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The Market Evolution and Sales Take-off of Product Innovations

Rajshree Agarwal and Barry L. Bayus

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W O R K I N G   P A P E R   S E R I E S

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Report Summary: The Market Evolution and Sales Take-off of Product Innovations

Rajshree Agarwal and Barry L. Bayus

Empirical research and observation have shown that the early market evolution of consumer and industrial product innovations follows a predictable course: a period of slow growth immediately after commercialization followed by a sharp increase, or take-off, that corresponds to the first large increase in sales. Understanding the timing of this sales take-off is critical for industry analysts and managers since it influences the allocation of resources to R&D, product development, marketing, and manufacturing.

Conventional wisdom views price as the key explanatory variable in determining sales take-off time. According to this perspective, sales for a product innovation are initially low due to the product's relatively high prices; as prices decline over time, however, the new product crosses a threshold of affordability and sales take off.

Study and Findings

In this report, authors Agarwal and Bayus argue that shifts in demand as well as supply curves lead to market take-off. They identify product improvement as the key factor in the diffusion and sales take-off of new products.

To provide empirical evidence, they explore the relationship between take-off time, price decrease, and firm entry for a sample of 30 consumer and industrial product innovations commercialized in the U.S. over the past 150 years. They find that firm take-off systematically occurs before sales take-off and that new firm entry and the demand shifts during the early evolution of a new market that result from non-price competition dominate other factors in explaining observed sales take-off times.

Based on their findings, the authors propose a revised narrative for the market evolution of a product innovation, as follows: a long incubation period ensues after the pioneering invention, eventually followed by the commercialization of various specific product forms or models by one or more firms (either small or large). As the new market evolves, the activity of competing firms legitimizes the product innovation as a real opportunity, and the number of firms competing in the new market increases. As a result, supply-side capacity increases. Demand also increases as the aggressive, non-price competition that occurs among incumbents and entrants in the new oligopolistic market focuses on demand-enhancing efforts such as R&D directed toward product improvements. Depending on the specific product innovation and the nature of its supply and demand curves, prices either decrease or increase. More importantly, consumers respond to this competitive activity and accept that the product innovation provides real benefits over existing products. As a result, sales take off. After this, both sales and the number of competing firms continue to increase but at a less dramatic rate. Eventually, there is a shakeout of firms in the industry, and the number of competitors drops and then stabilizes.

Managerial Implications

These findings are good news for managers since they suggest that sales growth does not have to come at the expense of the compressed profit margins typically associated with declining prices. However, these results also suggest that it may be very difficult for a single firm to significantly reduce the time to take-off for a new product. While individual firm decisions on advertising expenditures, distribution policies, and product development may influence their own brand sales, the collective marketing efforts of competitors seem to be the driving force for market growth and take-off. This suggests that monopolies dampen the growth of new markets and that competing firms work together to influence the take-off of a product innovation.

With an eye towards identifying the factors related to a swift sales take-off, future research should thus empirically and analytically investigate the nature of firm alliances and collaborations during the formative stages of a new market.

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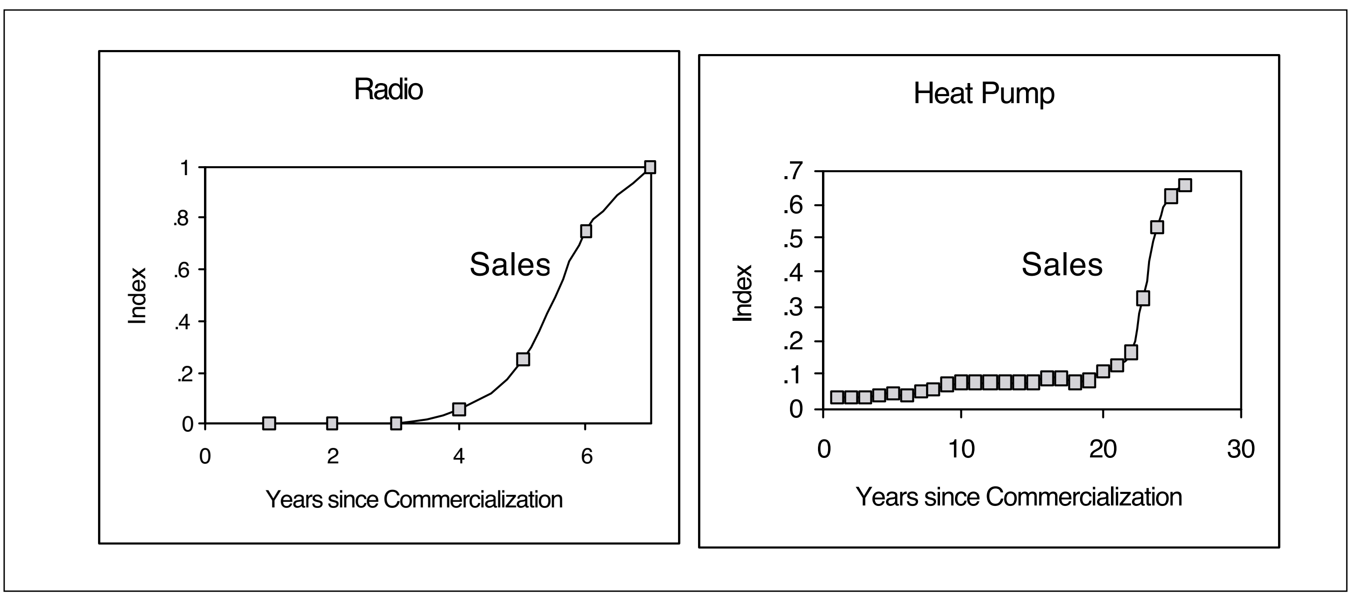
Introduction

One of the most enduring research streams in marketing examines the diffusion of product innovations (review in Rogers 1995). Although previously attention centered on estimating sales diffusion models and then using these models for forecasting purposes, recent interest has shifted toward deepening our understanding of the temporal patterns associated with new product sales (Mahajan, Muller, and Wind 2000). This shift in the emphasis of the research reflects the growing interest in and importance of expanding our knowledge of how new markets evolve (Marketing Science Institute 1998).

The early market evolution of successful consumer and industrial product innovations generally follows a recognizable course: an initial period of slow growth occurs immediately after commercialization and is followed eventually by a sharp increase (Mahajan, Muller, and Bass 1990; Golder and Tellis 1997; Klepper 1997). For most new products, this take-off point is clear since it corresponds to the first large increase in sales. For example, consider Figure 1, which shows a sharp increase in sales for two product innovations. This "hockey stick" pattern seems to be popular among industry pundits since it is commonly used to depict the sales of really new technological products (Moore 1991).

Figure 1. The Sales Take-off of Product Innovations



As Figure 1 suggests, the time that elapses before a sales take-off can vary considerably: some product innovations take off quickly after commercialization, while others languish for years with low sales (Mahajan, Muller, and Bass 1990; Golder and Tellis 1997). Understanding the timing of a sales take-off is critically important for industry analysts and managers since the time between commercialization and sales take-off can have serious short- and long-term resource implications for R&D, product development, marketing, and manufacturing.

Conventional wisdom holds that primarily supply-side factors explain sales take-off times (Bass 1980; Russell 1980; Metcalfe 1981; Foster 1986; Stoneman and Ireland 1983; Golder and Tellis 1997). According to this line of thought, price is the key explanatory variable that determines the sales take-off time: initially, relatively high prices keep sales for product innovations low; as its price declines, the new product crosses a threshold of affordability and its sales take off dramatically.

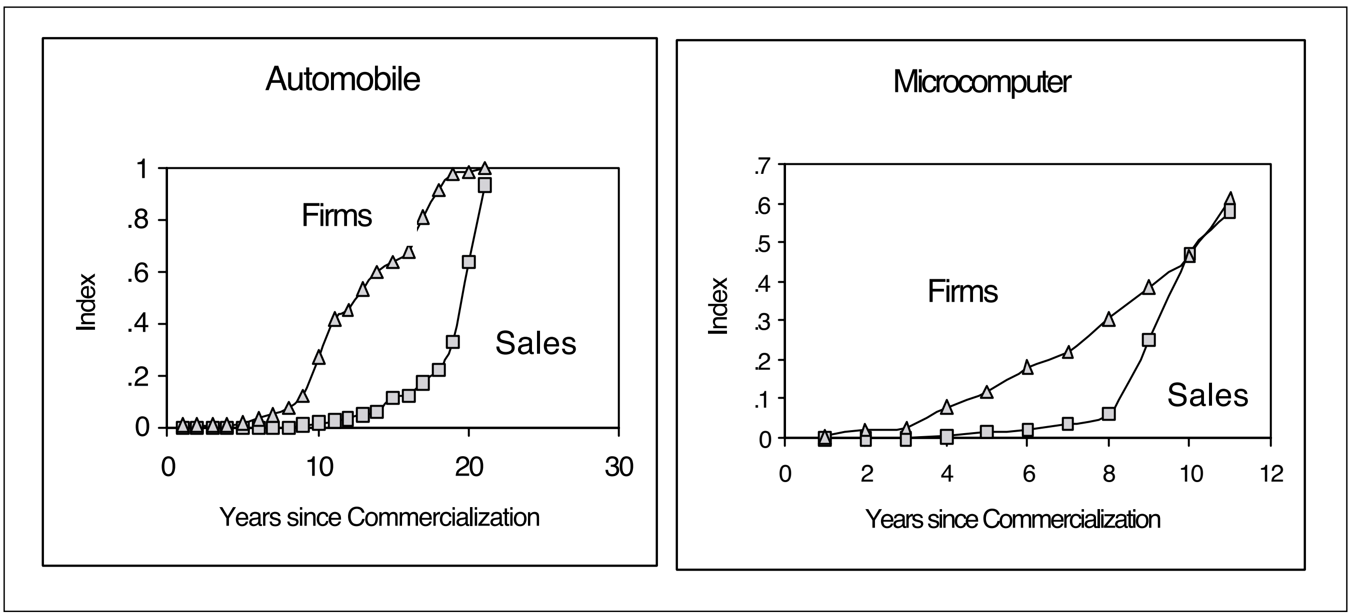
In this paper, we argue that the conventional, supply-side explanation is incomplete. Our fundamental idea is that a sales take-off is caused by outward shifting supply and demand curves (Stoneman 1983; Thirtle and Ruttan 1987; Karshenas and Stoneman 1995). Thus, we propose that sales are initially low due to the relative primitiveness of the first commercialized forms of new innovations, and increases in sales occur as new firms enter the market. Firm entry affects demand for the product as well as supply since new firms seek to differentiate themselves through product improvements, expanded distribution, and increased consumer awareness of brand quality. Our explanation is consistent with the findings in the economics and technology literature that firm competition in the early stages of new market growth focuses on continual product improvement (Shapiro 1986; Thomson 1986; Utterback 1994; Klepper 1997; Adner and Levinthal 2001).

