Innovation and Industry Shakeouts

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Many industries such as automobiles were initially populated by a large number of competitors but subsequently experienced a pronounced decrease or shakeout in the number of producers. Such shakeouts are common in manufacturing industries, with the number of producers often dropping by 50% or more during the formative eras of new manufacturing industries [9, 12]. This paper summarizes the findings of a more detailed investigation [13] concerning the role of technological change in causing shakeouts.

Three recent models of shakeouts featuring technological change were used to guide our investigation. In one theory [10], which we label the innovative gamble theory, after an initial period of entry a major innovation or trajectory of innovations is opened up by technological developments outside the industry. The major innovation(s) are challenging to develop, providing the basis for the innovative gamble. Some firms may enter if the gamble is sufficiently attractive. Incumbents and entrants that are unable to develop the innovation(s) lose the gamble and exit, contributing to a shakeout. As unsuccessful innovators exit, the rate of exit subsides and the number of firms stabilizes. Entrants during the shakeout have lower survival rates than preshakeout incumbents due to their lesser experience, but over time these differences in survival rates diminish as unsuccessful innovators exit.

In the second theory [20], firms initially enter based on novel variants of the product, but subsequent experimentation and investments in complementary goods lead to the emergence of a dominant design for the industry's product. Competition then shifts from product innovation to improving the production process for the dominant design as firms no longer fear that investments in the production process will be rendered obsolete by major product innovations. This leads to a marked rise in process innovation and a decline in product innovation. Entry based on novel product variants becomes more difficult and less able process innovators exit, contributing to a shakeout. Similarly to the first theory, firm exit rates eventually subside as the least able process innovators exit. Also similarly to the first theory, entrants during the shakeout initially have higher exit rates than preshakeout entrants due to their lesser experience, but over time these differences diminish as firms gain experience and the least capable innovators exit.

In the third theory [11], shakeouts are not triggered by particular technological developments but are part of a broader evolutionary process in which technological

change gives rise to increasing returns. The key idea of this theory is that larger firms earn greater profits from R&D, particularly process R&D, because they can embody their innovations in a larger level of output. As firms expand over time, this induces them to increase their effort devoted to process innovation, contributing to lower costs and prices. Entrants must be increasingly competent to offset this advantage of incumbents, and eventually the disadvantage of entrants becomes so large that entry is no longer feasible. Exit continues, though, as the most competent early entrants take over the industry by dint of their head start in growth. This contributes to a shakeout. In contrast to the first two theories, later entrants may initially have comparable survival rates to early entrants due to their greater competence, but at older ages their survival rates decline relative to early entrants as the industry is increasingly dominated by some of the earliest entrants.

These three theories embody the bulk of the ideas to date about how technology may contribute to industry shakeouts. We investigate whether the characteristic patterns of entry, survival, and technological change corresponding to these theories hold in the evolution of four products that experienced sharp shakeouts: automobiles, tires, televisions, and penicillin. All four products experienced declines of around 80% in the number of producers even as output continued to grow. The products span a range of technologies and eras in which their shakeouts occurred, suggesting that any common patterns among them would hold generally. All four products were developed commercially mainly in the United States, so our analysis focuses on U.S. producers. We analyze each product in turn and then integrate the findings for the four products.

Automobiles

The first commercial sale of a US-made automobile occurred in 1896. Subsequently the output of the industry grew exponentially, with production of automobiles reaching 23,000 by 1904 and climbing to 5.3 million by 1929. To track the participation of firms in the market, we used a list of automobile makes and producers compiled by Smith [18]. Smith also provided detailed information about mergers and acquisitions. These were treated as continuations of the firm with the same name as the new entity or of the largest firm involved if the new entity did not share the name of any of its constituents (such as General Motors), and exit of all other participants in the merger or acquisition. Comparison with other sources suggests Smith comprehensively identified manufacturers of automobiles, even very small ones, while excluding the numerous aspirants that never made it into full-scale production.

Smith lists four producers entering production in 1895, with the number of firms climbing sharply to a peak of 274 in 1909, then falling to 121 by 1918 and continuing to fall to an eventual low of seven firms in 1955. We date the shakeout of producers as starting in 1909 when the number of firms peaked.

