

The PC Industry: New Economy or Early Life-Cycle?

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Abstract

The paper studies the co-evolution of industrial turbulence and financial volatility in the *early* phase of the life-cycle of an old high-tech industry and a new high-tech industry: the US auto industry from 1899-1929 and the US PC industry from 1974-2000. In both industries, the first three decades were characterized by industrial turbulence: radical technological change, high entry and exit rates, and rapidly falling prices. However, unlike in the auto industry, in the PC industry technological change and new entry did not lead to strong instability of market shares—at the core of the monopoly destroying effect of Schumpeterian creative destruction—until the 1990's when the lead of the incumbents from the pre-existing mainframe and minicomputer industries was undermined. In both industries, stock prices were the most volatile and idiosyncratic during those years in which technological change disrupted market shares the most (Autos: 1918-1928, PCs: 1990-2000).

Keywords: industry life-cycle, new economy, technological change, risk, stock price volatility.

JEL Classification: L11 (Market Structure: Size Distributions of Firms), O30 (Technological Change), G12 (Asset Pricing).

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I. Introduction

While the concept of the “new economy” has inspired studies to compare the effect that new technologies have had on economy-wide productivity in previous eras with the effect that information technology (IT) has—or hasn’t yet—had in the current era, there has been much less attention devoted to whether industry-level dynamics have really changed. That is, are the patterns that describe the evolution of new high-tech industries a result of something exciting behind the “new economy” or something more common behind the industry life-cycle? Or some of both?

To investigate this question, the paper compares the co-evolution of industrial and financial dynamics in the early phase of the industry life-cycle of the US automobile industry (1899-1929), today a traditional industry that emerged with the second industrial revolution, with the early phase of the life-cycle of the US PC industry (1974-2000), a new high-tech industry that emerged with the third industrial revolution, often called the IT revolution or the New Economy. The goal is to see whether patterns which are commonly associated with new high-tech industries, such as the importance of small innovative firms, turbulence in market shares, the increased role of expectations and stock price volatility, and the low correlation between earnings and market values, were just as common in the early phase of an industry which is today considered mature.

To the extent that similarities between the two industries’ early stages are found, the much longer time series available for automobiles allows insights to be drawn on the patterns that might in the future characterize the mature phase of the PC industry. Furthermore, since the debate on economic growth in the new economy often centers around a comparison between the boom years of the 1920’s, which were based on the rise of the internal combustion engine, to the boom years of the 1990’s, which were based on the rise of information technology, a comparison of the industries which produced the products underlying these different eras shed light on which lessons from the 1920’s we can make use of today.

Section III (following a review of the data in Section II) uses the industry life-cycle framework (Gort and Klepper, 1982) to document the characteristics of instability and turbulence in the early evolution of the US automobile and PC industry. In both industries, the first 30 years were characterized by a great deal of turbulence in the form of: radical technological change, high entry and exit rates, short firm life-spans, and a rapid fall in prices. However, while in the auto industry these changes led straightaway to market share instability—at the core of the monopoly destroying effect of Schumpeterian creative destruction—in the PC industry, technological change and new entry did not upset the existing market structure until 1990 when the lead of the incumbents in the mainframe and minicomputer industry was destroyed. And, in fact, it is this market share instability, caused by “competence-destroying” innovations, that provides the link between the industrial dynamics in Section III and the stock price dynamics in Section IV.

Section IV studies the relationship between industrial turbulence and stock price volatility. How do the dynamics of high entry and exit rates and radical technological change affect the volatility of stock prices over time, the relationship between stock prices and the underlying fundamentals, and the relationship between firm and industry-level stock returns and the market-level stock returns? Results indicate that stock prices are most volatile during the decades in which market shares are the most unstable and technological change the most radical: 1918-1928 in the auto industry and 1990-2000 in the PC industry. Furthermore, “idiosyncratic risk”, as measured through the Capital Asset Pricing Model, is found to be higher in the early stage of industry evolution.

The strong similarities between the early patterns of industrial turbulence and financial volatility in the two different industries—separated by almost 100 years— prompts the question: is it the economy that is new or the industries that are driving it?

II. Data

The study focuses on the US market for automobiles and personal computers (including both domestic and foreign producers). The firm-level and industry-level data is annual. Sales are measured in terms of annual units produced of automobiles (cars and trucks) and personal computers (all microcomputers, e.g. desktops and notebooks). In both industries, units produced follow the same general qualitative dynamic as that of net sales in dollars but is preferred since sales figures are affected by different accounting procedures.