To provide empirical evidence for this explanation, we examine how price decreases and new firm entry affect the initial sales take-off for a set of consumer and industrial product innovations commercialized in the United States during the last 150 years. While recognizing that firm entry creates additional supply-side capacity, we follow prior research and suggest that entry in the formative stages of a new market is primarily associated with demand-side changes from both incremental product improvements and the efforts by firms to develop market infrastructure. If entry is only associated with outward shifts in the supply curve, firm entry and price declines should be highly correlated, with each explaining roughly the same amount of variance in sales take-off times. Based on a proportional hazards analysis, we find that price reductions and new firm entry are significant explanatory variables. Yet price reductions account for less than 5 percent of the variance in sales take-off times while new firm entry explains almost 50 percent of this same variance. Although we find no evidence of price mediating the effects of firm entry on sales take-off times, we find that price reductions matter more for products that can be improved with low R&D costs. We interpret these results as supporting the idea that demand-side shifts during the early market evolution of new innovations due to non-price factors significantly affect the timing of a sales take-off.

The Timing of a Sales Take-off

We follow the industrial organization literature (reviews in Geroski 1991, 1995) and focus on how firm entry affects supply and demand curves. See Appendix 1 for an extended discussion of a theoretical framework for the sales take-off phenomenon. As Figure 2 indicates, the literature finds a sharp take-off in the number of firms in the early stages of market evolution (Gort and Klepper 1982; Rosegger and Baird 1987; Klepper and Graddy 1990; Utterback and Suarez 1993; Jovanovic and MacDonald 1994; Utterback 1994; Agarwal and Gort 1996; Klepper and Simons 1997, 2000). However, this research does not look directly at the sales take-off phenomenon; its emphasis is more on explaining how market structure evolves as an industry matures (Klepper 1997).[1]

Figure 2. The Evolution of Market Structure for Product Innovations



As suggested by these studies, firm entry into a new market results in increased capacity. In the context of new product markets, firm entry also may result in an increase in competition or decreases in production costs due to new process innovations. Concentrating on this supply-side perspective, several researchers argue that a price decrease is the key factor leading to a take-off in sales (Russell 1980; Foster 1986; Golder and Tellis 1997). Theoretical research concludes that optimal prices are decreasing when the supply curve shifts outward (Bass 1980; Metcalfe 1981; Stoneman and Ireland 1983; Klepper 1996). Empirical studies supporting this conclusion include Golder and Tellis (1997), who find quick sales take-off times for new consumer durables that have low relative prices, and Agarwal (1998), who reports declining price trends for most new consumer and industrial products.

At the same time, however, this literature also indicates that firm entry during the early years of market evolution can shift the demand curve outward. Demand increases stem from firm activities in new markets that are geared toward increasing actual or perceived product quality.[2] As suggested by Gort and Klepper (1982), early entrants often bring crucial new information, skills, and product quality improvements that result in demand increases. These contributions are particularly important since the early commercialized forms of new innovations are generally quite primitive (Rosenberg 1982, 1994; Shapiro 1986; Thomson 1986; Klepper 1997). In addition, as a new market evolves, the consumer base expands due both to increases in product offerings and to attempts at product differentiation by the new entrants and by the incumbents who respond to the threat posed by these new entrants (Brown 1981; Bayus and Putsis 1999). Several researchers note that competition during the early stages of market growth primarily takes the form of continued product improvements (see reviews in Geroski 1991, 1995 and Klepper 1997). Consistent with this idea, Gort and Konakayama (1982) report a positive and significant relationship between firm entry and the rate of patenting for a sample of seven industrial innovations.[3]

In addition to the above studies, all of which examine broad indicators of product quality improvements through entry across several product markets, detailed evidence of the relationship between early firm entry and product improvements is available from various industry case studies (Christensen 1993; Utterback 1994). Consider, for example, the evolution of major product and process innovations (innovations ranked 4 or higher on a 7-point scale by Abernathy, Clark, and Kantrow 1983) in the automobile industry as shown in Table 1.

Firm entry in this industry accelerated only after 1899, and sales of automobiles did not take off until 1909. As discussed in Klepper and Simons (1997), product innovation in the automobile industry was greatest from commercialization until the first decade of the twentieth century, whereas process innovation was very low during this period. More importantly, Klepper and Simons (1997) note that it was new entrants that contributed the largest share of product innovations, including the front-mounted four-cylinder engine, shaft-driven transmission, and pressed steel frame. New entrants also caused the automobile to evolve from its bicycle and carriage origins toward the design of luxury cars pioneered in France. Introduced in 1908, Ford's Model T represented the culmination of many of these incremental product improvements. Not surprisingly, overall automobile sales dramatically increased in 1909.

The later history of the automobile industry shows that the majority of process improvements came after 1909, with the most dramatic improvements in manufacturing occurring after the sales take-off when Ford pioneered the moving assembly line (1913–1914). Klepper and Simons (1997) state that with few exceptions, the industry's major process innovations were dominated by the largest firms (Ford and General Motors). Although anecdotal in nature, this example strongly suggests

Table 1. The Evolution of Major Product and Process Innovations in the Automobile Industry

Year	Firm	Product Innovation	Process Innovation
1890 Commercialization			
1893	Duryea	Single plate clutch	
1895	Haynes-Apperson	Aluminum engine	
1896	King	En-bloc engine	
1896	Duryea		First multiple production of one car design
1898	Duryea	Internal-expanding brakes	
1898	Columbus	Enclosed car body of wood/steel	
1899 Firm Take-off			
1899	Packard	Automatic spark advance	
1900	Most Producers		Gasoline engine mounted in front
1901	Autocar	First shaft-driven American car	
1901	Oldsmobile		First mass-produced auto
1902	Locomobile	4-cylinder, front-mounted engine	
1902	Northern	3-point suspension of power unit	
1902	Northern	Planetary gear set	
1902	Northern	Integral engine and transmission unit	
1902	Marmon		First all metal body (aluminum casting)
1903	A.O. Smith	Pressed steel frame	
1904	Ford	Torque tube drive	
1906	Ford	Wiring harness for elec. system	
1907	Ford		Multiple simultaneous machining operations
1908	Ford	Detachable cylinder heads	
1908	Ford	Magneto integrated into flywheel	
1908	Ford		Vanadium steel components
1909 Sales Take-off			
1910	Ford		First branch assembly plants
1913	Ford		Moving flywheel-magneto assembly line
1914	Ford		Elevated moving chassis assembly line
1914	Cadillac (GM)	First large-scale production of V8 engine	
1917	Ford		Baked enamel finishes
1920	Ford		Continuous pouring of molten iron

Source: Abernathy, Clark, and Kantrow 1983 that product improvements in the automobile industry occurred during the early years of market evolution when firm entry was high.

Studies also indicate that product improvements, relative to process improvements, typically are emphasized in the early stages of a new market (Abernathy and Utterback 1978; Utterback 1994; Klepper 1996, 1997; Klepper and Simons 1997). Thus, it is not surprising that the dramatic price decreases due to declining costs from process improvements and increasing cumulative sales volume are usually observed only after the sales take-off (Bass 1980; Metcalfe 1981; Stoneman and Ireland 1983).

In addition to incremental product innovations, demand for the product also may increase as a result of efforts by incumbents and new firms to increase the perception of product quality. For example, extensive advertising and promotion may be required to educate and inform potential consumers about the benefits of a new product innovation (e.g., the first phonographs brought the famous opera singer Caruso into people's homes). As suggested by Brown (1981), the timing of a sales take-off for a product innovation also may be related to the evolution of a market infrastructure; in particular, new firm entry may proxy for infrastructure development. This infrastructure can take different forms and might be established in various ways. New distribution channels and pricing arrangements may be necessary for some innovations (e.g., sewing machines required the establishment of new retail outlets as well as credit terms). Similarly, widespread adoption of product innovations often requires the development of complementary products and services (e.g., automobiles needed roads and gas stations). Such fundamental changes in infrastructure often result from either the new information brought in to the market by entrants or from the competitive strategies of incumbents to stave off entry.

Based on the discussion so far, new firm entry clearly impacts both the supply and demand of a new product innovation. Accordingly, our first hypothesis highlights the importance of new firm entry in the take-off of product innovations.

> H_1: Product innovations with a high (low) level of new firm entry have short (long) take-off times.

Next we address the relative importance of demand- and supply-side effects associated with firm entry as explanatory factors for sales take-off. The related literature generally emphasizes supply-side effects and concludes that price declines are the crucial determinant of sales take-off (Golder and Tellis 1997). But outward shifting demand and supply results in an indeterminate price effect, not unambiguously increasing sales. Further, the demand-increasing efforts of firms may come at additional costs that can themselves affect product supply. For example, crucial R&D expenditures in the early years of market evolution may actually increase costs, thereby offsetting effects on price of outward shifts in supply. Thus, the possibility of outward shifting demand and supply implies that sales increases may be associated with *either* higher *or* lower prices. Importantly, this ambiguity in price effects can possibly account for actual industry cases such as turbojet engines, cathode ray tubes, and microwave ovens in which sales took off even though prices were increasing.