Entry was concentrated in the years preceding the peak number of firms. Entry averaged 48 firms per year from 1902 to 1910 and then dropped at the start of the shakeout by two-thirds, averaging 16 firms per year from 1911 to 1921. Thereafter entry became negligible, with only 22 entrants in the entire period from 1922 to 1966. In contrast to these fluctuations in entry, exit rates remained remarkably stable over time. From 1900 to 1918, the percentage of firms exiting averaged about 16% per year. It decreased to 9% per year in 1919 to 1922 and then rose to 28% per year in 1923 to 1925, after which it fell back to an average of 12% per year from 1926 to 1939. The decline in entry after the start of the shakeout accords with all the theories, but the absence of any pronounced rise in the exit rate with the onset of the shakeout does not accord with the innovative gamble and dominant design theories.

The differences in survival rates of early and late entrants also did not display the initial disadvantage of shakeout entrants predicted by the innovative gamble and dominant design theories. Examining the survival rate of firms during their first five years, 34% of the 490 entrants through 1909 survived at least five years versus 33% of the 233 entrants after 1909. In contrast, the fifteen-year survival rate was considerably higher for the earlier entrants, with 18% of the entrants between 1895 and 1904 surviving over fifteen years versus 7% of the entrants between 1905 and 1909 and only 3% of the entrants after 1909. In terms of even longer-term survival rates, all of the sixteen firms that survived at least thirty years had entered by 1909, and only two of the sixteen entered after 1904. Thus, consistent with the increasing returns to R&D theory, later entrants did not initially experience a lower survival rate, but at older ages the earliest entrants increasingly took over the industry.

To analyze possi ble dominant designs and innovative gambles that might have triggered the shakeout in autos, we relied on a comprehensive list of automobile innovations from 1893 to 1981 [2] and various analyses of automobile innovations. The main candidate for a dominant design and also for a major innovation triggering the shakeout involved the Ford Model T. Introduced in 1908, the Model T solidified several features of the automobile [1, p. 13] and may have led to a shift from radical to incremental product innovation and a greater emphasis on process design [14, pp. 366-367], characteristic of a dominant design. Yet the Model T design did not endure nor did it make it safe to invest in process innovation without fear of obsolescence of the investment, two characteristics central to a dominant design. Indeed, by the early

1920s product innovation had largely rendered the novel features of the Model T obsolete, including its magneto integrated into the flywheel, planetary transmission, brakes, and four-cylinder engine. Alternatively, the all steel closed body of 1923 has been considered as the dominant design in autos [20]. However, it came well after the start of the shakeout. It also came after the enormous rise in process innovation in the 1910s that a dominant design would be expected to explain.

In terms of a major product innovation that might have triggered the shakeout in autos a la the innovative gamble theory, the Ford production system is a logical candidate. It ushered in a whole new era of "mass production" which revolutionized production of not just automobiles but many other products as well. It was not, however, based on a single innovation but the confluence of a number of important innovations that were developed over time. If any single innovation in the Ford system were to be singled out as the most influential, it would be the moving assembly line, but that came too late to have triggered the shakeout. Furthermore, process innovation hardly ceased after the introduction of mass production methods in the 1910s. Many significant process innovations were developed in the 1920s and 1930s, making it awkward to single out any particular innovation as the cause of the shakeout in autos.

While neither a dominant design nor major innovation appears to have triggered the shakeout in autos, the rate of process innovation grew markedly, both absolutely and relative to product innovation, as the industry developed. When output started to grow sharply after 1905 or so, the rate of process innovation increased greatly. These patterns are consistent with the increasing returns to R&D theory. Furthermore, consistent with the theory the leading firms were in the vanguard of innovation, particularly process innovation. The two industry leaders, Ford and GM, accounted for nearly all of the industry's major process innovations from 1907 to 1940. Keeping up with these innovations was critical for survival, and many firms exited in the face of the large costs required to assimilate these innovations into production.

Automobile Tires

Nearly all automobile tires were of the pneumatic variety, so our analysis focuses on pneumatic tires. In the U.S. the first pneumatic automobile tire was produced by Goodrich in 1895. Soon after the remaining members of the "big four" that would come to dominate the industry, Goodyear, Firestone, and U.S. Rubber, entered. To track participants in the industry, we compiled a list of firms and their dates of production starting in 1905 using the trade register *Thomas' Register of*

American Manufacturers. Information on mergers was developed from various sources [13].

