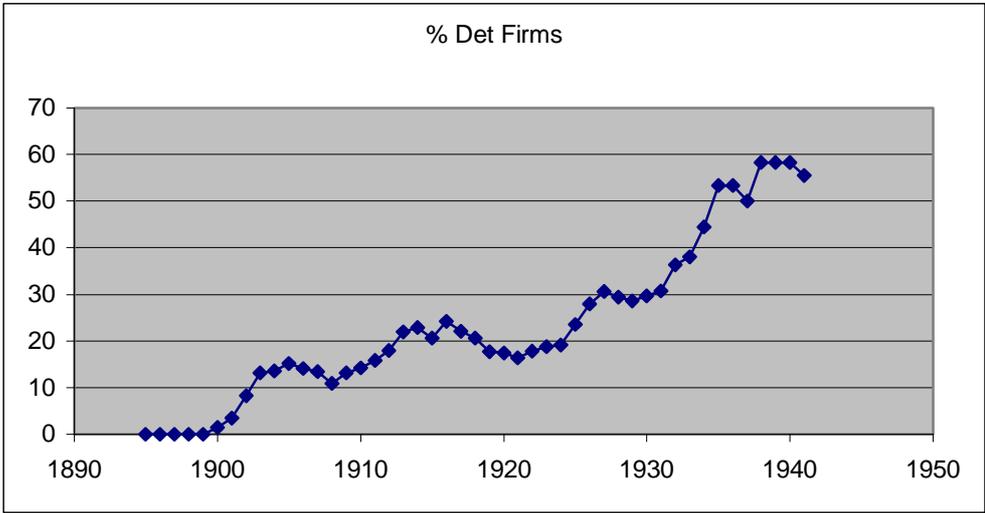
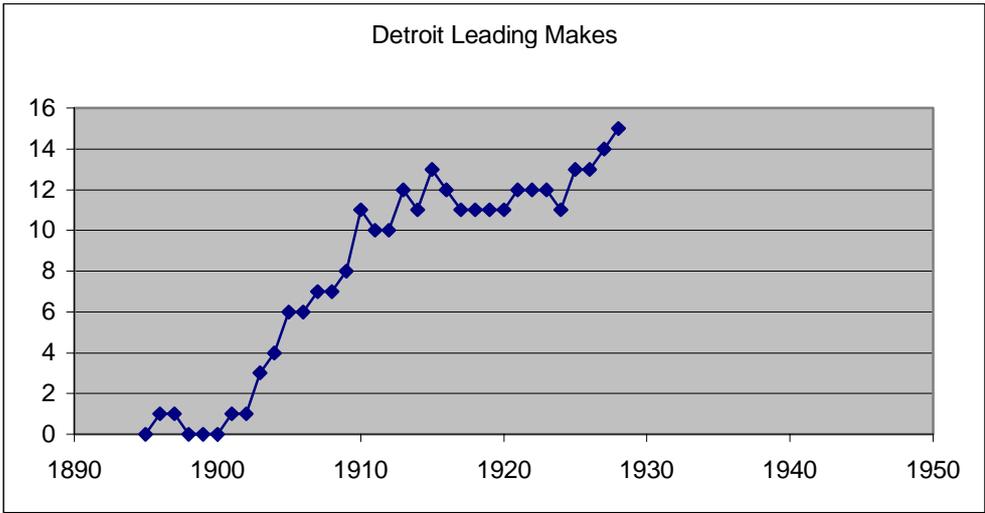
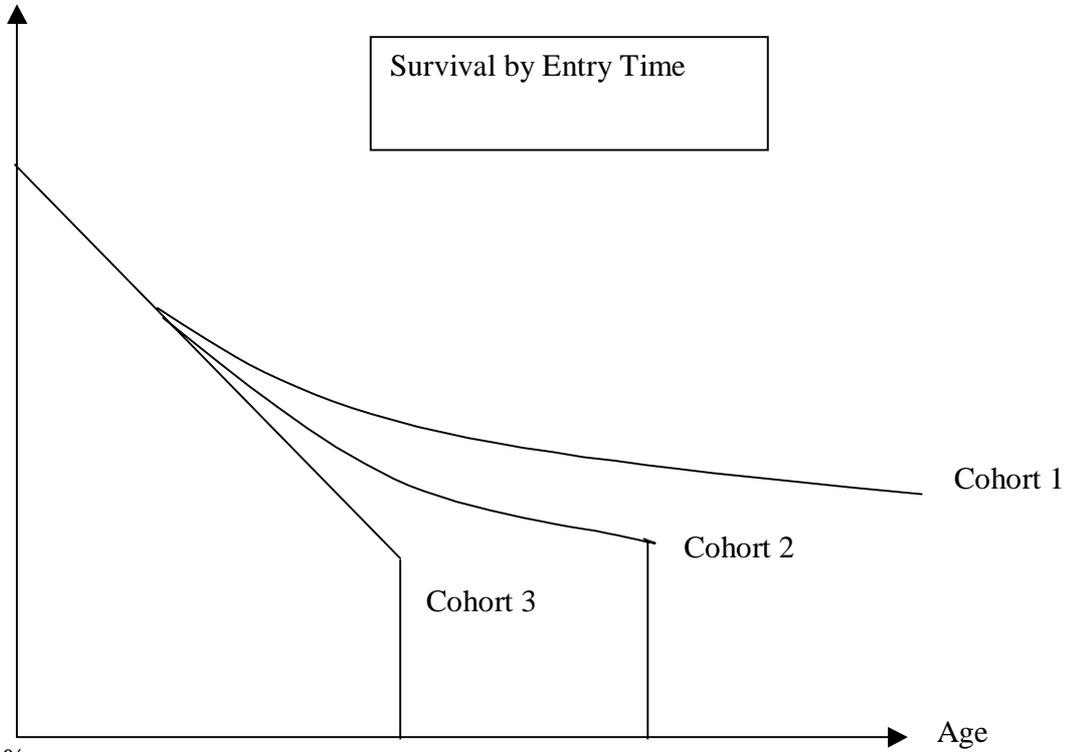