Following prior empirical research, the isolated effects of supply shifts during the early stages of new market formation can be assessed by relating a direct measure of price decreases to take-off times. By studying the relationship between price decreases, new firm entry, and take-off times across a set of product innovations, we can also explore the role of shifting supply and demand curves in leading to a sales take-off. To the extent that supply-side factors alone drive take-off times, price declines and firm entry should be highly correlated, with each separately accounting for very similar amounts of variance in observed take-off times. On the other hand, if demand-side factors are also important, firm entry should offer some explanation beyond price decreases for observed take-off times (since in this case, firm entry will include the effects of price decreases due to both supply and demand changes). If demand shifts due to the actual and perceived product improvements associated with new firm entry are a key driver of take-off times, firm entry should dominate price as an explanatory variable of take-off times. Alternatively, if price mediates the relationship between firm entry and take-off time, then a statistically significant relationship between firm entry and take-off time should disappear when price is added to the model (Baron and Kenny 1986).

Based on this discussion, our next two—competing—hypotheses addresses the relative importance of supply (measured directly by changes in price) and demand (measured indirectly as the impact of new firm entry after accounting for price effects) in explaining take-off times.

H_{2a}: Supply-side effects, as measured by price changes, dominate demand-side effects in explaining the take-off times of product innovations (i.e., changes in price and new firm entry account for the same amount of variance in take-off times).

H_{2b}: Demand-side effects, as measured by the differential impact of new firm entry over price changes, dominate supply-side effects in explaining the take-off times of product innovations (i.e., price does not mediate the relationship between new firm entry and take-off).

An Empirical Analysis of Market Take-off

In this section, we focus our attention on the sales take-off time and possible explanations for its variation across products. Similar to prior research efforts, we do not consider possible sales patterns after take-off (e.g., some products like eight-track tape and videodisc players did achieve a sales take-off but had very short market lifetimes). We use secondary data to empirically examine the market evolution of product innovations, and our study is consistent with prior research in that we only consider "successful" innovations. This sample bias concern, however, is mitigated by the fact that new products historically exhibit a wide variation in the time to sales take-off. Since several products in our sample take well over 20 years before achieving a take-off (see Figure 1), innovations that could have been considered "failures" based on their very low sales in the early years of industry formation are included in our analysis. We also examine the take-off phenomenon for industrial as well as consumer products.

Data Sources

To develop an appropriate sample of innovations, we began by consulting various technical sources: scientific journals, chronologies, and encyclopedias of new inventions. To be considered for inclusion in our study, a consumer or industrial product innovation had to be deemed significant by experts in the field. It also had to result in entirely new product markets rather than just generating improvements or sub-sections of existing markets. Once we had identified an appropriate list of innovations, the hurdle then became the availability of consistent data for variables related to both demand (sales, price) and market structure (number of firms).

Accurate historical data on new product-markets are typically very difficult to obtain, and even harder is the task of matching sales and price information to data on entry and the number of firms competing in the market. While there are several consumer and industrial product innovations for which sales and price information are available, often data on the entry, exit, and number of firms are not readily available. After several hundred hours of research, we were able to develop consistent time series data on the key variables for 30 product innovations introduced in the United States between 1849 and 1984 (see Table 2 for a list of the product innovations).

Table 2. Key Dates for Sample of Product Innovations

Product	"Invention" Year	"Commercialization" Year	Firm Take-off Year	Sales Take-off Year
Sewing machine	1830	1849	1853	1859
Automobile	1771	1890	1899	1909
Phonograph record	1877	1897	1917	1919
Vacuum cleaner	1907	1911	1928	1934
Outboard engine	1905	1913	1916	1936
Electric blanket	1914	1915	1923	1952
Dishwasher	1898	1915	1951	1955
Radio	1912	1919	1922	1923
Clothes washer	1901	1921	1923	1933
Freon compressor	1930	1935	1938	1964
Cathode ray tube	1897	1935	1943	1949
Clothes dryer	1930	1935	1946	1950
Electric razor	1928	1937	1938	1943
Styrene	1831	1938	1943	1946
Piezoelectric crystals	1880	1941	1944	1973
Home freezer	1924	1946	1947	1950
Antibiotics	1928	1948	1950	1956
Turbojet engine	1934	1948	1949	1951
Ballpoint pen	1888	1948	1957	1958
Garbage disposer	1929	1949	1953	1955
Magnetic recording tape	1928	1952	1953	1968
Heat pump	1851	1954	1960	1976
Computer printer	1944	1960	1971	1979
Home microwave oven	1947	1970	1974	1976
Monitor	1927	1971	1975	1981
Microcomputer	1962	1974	1977	1982
Home VCR	1951	1974	1975	1980
Compact disc player	1979	1983	1984	1985
Cellular telephone	1970	1983	1985	1986
Optical disc drive	1979	1984	1987	1993

Our sample size compares favorably with the average sample size of 14 product categories used in prior new product diffusion studies (Sultan, Farley, and Lehmann 1990). These 30 innovations encompass a broad spectrum of important products introduced over the past 150 years, and include a diverse mix of consumer and industrial products, as well as products that vary in their capital and technological intensiveness. In addition, the product innovations we study overlap with those studied by other researchers (Table 2 includes 13 of the new consumer durables examined by Golder and Tellis 1997 and 11 of the consumer and industrial innovations studied by Gort and Klepper 1982).

Annual data were gathered for these 30 products from a variety of published sources (see Appendix 2 for a summary of these sources). Since we had no prior information on the actual take-off times for each product, the collected data generally extended well beyond the introduction and growth stages. Information on the commercialization date, entry, exit, and number of firms producing the product in any given year were mainly compiled from the *Thomas Register of American Manufacturers*, a source that has been widely used to study the evolution of markets (e.g., Gort and Klepper 1982; Klepper and Graddy 1990; Jovanovic and MacDonald 1994; Agarwal and Gort 1996; Klepper and Simons 2000; Robinson and Min 2002).[4] The *Thomas Register*, which dates back to 1906, is a national buying guide that is used primarily by purchasing agents.[5] In extensively describing various sources of business information, Lavin (1992) states that the *Thomas Register* is the best example of a directory that provides information on manufacturers by focusing on products. According to Lavin (1992), "The *Thomas Register* is a comprehensive, detailed guide to the full range of products manufactured in the United States. Covering only manufacturing companies, it strives for a complete representation within that scope" (p. 129).

In choosing product-markets, we excluded those product-markets for which there was a lack of consistency of boundaries between the *Thomas Register* and those defined by other agencies such as the U.S. Census of Manufacturers and various trade organizations. This ensured accurate matching of the data for the number of firms with data on sales and price information. In addition, multiple *Thomas Register* categories were combined as needed to ensure the inclusion of all competitors in a market.[6] Firm listings were also subjected to several checks to ensure actual market entry rather than a renaming, relocation, or merger between existing firms (see Agarwal 1997 for details). We also used the asset size class reported in the *Thomas Register* to categorize firms as large or small after appropriately adjusting the boundaries of these classes over time to account for inflation.[7]

Data for sales and average prices were compiled from a variety of sources (see Appendix 2) widely used by other researchers (Golder and Tellis 1997; Agarwal 1998). The annual prices for each product were deflated by either the Consumer Price Index (consumer products) or the Producer Price Index (industrial products) to correct for inflation and general productivity changes (economy-wide rather than product specific). Finally, we also estimated an invention year for each product innovation based on several published sources (Giscard d'Estaing 1986) and analyses (e.g., Jewkes, Sawers, and Stillerman 1958; Enos 1962; Mensch 1979;

Kohli, Lehmann, and Pae 1999). We recognize, however, that there is considerable controversy over the accuracy of dating inventions (Freeman, Clark, and Soete 1982; Rosenberg 1994). Thus, these dates are included only to fill out the timeline of market evolution and should be used with caution.

Key Variable Definitions and Hypotheses

Our two key explanatory variables are price declines and firm entry. In addition, we consider several control variables, including year of commercialization, World War II, and product type. We do not include other economy-wide variables such as GNP since none were significant in explaining the take-off times. The variables we consider are summarized in Table 3 as well as briefly discussed below.

Table 3. Variables and Descriptive Statistics

Variable	Definition	Mean	Standard Deviation	Minimum	Maximum
Changes in Price (Price)	Estimated coefficient from an exponential time trend	–.06	.14	–.495	.428
New Firm Entry	$\frac{1}{n-1}\sum_{i=1}^{n-1}\frac{\#\,entrants_i}{\#\,firms_i}$	.30	.20	.052	.812
Year of Commercialization	Year of product commercialization (see Table 2)	1939.83	30.11	1849	1984
World War II	= 1 if WWII occurred between commercialization and take-off = 0 otherwise	.23	.42	0	1
Product Type (R&D Costs)	Average R&D expenditures as a percentage of sales (1987-1997)	4.92	3.33	2.20	13.00

Changes in Price. To measure Changes in Price, we follow prior observations (Bass 1995) and empirical analyses (e.g., Bayus 1992) by fitting an exponential time trend ($\lambda e^{\theta t}$) to the annual price series for each innovation. As expected, excellent fits are obtained. In this way, our measure of Changes in Price is the estimated exponential coefficient θ (which is independent of take-off times).

New Firm Entry. We define the annual percentage of new entrants as the ratio of the number of entrants (net of exits) to the total number of competitors in any year, and compute our measure of New Firm Entry between commercialization and the year prior to sales take-off as the average of the annual values during that period. Letting N = period in which sales take off, we have

$$\textit{New Firm Entry} = \frac{1}{n-1}\sum_{i=1}^{n-1}\frac{\#\,entrants_i}{\#\,firms_i}$$

New Firm Entry for the other time periods is defined similarly.

Year of Commercialization. Since our sample of product innovations spans more than a century, it is highly likely that there have been significant changes in the economic climate in which firms operate. Some notable examples include the broad leaps in communications and transportation, the general growth in GNP, and the expansion of populations and markets (through globalization, etc.). The year of product commercialization is one way to control for any systematic changes that may have occurred in the underlying structural conditions and barriers to entry across our sample of product innovations. Consistent with prior research, we expect that the effect of Commercialization Year on the probability of take-off is positive.