The number of tire firms increased steadily from 1905 to 1922, reaching a peak of 276 in 1922. Subsequently the number of firms declined sharply, falling to 50 by 1936 and to an eventual low of 23 in 1970. Comparison with other sources confirms that the number of firms peaked somewhere between 1919 and 1922 and then declined sharply. Thus, based on *Thomas' Register*, we date the start of the shakeout as 1922.

After the start of the industry, entry increased steadily up to the date of the peak number of firms. Entry averaged 15 firms per year from 1906 to 1911, then doubled to 30 firms per year from 1912 to 1922, with 122 entrants listed for 1922 alone. Subsequently entry declined sharply, becoming negligible after 1925. This accords with all three theories. In contrast to automobiles, exit rates did not remain steady through the shakeout in tires. Until 1922 the exit rate remained around 10% per year, then roughly doubled during the period 1922-1932 before returning to amounts typically under 10% per year. This accords with the idea that a dominant design or innovative gamble caused exit rates to surge and entry to slow, yielding a shakeout. An alternative explanation of the increase in the exit rate is an unexpected slowdown in the growth of automobile purchases after the 1920-1921 recession combined with the entry of chain stores such as Sears Roebuck that forced tire manufacturers to accept very low prices for volume sales of replacement tires. Indeed, in his analysis of the industry, Lloyd G. Reynolds cited Goodyear's 1926 contract with Sears as the most important factor depressing firm profit rates after 1920 [17].

Further insight can be gained about the rise in exit rates by examining the survival rates of different entry cohorts. Consistent with the predictions of the dominant design and innovative gamble theories, entrants during the shakeout had lower initial survival rates than preshakeout entrants, with 54% of entrants prior to 1922 surviving at least five years versus only 33% of entrants after 1922. Again, an alternative explanation for this pattern is the slowdown in auto sales and chain store entry in the 1920s. If the greater exit rates of shakeout entrants were due to forces featured in the innovative gamble and dominant design theories, then the difference in exit rates between preshakeout and shakeout entrants at young ages should have diminished as they aged. However, fifteen and thirty-year survival rates suggest the opposite pattern. Among the 209 entrants through 1916, for example, 23% survived at least fifteen years versus only 8% of the 399 entrants after 1916. In terms of thirty year survival rates, the pattern is similar, with 11% of the entrants through 1916 surviving thirty years versus only 4% of later entrants. The differences are most

pronounced between entrants prior to 1907 and all later entrants, primarily because the "big four" and most of the other significant firms in the industry entered prior to 1907. This eventual dominance of the industry by the earliest entering firms is consistent with the increasing returns to R&D theory.

We turn next to technological patterns, summarizing conclusions drawn in the longer version of the paper. Major characteristics of the tire continued to change through at least the mid-1920s, with the adoption of straightside tires and rims, the switch to cords instead of cross-weave fabric for reinforcement, and Firestone's gradual process reengineering that led to low pressure balloon-shaped tires. The balloon tire design, which was a major breakthrough, was not widely adopted until at least 1925, suggesting that a dominant design did not occur until after the industry's shakeout had begun. Moreover, labor productivity in tires grew rapidly starting at least as early as 1909, and a number of significant process innovations were introduced long before the start of the shakeout. These patterns are not consistent with the dominant design theory.

To search for major innovations that could have triggered the shakeout a la the innovative gamble theory, we considered various lists of tire innovations such as the one compiled by Warner for 1895-1965 [21]. These lists indicated that the major product innovations in tires were introduced either well prior to the start of the shakeout or after the start of the shakeout. Moreover, the most significant product innovations often took many years to diffuse through the industry, suggesting that the shakeout was not triggered by a particular product innovation. The authors of the innovative gamble theory actually applied the theory to the tire industry. They proposed a major process innovation developed in 1916, the Banbury mixer, as the trigger of the shakeout. The Banbury mixer, though, lacked two essential characteristics as a candidate for the innovative gamble. First, it was not challenging to adopt. It was readily available from its supplier, who helped buyers adapt their production lines to use it. Second, its effects were confined to a stage of tire production involving only 17% of the production man hours used in manufacturing tires and tubes, and other stages experienced greater productivity advances than the one using the Banbury mixer. Indeed, some major producers only gradually replaced their older mixers with Banburys and were still using many of their older machines in the 1930s [19, pp. 41, 44, 55, 63, 72].