Figure 2: Location of Firms Around Detroit

Log %  
Survival



Log %  
Survival

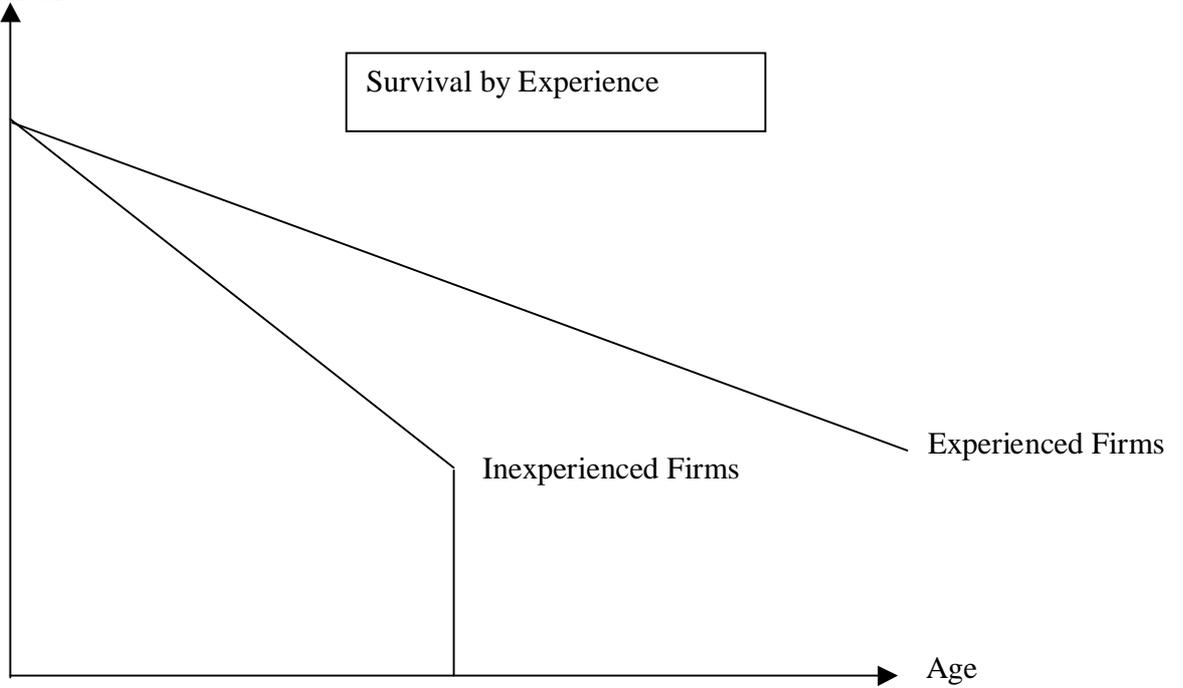


Figure 3: Survival Graphs