World War II. Major economic upheavals due to events such as World War II can affect take-off times. Therefore, our analyses include a dummy variable controlling for the possible effects of World War II on take-off times. We expect that the take-off time is greater for an innovation if World War II occurred between its commercialization and its time to firm or sales take-off.[8]

Product Type. The variation in take-off times across product innovations may be related to product characteristics.[9] In particular, the resources required to improve an early commercialized form of a new product are expected to be negatively associated with take-off times. We control for the possible relationship between take-off times and product improvement costs by including a measure of R&D Costs. Cross sectional differences in the product markets are measured by constructing a steady-state measure of R&D Costs, calculated as average R&D expenditures as a percentage of sales between 1987 and 1997 for each innovation in our sample (at the three-digit SIC level) using NSF data. Although we recognize that this is a crude measure, it represents the best set of consistent data that are available.[10]

Determining Take-off Times

To consistently identify take-off times, we follow Gort and Klepper (1982) and Agarwal and Gort (1996) by using a statistical procedure that is described in Appendix 3. Briefly, this methodology allows us to distinguish between any two consecutive intervals by examining the data on annual percentage change in sales (for the sales take-off) and annual net entry rates (for firm take-off) for each product. To determine the take-off year for a product, we first partition the appropriate series into three categories—the first and third categories contain the years where the percentage change in sales or net entry rate clearly reflect the pre- and post-take-off periods, respectively. Periods for the in-between years are then optimally classified based on mean values.

As a final validity check, we also carefully matched the calculated take-off times with information in available published histories of the product innovations. Applying this procedure to each of our 30 product innovations gives the take-off times reported in Table 2. For the set of product innovations we consider, it is clear that the firm and sales take-off years do indeed represent sharp increases over the prior year since, on average, the percentage change in the number of firms at firm take-off is +123 percent and the percentage change in sales at sales take-off is +136 percent.

Descriptive Statistics

Simple correlations between the variables are reported in Appendix 4; Figure 3 summarizes the descriptive statistics on key variables. As noted in the literature (Jewkes, Sawers, and Stillerman 1958; Mensch 1979; Kohli, Lehmann, and Pae 1999), the time between invention and commercialization is generally very long (the average for our product innovations is almost 30 years). Consistent with Schumpeter's (1939, 1943) thesis that early entrants into a new market base their entry decisions on expected rather than realized sales, Table 2 shows that firm take-off precedes sales take-off for every one of our 30 product innovations. Moreover, for 26 of the 30 innovations, firm take-off preceded sales take-off by three or more years. As shown in Figure 3, the mean time between commercialization and firm take-off is just over six years for our set of innovations, and the mean time between firm and sales take-off is eight years.

Figure 3. Descriptive Statistics for the Market Evolution of Product Innovations (means)

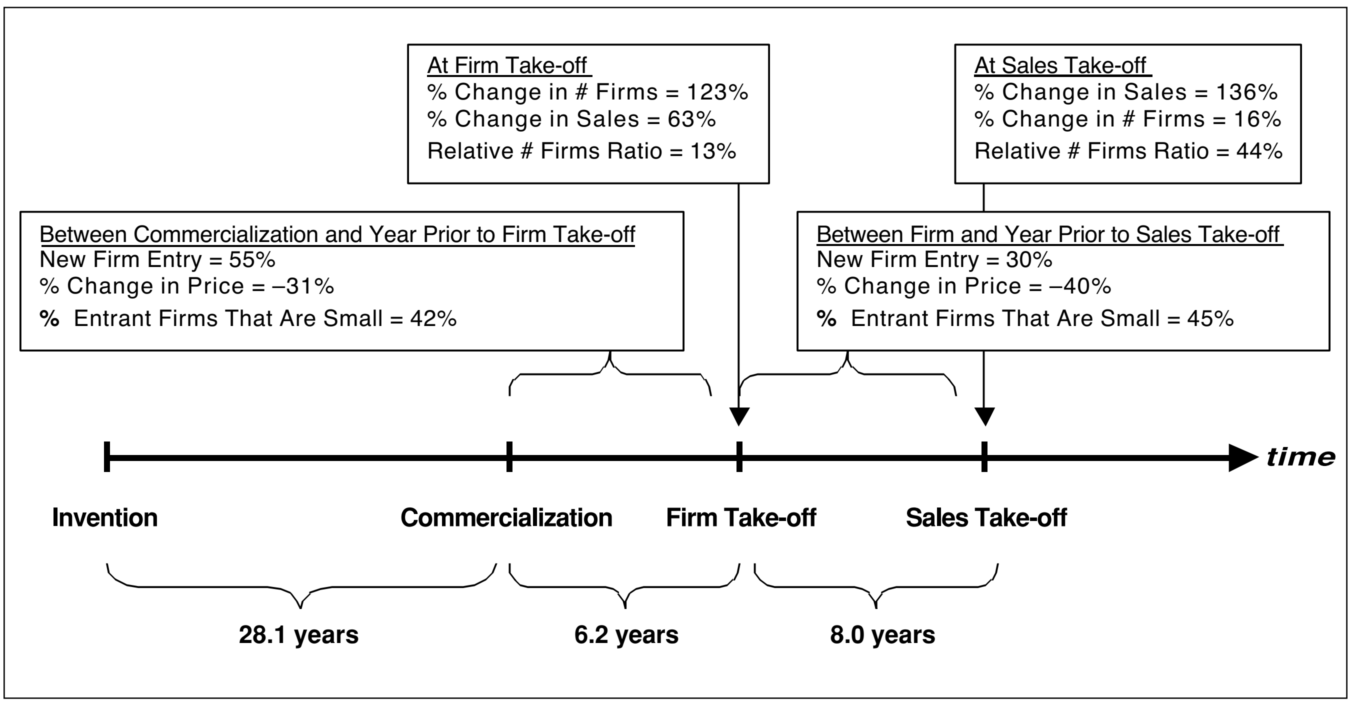


Figure 3 reports that New Firm Entry between commercialization and firm take-off for our set of innovations is 55 percent, i.e., over half of the competitors in each year before the firm take-off tend to be new entrants. However, these firms still only represent 13 percent of all potential competitors (see the Relative # Firms Ratio in Figure 3, defined as the ratio of the number of firms to the peak number of firms over the observed product life cycle). New Firm Entry between the firm and sales take-off is 30 percent, and by the year of sales take-off, 44 percent of all the potential competitors have already entered the market. Together, these results indicate that almost one-third of all the eventual competitors (Relative # Firms

Ratio at sales take-off less Relative # Firms Ratios at firm take-off) enter in the period between firm and sales take-off. In other words, a large fraction of the competitors in a new market enter before the sales take-off (although over half of a new market's eventual competitors do enter after the sales take-off). These statistics strongly suggest that the monopoly period for a product innovation is brief at best and occurs well before the product growth stage.

Based on the estimated, exponential price trends for each innovation, Figure 3 also reports that the percentage change in price between commercialization and year prior to firm take-off is –31 percent, and between firm and year prior to sales take-off is –40 percent. Clearly, prices are declining over time for this set of product innovations.

Table 4 suggests that the time intervals vary by commercialization year. In particular, the time between commercialization and firm take-off has significantly declined over time for this set of product innovations, and the time between commercialization and sales take-off has also shrunk. Interestingly, the time between firm and sales take-off has not significantly declined over this period. In addition, Table 4 suggests that the fraction of large entrants has increased over the last 150 years (see also Chandler 1977).

Table 4. The Market Evolution of Product Innovations (*t*-statistics in parentheses)

Products Commercialized	Invention to Commercialization	Commercialization to Firm Take-off	Firm to Sales Take-off	Commercialization to Sales Take-Off
Average Number of Years				
Before WWII	27.07	9.29	9.43	18.71
After WWII	29.00	3.50	6.75	10.25
	(–.16)	(2.18)[b]	(.89)	(2.40)[a]
% Entrants That Are Small				
Before WWII	NA	56	52	54
After WWII	NA	30	40	36
		(2.71)[a]	(1.20)	(2.20)[b]

n = 30; [a]significant at 0.01 level; [b]significant at .05 level

Although the details are not reported here, we also explored the potential relationship between firm entry, entrant size, and market opportunity. We find that New Firm Entry between commercialization and year prior to firm take-off is a significant negative correlate with the percentage of entrant firms that are small ($r = -.41$; $p \leq .05$). On the other hand, entrant size is not significantly related to New Firm Entry between firm and year prior to sales take-off. Although entrepreneurs may play a pivotal role in the initial commercialization of a product innovation (Schumpeter 1943; Feller 1967), these results suggest that the entry of larger firms with greater resources and commitment to build the market may attract other firms to the nascent industry. These results are also consistent with the idea that potential industry participants need some signal (e.g., the participation of larger firms) that an infant industry is legitimate before they enter en masse (Aldrich 1999; Van de Ven, Garud, and Venkataraman 1999). We also find that New Firm Entry between firm and year prior to sales take-off is a significant negative correlate with the relative number of firms at take-off ($r = -.40$; $p \leq .05$). At the same time, the relative number of firms is not significantly related to New Firm Entry between commercialization and year prior to firm take-off. These results suggest that the entrants after firm take-off base their entry decision on perceived market opportunities as reflected by the remaining competitive potential associated with the product innovation. Not surprisingly, these entrants generally want to get to market before the competitive landscape is fully established (Lieberman and Montgomery 1998).

Estimation Approach and Results

We use Cox's (1972) proportional hazards regression model to study sales take-off times. The proportional hazards model is appropriate since it allows for estimation of the determinants of the hazard rate, i.e., the probability of take-off in period t given that the product has not taken off till period t-1. See Helsen and Schmittlein (1993) for an excellent discussion of this model and its benefits over other modeling approaches.

For the i^{th} product, the hazard rate function $h_i(t)$ is defined as

$$log\, h_i(t) = log\, h(t; x_i) = \alpha(t) + x'_i \beta \quad (1)$$

where $\alpha(t)$ is an arbitrary and unspecified baseline hazard function, x_i is a vector of measured explanatory variables for the i^{th} product, and β is the vector of unknown coefficients to be estimated. As suggested by Allison (1984), we do not include a term for unobserved heterogeneity since we only analyze non-repeated events. Parameter estimation is accomplished using the partial likelihood method as implemented in the SAS PHREG procedure. To account for the possibility that two product innovations have the same observed take-off time, we assume that there is a true but unknown ordering for the tied events times and use the EXACT method in the SAS PHREG procedure (e.g., see Allison 1995 for details).[11]

Table 5 reports the results of our proportional hazards analyses of sales take-off times.[12] We note that the same basic results are also obtained for various sub-samples of the product innovations. We use McFadden's (1974) Likelihood Ratio Index, ρ^2 (which, for our models, is the same as the U^2 measure discussed by Hauser 1978), as a measure of model fit ($0 \leq \rho^2 \leq 1$). The Likelihood Ratio Index is calculated as $1 - L(\boldsymbol{x})/L_0$, where $L(\boldsymbol{x})$ is the log likelihood of the model. From the results presented in Table 5, New Firm Entry is significant and in the expected direction for all models. Thus, H_1 is strongly supported, i.e., a sales take-off occurs quickly (slowly) for innovations with a high (low) fraction of new entrants. As indicated by the results for Model 1, Price decreases are significantly related to sales take-off times. In addition, Model 4 reports the estimation results with the other control variables: Commercialization Year and World War II are not significant, whereas R&D Costs is negative and significant. This latter result suggests that product innovations for which there are relatively high costs of improvement tend to have longer take-off times.