The inability to find a dominant design or innovative gamble behind the industry's shakeout should not be interpreted as an indication of the lack of importance of technological change in tires. From 1909 to roughly 1925, the tire industry had the highest rate of labor productivity growth of any U.S. industry [8, pp. 31, 52]. Indeed, the lack of an early dominant design or single outstanding innovation

reflects the large number of competitively significant innovations that were introduced before and during the shakeout. Consistent with the increasing returns to R&D theory, nearly all of these innovations that originated from tire producers came from the leading firms [21]. The vast number of later entrants did not keep up with these innovations and were soon forced from the industry [16, p. 48].

Televisions

Sales of U.S. television sets designed to receive experimental broadcasts began in 1939. World War II forced a suspension in these sales until 1946, when the Federal Communications Commission approved black-and-white broadcasting standards. Thereafter production of television receivers began in earnest.

To analyze patterns in entry and exit, we compiled a list of producers using the annual publication *Television Factbook*, supplemented with additional information on mergers and acquisitions. Entry was concentrated in the 1940s and early 1950s. By the time the *Factbook* first listed television producers in 1948, 70 firms were identified, with 71 additional firms entering from 1949 to 1953. The number of producers peaked at 89 in 1951, which is when we date the start of the shakeout. In the 35 years after 1953, only 25 U.S. based firms entered production, with 17 foreign TV manufacturers also setting up production or acquiring branch facilities in the U.S. beginning in the 1970s. Competition from imports also became substantial in the 1970s.

Exit rates were steady from 1948 to 1957, averaging around 20% per year, and then dropped to 12% per year for U.S. based firms (9% including foreign-based firms) during the following 32 years. While this does not reflect the rise in exit rates with the onset of the shakeout predicted by the dominant design and innovative gamble theories, the paucity of data for the preshakeout period precludes a sharp comparison. Consistent with the dominant design and innovative gamble theories, post-1951 entrants had higher initial exit rates than preshakeout entrants, with only 36% of post-1951 entrants surviving at least five years versus 51% of earlier entrants. However, these differences did not diminish over time, as predicted by the two theories, but increased. The fifteen year survival rate was 23% for the 70 firms listed in the initial publication of the *Factbook* in 1948, 19% for the 54 entrants in 1949 to 1951, and only 8% for the 41 post-1951 U.S. based entrants. The comparable rates for firms surviving at least thirty years were 7% for the 1948 firms, 2% for entrants in 1949 to 1951, and 0% for post-1951 entrants, with all the thirty-year survivors having entered by 1949. Thus, like autos and tires, these patterns reflect a growing dominance of the earliest entrants, consistent with the increasing returns to R&D theory.

The most important TV set design standards were established with the beginning of commercial black-and-white sales and later color television sales. Indeed, the advent of the FCC's color broadcast standard, coupled with the growing use of 21-inch picture tubes, was identified by the authors of the dominant design theory as the dominant design for TVs. However, these design features could not have caused the television shakeout, which began in 1951. Color sales were less than one-tenth black-and-white sales even in dollar terms until 1962, and black-and-white sales remained high until 1966. Furthermore, the 21-inch tube was hardly an industry standard. Not only were a great range of picture tube sizes used at any given point in time, but the market share of various sizes continued to change through the 1960s. No other developments would seem to qualify for the status of a dominant design, suggesting that the shakeout in televisions was not triggered by a dominant design. To identify a possible major innovation that might have triggered the shakeout a la the innovative gamble theory, we used lists of innovations such as the one compiled by Levy [15]. Among innovations introduced in the 1940s and 1950s around the time of the shakeout, no single innovation was particularly significant. Indeed, television engineers and executives uniformly indicated that television improvements were evolutionary rather than revolutionary [15, p. 36], suggesting the shakeout in televisions was not triggered by any single innovation.

Despite the evolutionary character of television innovations, set quality was critical to television firms' success. In studies of the black-and-white and color eras, firm survival was found to be more closely related to set quality than any other characteristic considered, including price, advertising, firm size, degree of vertical integration, and overall firm profitability [5, 22]. Furthermore, consistent with the increasing returns to R&D theory, the leading U.S. producers were in the vanguard in early manufacturing process innovations. Indeed, it was the greater attentiveness of foreign firms to solid state circuits, a leading edge technology affecting set quality and production cost, that enabled foreign firms to capture a large share of the U.S. market starting in the 1970s.