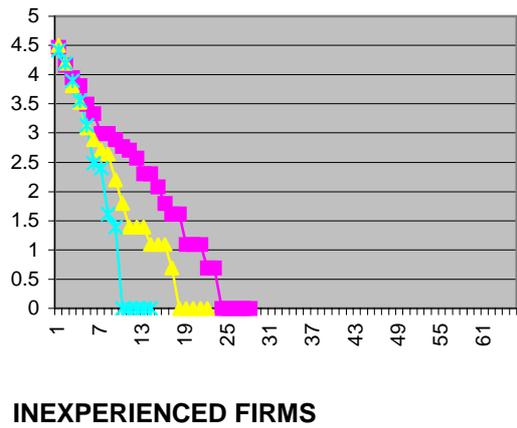
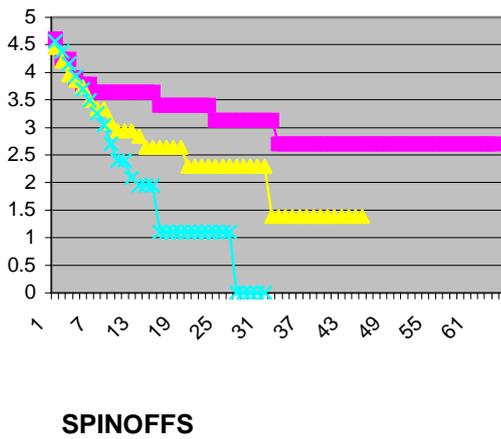
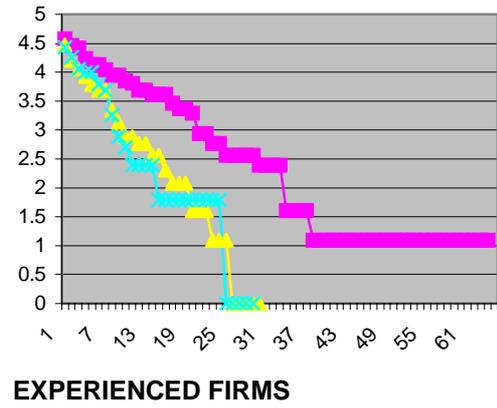