Table 5. Proportional Hazards Analysis of the Probability of Sales Take-off after Commercialization (standard errors in parentheses)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
Price	–6.54 (3.23)[a]	—	1.98 (4.24)	4.50 (4.22)	–17.38 (13.31)[c]
New Firm Entry	—	16.17 (3.69)[a]	16.64 (3.86)[a]	22.16 (6.01)[a]	21.09 (5.91)[a]
Commercialization Year	—	—	—	.01 (.01)	.01 (.01)
World War II	—	—	—	.37 (.86)	.28 (.87)
R&D Costs	—	—	—	–.27 (.14)[a]	–.08 (.20)
Price x R&D Costs	—	—	—	—	3.37 (1.96)[b]
ρ^2 –2LL Chi-square	.04 98.18 3.68[b]	.46 55.01 46.85[a]	.46 54.78 47.08[a]	.51 49.49 52.37[a]	.55 45.74 56.12[a]

n = 30; [a]significant at .01 level; [b]significant at .05 level; [c]significant at .10 level; one-tail significance tests with covariates and L_0 is the null model.

Following Cohen and Cohen (1983), we compare the ρ^2 values of the various models to determine the relative importance of the factors. Clearly, the ρ^2 values for the single variable model of New Firm Entry (Model 2: $\rho^2 = .46$) is much larger than the single variable ρ^2 model value for Price (Model 1: $\rho^2 = .04$). In addition, the ρ^2 values of the multivariate models (models 3 and 4) are only marginally larger than the single variable model of New Firm Entry (Model 2), indicating that the other variables do not contribute much additional explanatory power over New Firm Entry. Thus, it must be the case that our measure of New Firm Entry captures much more than just the effects of price decreases alone.[13]

In addition, we find no evidence that price mediates the relationship between firm entry and take-off times. Following Baron and Kenny (1986), price acts as a mediator when: (1) take-off time is significantly related to price and firm entry separately, (2) price and firm entry are significantly related, and (3) a significant relationship between firm entry and sales take-off time disappears when price is added to the model. Condition 1 is satisfied since the results for Model 1 in Table

5 are significant, but Condition 2 is not met since the Pearson correlation between Price and New Firm Entry is insignificant ($r = -.18$; $p \leq .35$). Examining the results for models 2 and 3, we also find that Condition 3 is not met; rather than having the relationship between New Firm Entry and take-off time disappear with the addition of Price, Price is insignificant in a model with New Firm Entry.[14]

Taking these results together, we find strong evidence that firm entry into a new market dominates price in explaining the timing of a sales take-off. Thus, H_{2b} is supported. We interpret these results as supporting the idea that demand shifts due to actual and perceived improvements in product quality during the early market evolution of innovations are the key driver of a sales take-off.

At the same time, however, the fact that prices are generally declining over time suggests that the supply curve is also shifting outward. Since both the demand and supply curves are shifting outward, we further explore two possible explanations for our empirical results that firm entry explains sales take-off better than price reductions. First, it may be that growth in demand leads to a transitory disequilibrium which delays price reductions. In this case, the duration of disequilibrium should be inversely related to entry barriers in the market. But as noted above, the correlation between Price (a proxy for price reduction lags[15]) and New Firm Entry (a proxy for entry barriers) is insignificant. This suggests that the speed of price declines (and thus price lags) is not related to barriers to entry. A second possible explanation is that the research and development costs related to product improvements may vary greatly across innovations and these research and development costs may offset the effects of manufacturing cost reducing process innovations or additional capacity that are associated with price reductions. Consistent with this idea, we find that the correlation of Price and R&D Costs is positive and significant ($r = .43$; $p = .01$). In addition, Price and R&D Costs should have a positive interactive effect on the probability of take-off (i.e., the effect of price reductions on sales take-off is observed for innovations that have relatively low costs of product improvements). We note that this explanation is consistent with our emphasis on the critical role of product improvements in the early stages of new markets. From Model 5 in Table 5, we find that Price and New Firm Entry are significant and have the expected coefficient signs.[16] Moreover, the interaction of Price and R&D Costs is significant and has a positive effect on the probability of a sales take-off for our set of product innovations. This result suggests that innovations with steep price declines (i.e., Price < 0) and low costs of product improvement tend to have higher probabilities of sales take-off than innovations with steep price declines and high R&D costs. Thus, although New Firm Entry is still the dominant explanatory variable of a sales take-off, we find evidence that price reductions are relatively more important for product innovations that can be improved with low research and development costs.[17]

Discussion

Three key findings emerge from our empirical analyses of the market evolution and take-off of consumer and industrial product innovations.

- ❒ We find that sales and the number of competing firms for consumer and industrial product innovations exhibit an initial period of slow growth that is eventually followed by a sharp take-off.
- ❒ We find that the time between firm and sales take-off varies considerably across products, and that a firm take-off systematically occurs before the sales take-off. This suggests that the market entry decisions of early entrants are based on expected sales rather than actual realized sales.
- ❒ We find strong evidence that firm entry into a new market dominates price reductions in explaining take-off times. We interpret this result as supporting the idea that demand shifts during the early evolution of a new market due to non-price factors are the key driver of a sales take-off.

Our first finding adds to the limited empirical research on the take-off phenomenon that has appeared in distinct literatures (evidence for a sales take-off is reported in Golder and Tellis [1997] and for a firm take-off in Gort and Klepper [1982]). Our second and third findings represent new empirical results that have not as yet been reported in the published literature. Our third finding is also good news for managers of product innovations since it suggests that sales growth does not necessarily have to come at the expense of the compressed profit margins typically associated with declining prices.

Our findings add to the set of empirical regularities that have been reported in the literature (e.g., see the review in Klepper 1997). Based on our accumulated knowledge up to this point, we speculate that the market evolution for a product innovation unfolds as follows. First, there is an initial discovery of a potential product innovation. Typically a long incubation period ensues after the pioneering invention, which is eventually followed by the commercialization of various specific product forms by one or more small and/or large firms. Based on early competitive activity in the nascent market, such as the relative number of initial entrants that are small entrepreneurs or large corporations or the early entrants' level of success, potential entrants update their assessments of the benefits and risks associated with entry. As the new market evolves over time, competing firms collectively legitimize it to be a real opportunity. The number of firms competing in the new market then takes off as entrants rush in anticipating large profits. As a result, supply-side capacity increases. Demand also increases due to the aggressive non-price competition that occurs among incumbents and entrants in new oligopolistic markets; in the early stages of market evolution, fierce competition usually centers on demand-enhancing efforts such as R&D directed towards product improvements. Depending on the specific product innovation and the nature of its supply and demand curves, prices can decrease or increase. As a result of this competitive activity, consumers eventually legitimize the product innovation by accepting that it provides real benefits over existing products. Sales of the product innovation then take off. After the sales take-off, both sales and the number of competing firms continue to increase but at a decreasing rate. Eventually, there is a shakeout of firms in the industry, and the number of competitors drops and then stabilizes. We note, however, that this story is speculative at this point since it has not been formally tested with a complete set of empirical data.

Implications

In this section, we consider some of the implications associated with our findings, as well as suggest several directions for future research.

Forecasting Implications

Similar to Helsen and Schmittlein (1993) and Golder and Tellis (1997), we could fit a specific parameterization of the hazard model and use it to forecast the timing of the sales take-off for our product innovations as a function of explanatory variables such as those in Table 5. We believe, however, that managers (and academics for that matter) would have a difficult time using such analyses for forecasting purposes without the underlying data and statistical routine. Therefore, we suggest a more practical, albeit statistically less precise, forecasting approach involving the relationship between sales take-off time and new firm entry.[18]

Figure 4 shows that there is a strong nonlinear relationship between the sales take-off time and firm entry between commercialization and sales take-off for the product innovations we study (the best fitting power curve is reported in Figure 4). Of course, this result is not surprising given our prior hazard model estimation results reported in Table 4. Given an estimate of the expected firm entry into the new market, the simple power curve results in Figure 4 suggest a promising approach for predicting the sales take-off time before the product innovation is initially commercialized. In practice, a first approximation of the firm entry associated with a new innovation might be based on prior experience with analogous products. Once a product innovation is commercialized, its expected firm entry can be estimated (and updated) using actual market events. For example, Figure 5 shows that there is a statistically significant relationship between the sales take-off time and firm entry between commercialization and firm take-off. Given the enthusiasm and optimism generally associated with product innovations, it is not surprising that firm entry before the firm take-off is relatively high (see Figure 2). The relatively low R^2 value reported in Figure 5 indicates that these initially high firm entry rates are generally not maintained as the market evolves. Figure 6 demonstrates that stronger results are obtained if the number of firms marketing the product innovation has already taken off.