Auto Industry: Individual firm units and total industry units from 1899-1999 come from annual editions of *Wards Automotive Yearbooks*. Although firm-level units are collected here only for 10 domestic firms and 5 foreign firms (the first foreign firms entered in 1965), the total industry sales include the units shipped by all existing firms (e.g. in 1909 that includes the output of 271 firms). Entry and exit figures from 1895-1965 come from Klepper and Simons (1997) using a list of producers found in Smith (1968)ⁱ. Data used to calculate the frequency distribution of the length of life of the auto firms comes from Epstein (1926). Hedonic prices and data on changes in quality are from the series used in Raff and Trajtenberg (1997). Firm-level stock prices and dividends come from annual editions of *Moody's Industrial Manual*. Industry-level stock price and dividend indices are from the Standard and Poor's *Analyst Handbook*ⁱⁱ. Since the S&P industry index for dividends only goes back to 1946, dividends for the pre-war period are aggregated from firm-specific data gathered from *Moody's Industrial Manuals*ⁱⁱⁱ.

PC Industry: Annual firm-level data on the total number of personal computers produced from 1973-2000 comes from the PC Database produced by the International Data Corporation (IDC). From the firm-level units, the following variables are derived: annual number of entry and exits, the average life-span of individual firms, the total number of firms, and total industry sales. Entry and exits are calculated using the same methodology in Klepper and Simons (2000). Firm-level stock price, dividend, and earnings per share data are from the *Compustat* database. Industry-level financial variables are from the Standard and Poor's *Analyst's Handbook* (2000). The firms which

define this index are all included in the firm-level analysis, except for Silicon Graphics and Sun Microsystems (the only two firms in the S&P computer index which don't produce personal computers)^{iv}. Hedonic prices are from the Bureau of Economic Analysis (BEA). Data on quality improvements are from Filson (2001).

III. Industrial Instability

This section looks at the early evolution of the US automobile and PC industry side by side to highlight the similarities and differences in their development. The “early” phase in each industry is used here (and in the figures) to determine its “Age.” This early phase includes the “introductory” phase in the industry life-cycle as well as the first half of the “growth” phase. In the automobile industry the early phase, defining industry age, covers the period 1899-1929. In the PC industry it covers the period 1974-2000.

Studies on the industry life-cycle have documented the following empirical regularities:

Introductory phase. At the beginning of an industry's history there are many types of firms—the pioneers— with different efficiency levels and historical backgrounds. The high technological opportunities in this phase cause the industry to be characterized by a lot of product innovation which results in many different versions of the product (Gort and Klepper, 1982). The high rate of entry and the lack of product standardization cause industry concentration to be relatively low and market share instability to be high.

Growth phase. The growth phase begins once there is relative convergence of production around a particular “standard” (Utterback and Suarez, 1993). The market grows as consumers gain more knowledge about the product. Economies of scale in production allow both costs and prices to fall. The fall in prices allows a wider group of consumers (the mass market) to purchase the goods so that it is no longer just a hobby or a luxury item. Economies of scale and the consequent fall in profit margins contribute to the occurrence of an industry “shakeout”: only the largest most efficient firms are able to compete while many smaller and/or inefficient firms are forced to exit (Klepper, 1996). If early mover advantages exist, those firms that innovate first are most likely to survive the shakeout. In fact, Klepper and Simons (1997) hold that the industry shakeout occurs not due to the advent of a dominant design (as suggested in Utterback and Suarez, 1993 and Jovanovic and Macdonald, 1994) but due to increasing returns in the innovation process.

Mature phase. The mature phase is one in which the opportunities for product innovation are low. Demand is centered on direct and indirect replacement. Firm strategies are focused on price competition, advertising and process innovation. Price wars create

further barriers to entry for smaller firms. Market shares in this phase tend to be more stable and concentration higher.

In both the automobile and the PC industry, the introductory period occurred after an initial period in which the product was produced more by hobbyists than by commercial manufacturers. Early versions of the products emerged from experiments carried out by “tinkerers” in their homes or workshops/garages. The introductory period in the auto industry, when production began to be for commercial purpose only, began in 1899. Prior to this period, the auto industry was not even listed in the census of manufacturers under a separate heading—by 1926 it had already attained an equal importance to shipbuilding and railroads (Epstein, 1928, p. 30). In the period running from 1899-1923, the industry experienced a large surge in entry of new firms that sought to take advantage of the new profit opportunities. Many of these firms failed. In 1901 Oldsmobile produced the world’s first mass produced automobile and in 1910 Ford used the industry’s first branch assembly plant to produce the first standardized car in the industry, the Model T. Product standardization introduced economies of scale, which allowed costs and prices to fall. By 1923, 50% of US households owned an automobile.