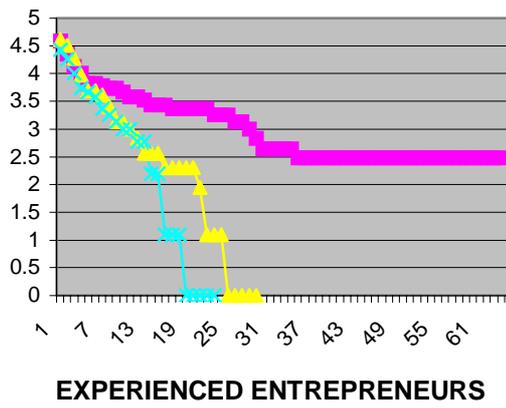
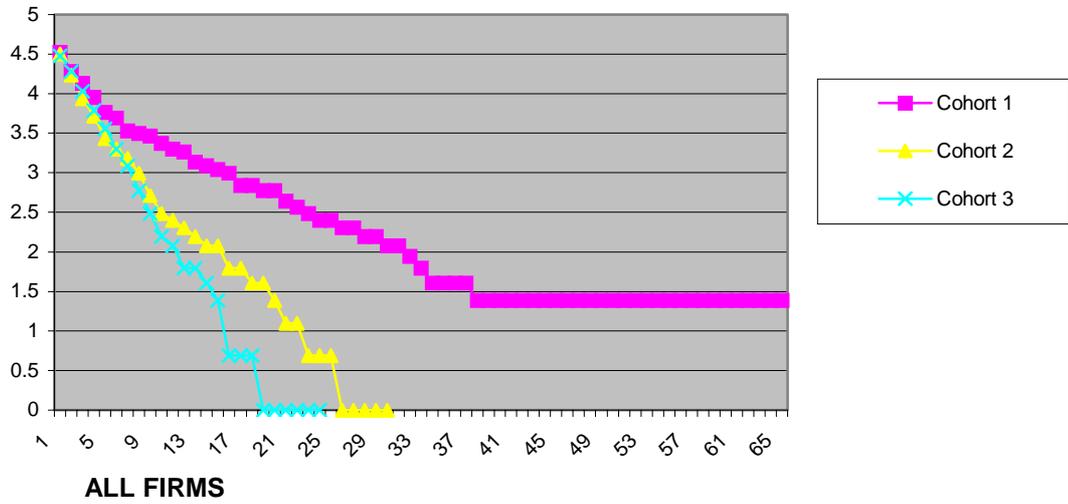
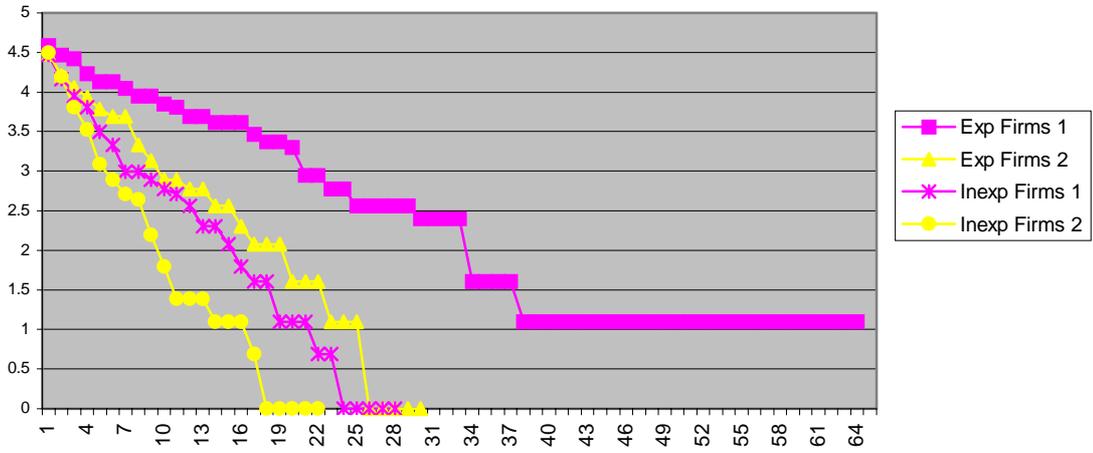
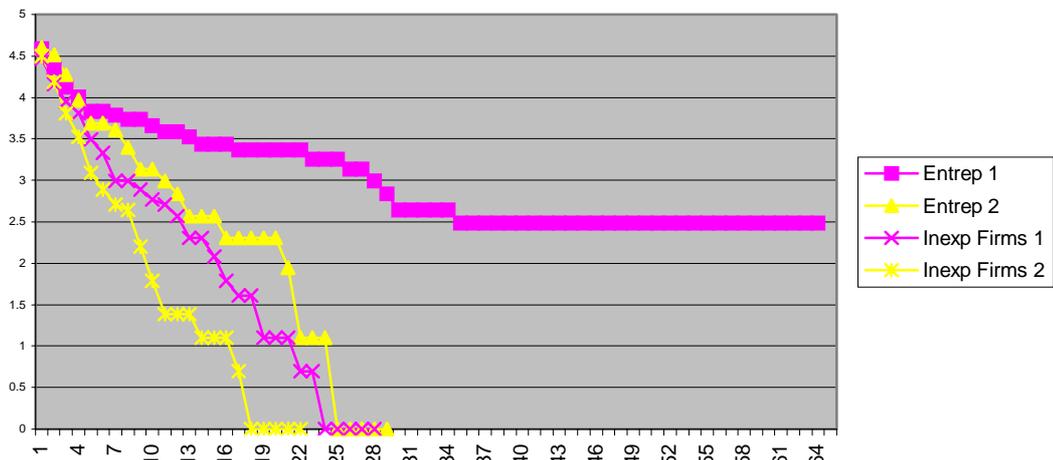