Figure 4. Forecasting Sales Take-off Time with Average Annual Firm Entry Rate

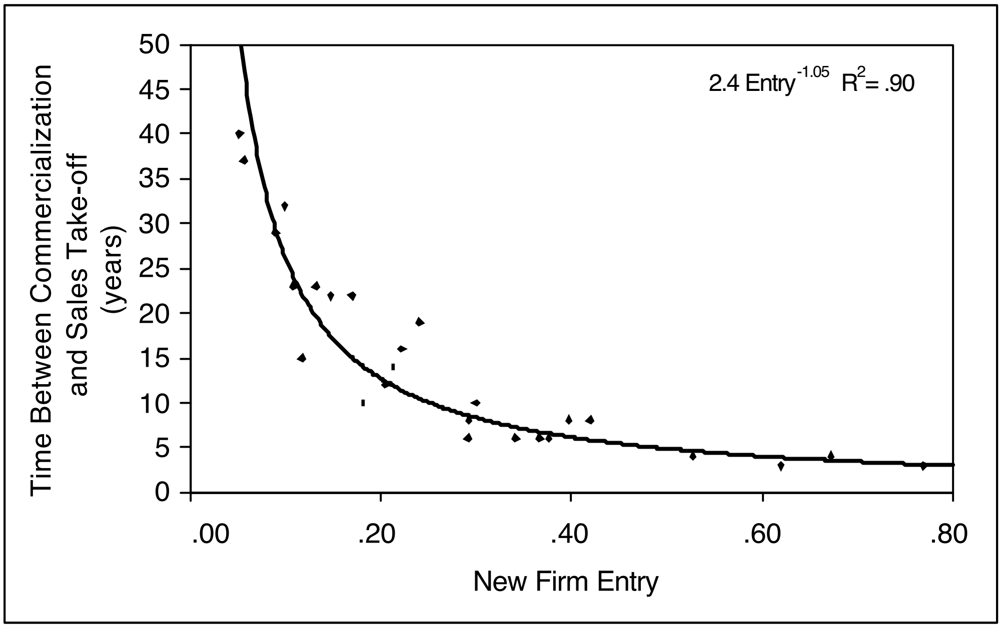


Figure 5. Forecasting Sales Take-off Time with Firm Entry Rate Between Commercialization and Firm Take-off

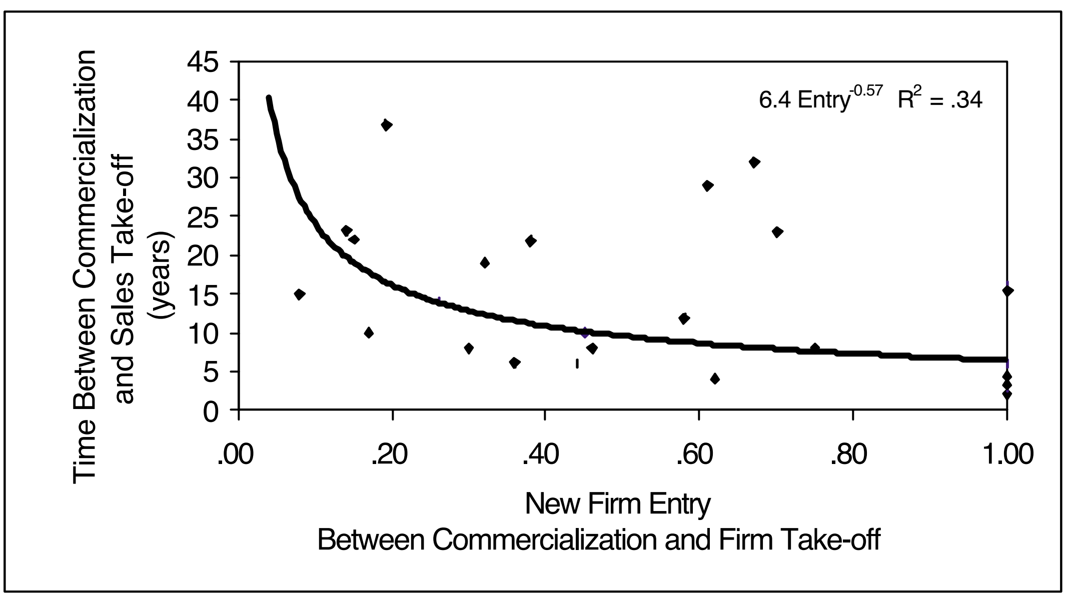
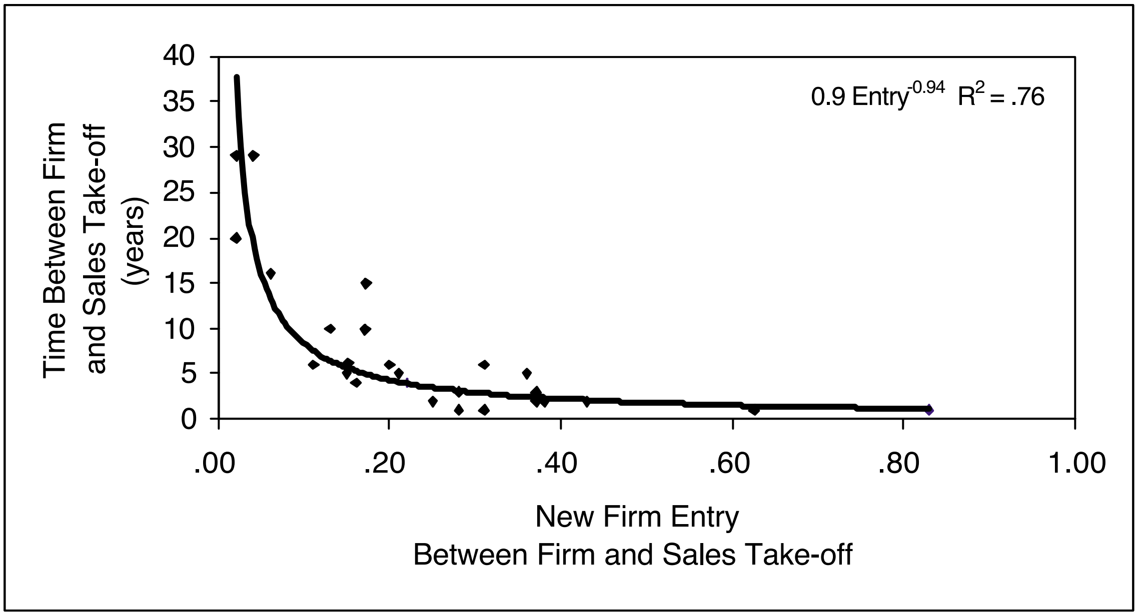


Figure 6. Forecasting Sales Take-off Time with Firm Entry Rate Between Firm and Sales Take-off



Given the broad interest in forecasting the timing of a sales take-off, two important directions for future research can be identified. First, a careful study of the possible relationship between new firm entry and product characteristics should lead to a better understanding of the "similarity" between product innovations. Such information then can be used to finetune the simple forecasting approach outlined in Figure 4. A second direction for future research is to more fully understand the reasons behind the initially high New Firm Entry values before firm take-off that were not maintained after firm take-off. For example, detailed historical analyses of the "outliers" in Figure 5, innovations like outboard engines, freon compressors, piezoelectric crystals, electric blankets, and VCRs (all of which had initially very high firm entry that was not sustained), might reveal some further insights into the creation and evolution of new markets. We speculate that one reason for the fall-off in firm entry is a compression over time in the firm rates of return on investment as more firms enter and incumbents expand (see Klepper 1996).

Strategic Implications

Our empirical results indicate that competition is important to the market evolution and take-off of product innovations. In particular, we find that a sharp increase in the number of competing firms in a new market precedes a sales take-off and that high firm entry rates are associated with quicker sales take-offs. Thus, our results imply that a strategy of erecting entry barriers is not conducive to the market take-off of a product innovation; monopolies dampen the growth of new markets. In contrast to Montaguti, Kuester, and Robertson (2002), our results also suggest that influencing the take-off times of product innovations is not a simple matter, and that it may be very difficult for a single firm to significantly reduce the time to take-off for a really new product. Importantly, individual firm decisions on advertising expenditures, distribution policies, and product development (e.g., technology standards and cross-licensing policies) may influence own brand sales, but it may be the collective marketing efforts of all competitors that are the driving force for market growth and take-off.

These results are generally consistent with the technology standards literature (McGahan, Vadasz and Yoffie 1997). For example, the sales (and firm) take-off of the home VCR was delayed due the existence of competing product standards: Betamax was sponsored by Sony, VHS was offered by JVC and Matsushita, and the V-2000 was marketed by Philips (Cusumano, Mylonadis, and Rosenbloom 1992). On the other hand, the compact disc player achieved a very quick sales take-off since Philips and Sony agreed on a common product standard (McGahan 1993). To establish this standard, low licensing fees were charged; subsequently, over 50 equipment manufacturers and recording companies agreed to produce players and discs for the system. In addition, these manufacturers and recording companies joined to form the Compact Disc Group to collaboratively advertise and promote this product innovation (Meyer 1985). These observations suggest that firms can collectively influence the take-off of a product innovation. With an eye towards identifying the factors related to a swift sales take-off, future research should thus empirically and analytically investigate the nature of firm alliances and collaborations during the formative stages of a new market.

Modeling Implications

Although our results strongly suggest that new firm entry rather than price decreases drives sales take-off for product innovations, research involving other measures of product evolution and improvement should be conducted to confirm this finding. Furthermore, our results imply that models of new product sales need to explicitly account for the take-off phenomenon and product evolution during the early stages of market development. Thus, for example, future research dealing with sales diffusion models (Bass 1980; Mahajan, Muller and Bass 1990) and models of the evolution of new markets (Klepper and Graddy 1990; Jovanovic and MacDonald 1994; Klepper 1996) should make provisions to account for these findings. It is likely that such research will require additional theoretical modeling of the take-off phenomenon.