Penicillin

U.S. penicillin production began in 1941 after British researcher Howard W. Florey, concerned that penicillin could not be successfully developed in wartime Britain, traveled to the U.S. to enlist help. After spectacular clinical trials, an enormous government-led effort commenced with the goal to produce penicillin in quantity. At least 21 companies, 6 laboratories, and 7 government agencies were

involved [6, p. 9]. The effort led to the development of commercial penicillin production after the War.

To analyze entry and exit, we combined information from *Thomas' Register of American Manufacturers*, the Federal Tariff Commission's annual directory *Synthetic Organic Chemicals*, and sources listing participants in the wartime penicillin program [6, 7]. The number of penicillin producers increased steadily after the War, with 23 firms entering from 1947 to 1953. The number of firms peaked at 29 in 1952 and declined after 1954, reaching a low of 5 firms in 1970. Thus, we date the start of the shakeout as 1952. After 1953, entry averaged only 0.3 firms per year through 1982, after which entry increased to one firm per year from 1983 to 1992. In contrast to the predictions of the dominant design and innovative gamble theories, the exit rate remained fairly steady before and during the shakeout, averaging about 6% per year from 1943 through 1978, after which it increased to 12% per year. Firm survival patterns were similar to tires and televisions. The five, fifteen, and thirty-year survival rates were respectively 75%, 55%, and 40% for firms entering during the War, 70%, 40%, and 15% for entrants from 1946 to 1954, and 30%, 0%, and 0% for subsequent entrants. This indicates that the disadvantage of late entry grew over time, consistent with the increasing returns to R&D theory.

Product innovation involved the creation of new forms of penicillin. Far from a dominant design being established, new forms proliferated, particularly after synthetic methods were pioneered around 1958. The new forms introduced prior to the shakeout were relatively minor advances [3], suggesting that they did not contribute to the shakeout. The number of patents, innovations, and papers increased steadily through 1970, especially after 1958 [3], consistent with the trend to greater product innovation seen in the proliferation of new forms of penicillin after 1958. The one available measure of process innovation, the yield of penicillin per liter of broth in which it was produced, indicates a 17% annual increase from 1950 to 1958 versus only an 8% increase in 1958 to 1986 [4, p. 120]. This suggests that the shakeout did not correspond to a rise in process innovation nor was it triggered by a major process innovation. Process improvements drove down costs by about two orders of magnitude from 1945 to 1980 and firms faced a continual challenge to keep pace with the cost reductions. Only some of the early, wartime producers continued to produce the old forms of penicillin that were subject to these large cost decreases, consistent with the increasing returns to R&D theory.

Conclusion

The following patterns were observed in the four products.

1. Entry slowed around the time of each shakeout, eventually becoming negligible.

2. Only in tires did exit rates rise markedly with the onset of the shakeout, and this may have been caused by the unexpected decline in auto sales and the depression of profit margins due to chain store competition rather than by a particular technological development.

3. Entrants during the shakeout initially had lower survival rates than preshakeout entrants in tires, televisions, and penicillin, suggesting a disadvantage relative to earlier entrants. Rather than fade over time, though, these differences tended to become more pronounced as the firms aged, with early entrants eventually dominating all four products.

4. We did not find evidence of technological milestones, either in the form of major breakthroughs or the emergence of *de facto* product standards, around the start of the shakeouts. If anything, the products experienced continual improvements whose cumulative impact typically dwarfed that of any single innovation.

5. There was no tendency for innovation to shift from product toward process innovation around the onset of the shakeouts. More generally, the timing of product and process innovation were not closely linked. If anything, the evidence suggested that firm success often depended on committing to process innovation well before any slow down in product innovation.

6. The largest firms in each product were leaders in innovation, particularly process innovation. They tended to enter early and devote considerable effort to innovation from their outset.

These findings do not support that the shakeouts in the four products were triggered by particular innovations or the emergence of dominant designs. Rather, they suggest that the shakeouts were part of a broader evolutionary process in which early entrants become leaders in product and process innovation and eventually dominated their industries. This is consistent with R&D imparting increasing returns, contributing to an evolutionary process in which success breeds success. It suggests that a spiraling R&D advantage may have been at the root of the shakeouts in the four products.

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