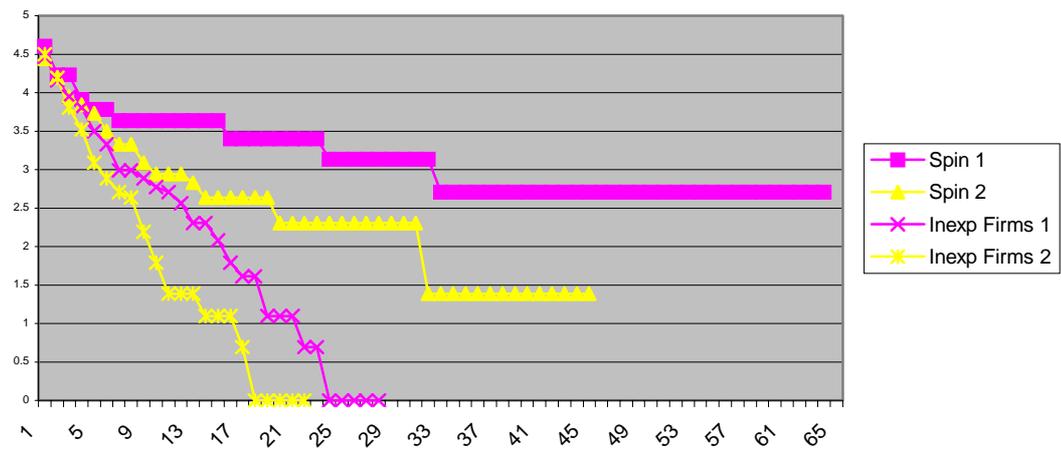
Figure 4: Survival Curves by Time of Entry