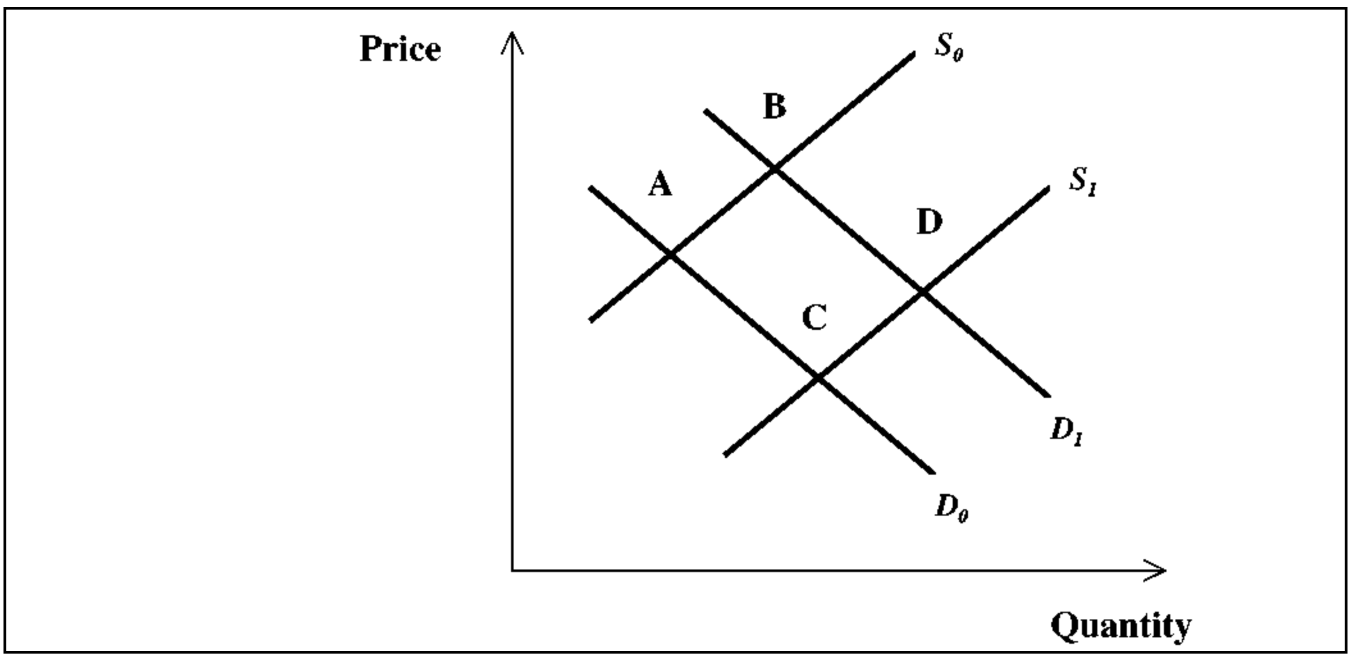
Efforts by new entrants to increase sales may take many forms, including product improvements, education of consumers, and market infrastructure development. While our results link new firm entry to sales take-off, further research is needed to assess the importance of each of these demand-enhancing factors. For instance, as suggested by Brown (1981), the time between firm and sales take-off for a product innovation may be related to the existence and evolution of a market infrastructure. This infrastructure can take different forms and might be established in various ways. Thus, it may be that the market infrastructure for a product innovation must be developed before a sales take-off can occur and perhaps occurs concurrently or ensues shortly after entry. This line of reasoning suggests that an important topic for future research is to empirically investigate the relationship between firm entry, market infrastructure development, and sales take-off.

Appendix 1. A Theoretical Framework for the Sales Take-off

Since very little research has explicitly studied the sales take-off phenomenon, the existing literature does not offer a strong theoretical foundation. Consequently, in this section we consider the supply and demand factors that are important in the early stages of market evolution to develop a basic framework that can be used to better understand the sales take-off of product innovations. Our discussion will show that market structure and its evolution can play an important role in determining the timing of a sales take-off. Although all of our arguments can be formalized mathematically, we keep our discussion as straightforward as possible by focusing only on simple economic principles.

We begin by considering an industry supply curve (S_0) and demand curve (D_0) as pictured in Figure A1. Here, the market clearing price and quantity (sales) are represented by point A. We concentrate our discussion on the conditions that might be related to a sharp increase in sales and briefly review the related literature.

Figure A1. The Evolution of Demand and Supply for Product Innovations



First let us consider the implications associated with a fixed supply curve and increasing demand. Comparing points A and B in Figure A1, it is clear that an upward shift in the demand curve to D_1 leads to higher sales and higher price. This purely demand-side perspective has been emphasized by the marketing literature involving new product diffusion models (see the review in Mahajan, Muller, and Bass 1990). Borrowing primarily from communication theory, these models assume that the underlying social structure in a market determines the time pattern of sales (Rogers 1995). Additionally, the basic model assumes that product changes and improvements over time do not influence the demand curve. While the basic new product diffusion model has been extended to include other variables such as price, the driving force behind the well known sigmoid sales pattern results from the assumption that sales are a nonlinear, inverted-U-shaped function of cumulative sales over time. Not surprisingly, the normative results reported in the literature for price are consistent with the basic results in Figure A1 (Kalish 1983). Implicit within this model is the limited insight that the sales take-off occurs when a critical mass of product adopters is achieved (Valente 1995).

Next we consider the implications associated with a fixed demand curve and increasing supply. Much of the economics literature emphasizes this supply-side perspective of market evolution by studying growth in the number of firms over time (see the review in Klepper 1997). Assuming a static demand curve, this research generally focuses on the implications of an outward shifting supply curve that can result from firm entry over time (Klepper and Graddy 1990; Jovanovic and MacDonald 1994; Klepper 1996). This research finds that an outward shift in the supply curve (to S_1) leads to lower prices (compare points A and C in Figure A1). Although this literature does not directly address the sales take-off phenomenon, it is clear that in this situation the largest growth in sales will occur when there is a corresponding increase in the firm entry rate.

Finally, we consider a situation in which both supply and demand increase over time. Comparing points A and D in Figure A1, an outward shifting demand curve (to D_1) and a downward shifting supply curve (to S_1) lead to higher sales and possibly a lower price. We note that the effect of price is theoretically ambiguous and depends on whether demand shifts dominate supply shifts. For most new products the supply shift seems to dominate, resulting in a declining price trend (Agarwal 1998). Increases in demand and supply reinforce each other's effect on sales, resulting in even larger increments than would be expected if only one curve had shifted. Consistent with this scenario, several researchers have studied models in which both the demand and supply curves are a function of cumulative sales (see the review in Stoneman 1983). For example, Bass (1980) formulates a model for a single monopoly firm that incorporates a demand-side, new product diffusion model with price and a supply curve that falls over time due to learning by doing (marginal costs are a declining function of cumulative sales). Metcalfe (1981) and Stoneman and Ireland (1983) develop similar models for process innovations. Klepper (1996) also considers the supply-side effects due to individual firms improving their marginal costs or expanding their production capacity through research and development expenditures. In agreement with Figure A1, these researchers find that price always declines over time. Since very low sales volumes initially characterize new markets, this research stream implies that a sales take-off will typically occur many years after commercialization.

Given the unique role that entrants play in new product markets, it is also possible that the supply and demand curves are both affected by firm entry. As suggested by Gort and Klepper (1982), early entrants can bring crucial new information regarding both product quality and cost improvements. Thus, their role as agents of change implies larger shifts in supply than would be expected from entrants in later stages of market evolution. In addition, early entrants also shape customer preferences for a product innovation since firm entry in the early stages of market evolution can be associated with a lot of experimentation and incremental product improvements. Competition among early entrants that increases consumer information by advertising and promotional offers also creates increased exposure to the product innovation.

More generally, the development of a market infrastructure that is crucial for sales take-off may be integrally related to firm entry (Brown 1981). Depending on the specific product innovation, the existence and evolution of a market infrastructure can be an important determinant of the sales take-off time. This infrastructure can take different forms and might be established in various ways. For example, new distribution channels and delivery methods may be necessary for some innovations (e.g., information products do not utilize traditional retail distribution outlets). Distinct pricing and credit arrangements might also be required (e.g., some product innovations are priced on a per use basis, whereas others have a fixed fee for unlimited use). Widespread adoption of some innovations requires the development of complementary products and services (e.g., automobiles need roads and gas stations; computers and entertainment devices need software content). As already mentioned, extensive advertising and promotion might be required to educate and inform potential consumers about the benefits of a new product (e.g., the first phonographs brought the famous opera singer Caruso into people's homes). These fundamental infrastructure developments often take place as a result of new entry into the market, either as new information brought in by entrants, or as competitive strategies of incumbents to stave off entry and increase their advantages.

This line of reasoning suggests that the market infrastructure for a product innovation must be developed before a sales take-off can occur, and that its development frequently occurs concurrently or shortly after entry. Thus, the sales take-off time should take place after a sharp increase in firm entry. Since entry is assumed to be a function of perceived profit opportunities and associated costs (Gort and Konakayama 1982; Geroski 1995), a sales take-off can occur when the expectations for significant profits translates into high firm entry rates. It is important to note that the driving force for firm entry into a new industry is the *anticipated* success of the product innovation (because realized sales and profits are very small in the early stages of market evolution). Moreover, early entrants, who are often entrepreneurs, may play a pivotal role in the initial commercialization of a product innovation (Schumpeter 1943; Feller 1967). At the same time, the entry of larger firms with greater resources may lead to the quick growth of a market infrastructure.

To summarize, our discussion and literature review indicate that the pure demand-side approach does not offer a compelling explanation for the sales take-off phenomenon. The pure supply-side approach also does not give a complete explanation since declining price is not always associated with a sales take-off. Instead, the role of market structure and its evolution seems to have more promise in enhancing our understanding of the sales take-off time. Assuming that firm entry into a market affects both the supply and demand curves offers a flexible framework that captures the various possibilities. Firm entry creates additional capacity (supply-side effects). But, more importantly, firm entry causes demand-related factors to change as well. This is due to the aggressive non-price competition that can occur among firms in new oligopolistic markets in which fierce competition on product quality, research and development, advertising, etc. can result in demand curve shifts. For example, as already discussed, comparing points A and D in Figure A1 shows that higher sales and lower price can result if the supply and demand curves shift over time. Although not pictured in Figure A1, it should also be clear that higher sales and higher price can occur if the demand shift dominates the supply curve movement. Thus, this basic economic framework suggests that the sales take-off time should occur after a large increase in firm entry.