**EXPERIENCED FIRMS VS. INEXPERIENCED FIRMS**



**EXPERIENCED ENTREPRENEURS VS. INEXPERIENCED FIRMS**



**SPINOFFS VS. INEXPERIENCED FIRMS**

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

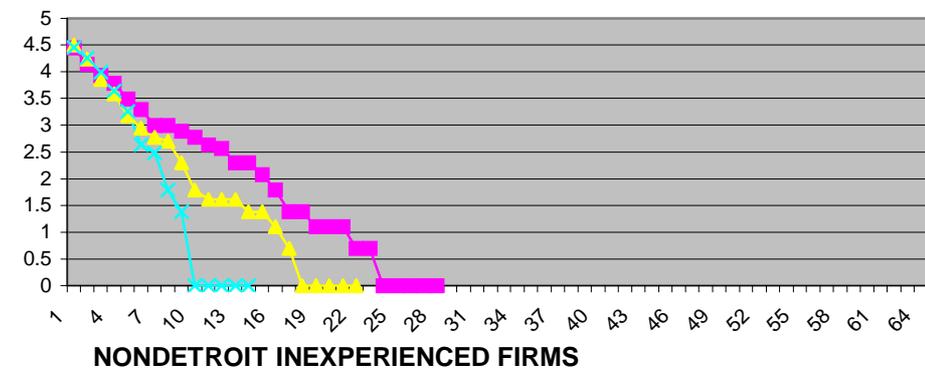
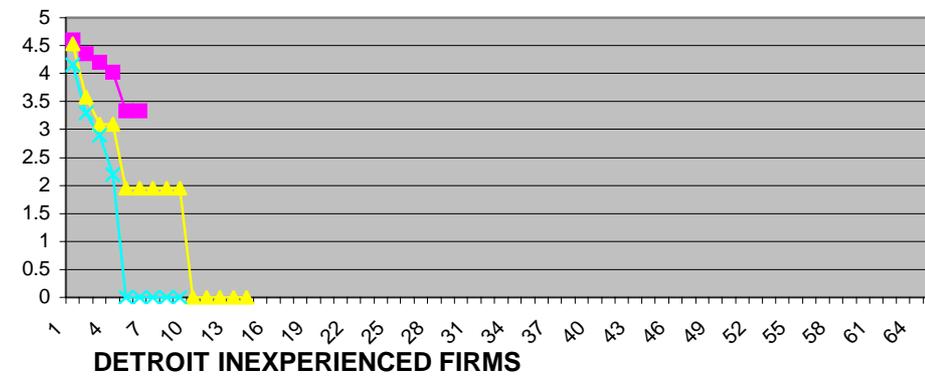
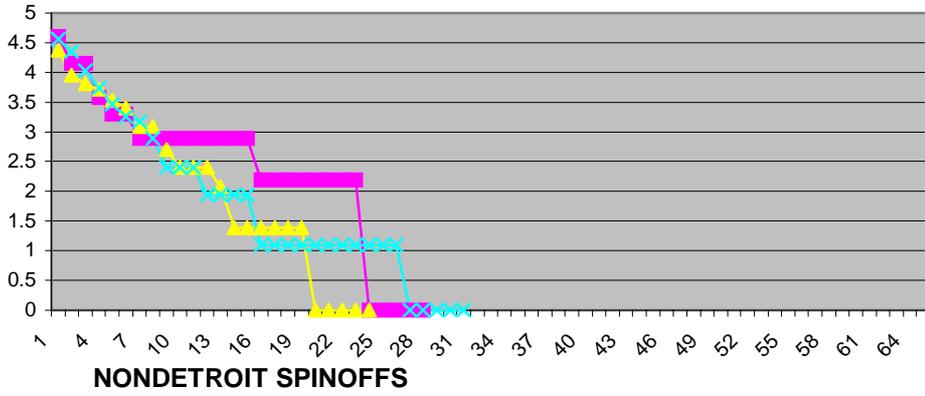
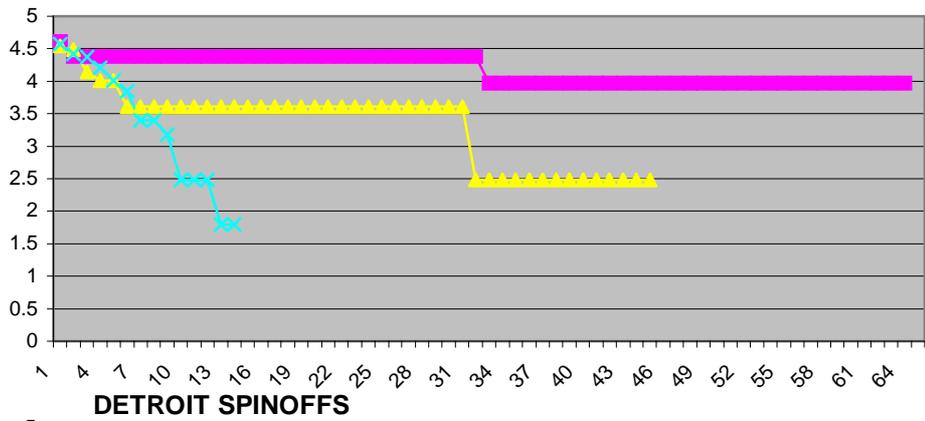


Figure 6: Survival Curves of Detroit and Non-Detroit Spinoffs and Inexperienced Firms

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