Appendix 2. Summary of Data Sources

Product	Sales & Price	Number of Firms
Sewing machine	BC, Brandon	Cooper
Automobile	MVMA	Smith
Phonograph record	BC, BLS	TR
Vacuum cleaner	DM	TR
Outboard engine	BC, BLS, Predicasts	TR
Electric blanket	DM	TR
Dishwasher	DM	TR
Radio	DM	Grinder
Clothes washer	DM	TR
Freon compressor	Predicasts	TR
Cathode ray tube	EMDB, BLS, Predicasts	TR
Clothes dryer	DM	TR
Electric razor	DM	TR
Styrene	ITC	TR
Piezoelectric crystals	Predicasts	TR
Home freezer	DM	TR
Antibiotics	ITC	TR
Turbojet engine	AIAA	TR
Ballpoint pen	WIMA, BLS	TR
Garbage disposer	DM	TR
Magnetic recording tape	Predicasts	TR
Heat pump	Predicasts	TR
Computer printer	ITI, Filson	TR, Filson
Home microwave oven	DM	TR
Monitor	ITI, Filson	TR, Filson
Microcomputer	IDC	IDC
Home VCR	DM	TR, LNA
Compact disc player	DM	TR, LNA
Cellular telephone	DM	TR, LNA
Optical disc drive	Disk/Trend, Golder	TR

AIAA: Aerospace Industries Association of America, *Aerospace Facts and Figures*
BC: Bureau of the Census, *Census of Manufacturers* & *Annual Survey of Manufacturers*
BLS: Bureau of Labor Statistics, *Producer Price Index* (previous name: *Wholesale Price Index)*
Brandon: Brandon, R. (1977), *A Capitalist Romance*, New York, N.Y.: Lippincott Publishing
Cooper: Cooper, G. (1968), *The Invention of the Sewing Machine*, Washington D.C.: Smithsonian Institution

Disk/Trend: *Disk/Trend Report*
DM: *Dealerscope Merchandising* (previous names: *Merchandising*, *Merchandising Week*)
EMDB: *Electronic Market Data Book*
Filson: Professor Darren Filson, personal communication
Golder: Professor Peter Golder, personal communication
Grinder: Grinder, R. (1995), *The Radio Collector's Directory and Price Guide*, Chandler, Ariz.: Sonoran Publishing
IDC: International Data Corporation, *Processor Installation Census*
ITC: U.S. International Trade Commission, *Synthetic Organic Chemicals: Production and Sales*
ITI: *Information Technology Industry Data Book*
LNA: Leading National Advertisers, *LNA/BAR Class/Brand YTD $*
MVMA: Motor Vehicle Manufacturers Association of US, *Motor Vehicle Facts & Figures*
Predicasts: *Predicasts Basebook*
Smith: Smith, P. (1968), *Wheels Within Wheels*, New York, N.Y.: Funk and Wagnalls
TR: *Thomas Register of American Manufacturers*
WIMA: Writing Instruments Manufacturers Association, *Mechanical Handwriting Instruments Industry*

Appendix 3. Methodology

To consistently identify the take-off time for firms and sales, we will use the approach employed by Gort and Klepper (1982) and Agarwal and Gort (1996). To determine the take-off year for each product, we first partition the appropriate series into three categories—the first and third categories contain the years where the percentage change in sales or the net entry rate clearly reflected the pre- and post-take-off periods, respectively. The series of the T consecutive in-between years of the second category are then labeled $x_1, x_2, \ldots, x_T$. The problem is then to choose an optimal dividing year j such that observations $x_1, x_2, \ldots, x_j$ are classified in the pre-take-off period, and $x_{j+1}, x_{j+2}, \ldots, x_T$ are classified in the post-take-off period. This can be accomplished using a three-step procedure:

1. For each $j = 1, 2, \ldots, T$, we compute

$$d_1(j) = \frac{1}{j}\sum_{i=1}^{j} x_i \qquad \text{(B1)}$$

$$d_2(j) = \frac{1}{T-j}\sum_{i=j+1}^{T} x_i$$

2. The choice of the dividing year is limited to those values of j for which

$$|d_1(j) - \mu_1| \leq |(\mu_1 - \mu_2)/2|$$

$$|d_2(j) - \mu_2| \leq |(\mu_1 - \mu_2)/2| \qquad \text{(B2)}$$

   where μ_1 and μ_2 represent the mean rate of net entry in categories 1 and 2. If there are no values of j satisfying (B2), then all observations are classified in the pre-take-off period; if $|d_1(T) - \mu_1| < |d_1(T) - \mu_2|$ then it is in the post-take-off period.

3. If there are multiple values of j satisfying (B2), then we select the value of j from this set that maximizes $|d_1(j) - d_2(j)|$.

Step 2 requires that the mean of the observations classified in each of the two periods is closer to the sample mean of the observations initially classified in that period than in the alternative. Step 3 ensures that, among the classifications that would satisfy (B2), the classification that is chosen maximizes the difference between the means of the points classified in the two alternative periods.

Appendix 4. Correlations among Key Variables

Variable		1	2	3	4	5	6
1	Time to Sales Take-off	1					
2	Changes in Price	.159	1				
3	New Firm Entry	–.787	–.175	1			
4	Year of Commercialization	–.418	–.311	.426	1		
5	World War II	.584	.160	–.461	–.170	1	
6	R&D Costs	–.189	.321	.274	.362	–.047	1

Notes

1. Kim, Bridges, and Srivastava (1999) propose a multi-equation diffusion model for sales and the number of competitors. Their *ad hoc* model formulation assumes, however, that an imitation effect within the consumer and firm populations is the only driving force behind market growth, and their empirical analysis of three products does not concentrate on the early stages of market evolution and sales take-off.

2. Using methods like hedonic price analysis to account for changes in product quality over time has a long and rich history in the economics literature (see the review in Gordon 1990). But we do not employ such methods in our study. Aside from the fact that suitable data to conduct these analyses are unavailable for the product innovations we study, it is not clear that these methods are appropriate for the early market time periods of interest to our research. In particular, hedonic analyses can only evaluate quality improvements when the product form has stabilized (i.e., the set of important attributes is established), which is not the case during the early evolution of new markets. See Gordon (1990) for a discussion of other pitfalls associated with hedonic analyses.

3. While patent statistics may seem like an obvious measure of incremental product improvements, they have several limitations. For example, innovations vary in their impact on the technological environment and a count of patents will not necessarily capture the differences in the importance of innovations (Schmookler 1966; Pakes 1985). Gort and Klepper (1982) note that patent counts do not clearly distinguish between product and process improvements, or between major and minor innovations. Industries can also differ in their propensity to patent, due in part to existing tradeoffs between the exclusive rights granted by a patent and the loss of secrecy. See Griliches (1990) for a general review of patent statistics and their use.

4. Some product innovations introduced in the nineteenth century were added because reliable information was available from reputable published sources (see Appendix 2). While we recognize that many innovations were commercialized in local markets shortly after their invention (often by the inventors themselves), we follow Gort and Klepper (1982) and Agarwal and Gort (1996) by assuming that the commercialization year is the first year the product was listed in the *Thomas Register*.

5. The importance of imports in manufacturing has increased over the last few decades. The *Thomas Register* includes foreign manufacturers of the product if the firm maintains an office or distribution channel for its product in the United States. Foreign firms that operate plants in the U.S. are also included.

6. For example, "Machinery: Dishwashing and Dishwashers" are two categories that list manufacturers of dishwashers. In these instances when firms might be listed in each category, we were careful to avoid the double counting of firms.

7. The smallest of the five broad asset categories reported in the *Thomas Register* represented assets less than \$1.4M (in 1982 dollars) at the turn of the century. We used this cut-point to define "small" firms and, over time, consecutive asset categories were added to the "small" firm definition to appropriately adjust for inflation.

8. Although not reported here, our analyses revealed that effects due to World War I and the Great Depression are insignificant.

9. We also examined a dummy variable capturing whether the innovation is a component or factor of production for other product "systems" (i.e., outboard engine, freon compressor, cathode ray tube, styrene, piezoelectric crystals, turbojet engine, magnetic recording tape, heat pump) or a good for final consumption. No significant results were obtained.

10. We note that relying on the later years for this measure of research and development costs may seem biased against products introduced early in the century since technological intensity varies over the product life cycle and is expected to be highest when a product innovation is first introduced. However, this concern is partly alleviated by two facts. One, the technological intensity of the industries is remarkably stable over a long period of time (e.g., chemicals, aircrafts, communications, etc.). Two, several of the product innovations in our study that are associated with high research and development costs were introduced early in the century (e.g., automobiles).

11. Since the price trend for some of our product innovations is positive, we allow for the possibility of non-proportional hazards using stratification (Allison 1995). In this case, $\alpha(t)$ in equation (1) is replaced by $\alpha_j(t)$ to allow the arbitrary function of time to differ for the two situations (i.e., θ is positive or negative). This model is estimated using the partial likelihood method by: (1) constructing separate partial likelihood functions for the two groups of innovations, (2) multiplying these two functions together, and (3) choosing values of β that maximize this function. This procedure is implemented in the SAS PHREG procedure using the STRATA option (see Allison 1995 for details).

12. The conclusions in this section are supported by other hazard analyses not reported here (but which are available from the authors) for the time between commercialization and firm take-off and the time between firm and sales take-off.

13. It is noteworthy that the ρ^2 values we report in Table 5 (models 2–5) are much higher than the ρ^2 value of .31 reported by Golder and Tellis (1997).

14. We note that there may be several reasons why some factors are significant in a single-variable model, yet insignificant in a multivariate model. For example, it is possible that after controlling for New Firm Entry, the other factors do not affect the likelihood of take-off. More likely though, is that the model without New Firm Entry is mis-specified (i.e., there is an omitted variable in this model). Thus, it may be that the estimated coefficient for Price is biased upwards, resulting in the significant conclusions for the single variable model in Model 1.

15. Similar conclusions are obtained for other measures of price lags, including time to a five percent reduction in price after take-off and average price reduction one year after take-off.

16. Since we have specific hypotheses about the coefficient signs, we use one-tail significance levels in Table 5. The same basic conclusion is also obtained using two-tailed tests with a more lenient alpha level of .20 (see Stevens 1996 for a discussion of improving the power of statistical tests for small samples using higher alpha level tests). See Boland et al. (2001) for a recent example that uses an 80 percent confidence level for analyses involving small samples.

17. It is interesting to note that the correlation between Price and New Firm Entry is negative and significant for the 13 product innovations in our sample that were also analyzed by Golder and Tellis (1997). This result suggests that price reductions may play a more important role for the consumer durables considered by Golder and Tellis (1997) than for the broader set of consumer and industrial product innovations we study.

18. We note that recent empirical work finds that price rarely adds to the forecasting ability of sales diffusion models (Bottomley and Fildes 1998).

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