The first 5-8 years of the PC industry (1974-1981) were also very experimental and run mainly by hobbyist firms. Entry was determined primarily by technological innovation and by system-compatible software (Stavins, 1995). The first mass produced minicomputer, the Altair 8800, was introduced by Micro Instrumentation and Telemetry Systems (MITS) in 1974. Until 1981, the different PC firms such as MITS, IMSAI, Apple, Commodore and Tandy each used their own platform: no single firm controlled the interface standards, the operating system or the hardware architecture. Real commercial growth began after IBM introduced the IBM PC in 1981. This initiated the phase of IBM “compatibility” in both hardware and software, whereby almost all firms used the IBM platform. Product standardization allowed economies of scale, costs and prices to fall and demand to increase. Three further developments markedly increased the growth of the PC industry: (1) Intel’s introduction of the 32-bit 386 processor in 1985 which allowed graphical interface and hence a more user-friendly environment, (2) the introduction of Windows 3.0 in 1990, which standardized the PC on the Windows

operating systems platform –allowing “cloning” of the IBM PC (based on its open-standards architecture), and (3) the commercial rise of the world wide web in the 1990’s. All three developments contributed to the rapid increase in sales and later to the rapid fall in prices. As in the auto industry, after only two decades of industry evolution, 50% of US households in 1999 owned a personal computer.

Entry and exit

Figure 1 illustrates the remarkable similarity between the auto industry and the PC industry during their first 27 of development: in both cases the industry went from infancy to just below 300 firms in about 12 years (271 auto firms in 1909 and 286 PC firms in 1987). In both cases, the industry “shakeout” began about 15 years after the initial growth spurt: around 1910 in the auto industry and around 1989 in the PC industry^v. In automobiles, by 1940 there were only a dozen firms left, a phenomena that is currently happening in the PC industry where just 5 firms share almost 50% of the global market^{vi}.

FIGURE 1

Figures 2-3 illustrate the churning of entry and exit underlying the changes in firm numbers. In both cases, entry and exit are often inversely correlated which suggests that firms choose good years to enter and bad years to exit. As in Jovanovic (1982), entry appears to lead exit. Due to the high level of vertical disintegration in the industry, entry rates in the PC industry lasted a little longer than in the auto industry.

FIGURE 2

FIGURE 3

An important difference between the two industries, which greatly affected the relative power of the new entrants, is that whereas the PC industry emerged from a pre-existing market for mainframe computers and minicomputers, the auto industry did not emerge from a pre-existing industry. The fact that de novo entrants in the PC industry had to

compete with incumbents like IBM, Digital Equipment Corporation and Hewlett-Packard, meant that new entrants would not reveal their weight until radical innovations in the industry undermined the lead of the incumbents. Although some background experience in the production of related products like engines, bicycles, carriages and wagons, was no doubt helpful to the new firms entering the auto industry, this is not comparable to the advantages that firms with experience in the production of mainframe and minicomputers had in the production of PCs^{vii}. Hence, while in the auto industry new entry led to an immediate and turbulent shuffling for market positions, in the PC industry new entry did not seriously upset industry structure until a decade and a half later.

Live fast - die young

Table 1 reveals that the business failure rate during the first three decades of both industries was much higher than the average failure rate in the economy at large during those same periods.

TABLE 1

The high risk and uncertainty faced by firms in this early period is also highlighted by their very short life spans. Figure 4 depicts the frequency distribution of the length of life of firms in the two industries. In both cases, as the length of (firm) life increases, the number of surviving firms decreases. Fifty percent of the total number of firms in both industries lasted about 5 years—with many not even making it to their first year^{viii}.

FIGURE 4

By 1926 only 33% of the firms that began producing automobiles during the previous 22 years had survived. By 1999 only 20% of the firms that began producing PCs in the previous 22 years had survived. What caused this industry “shakeout”?

Technological Change and Falling Prices

In both industries, the industry “shake-out” was a result of the combined dynamics of technological change and falling prices. In a paragraph that could easily describe IT

based industries today, Epstein (1927) describes the process of creative destruction in the early auto industry as follows:

“One would expect the hazards to be greater in a new industry, especially one making a complex fabricated product, subject to constant change and improvement in design and construction. This recurrent necessity of making innovations both in the character of the product and in methods of manufacture, if a firm’s place in the industry is to be maintained, probably serves to explain in large measure the complete disappearance of many automotive names that were highly respected.” (Epstein, 1927, p. 161).

In line with industry life-cycle theory, the shakeout in both industries occurred shortly after the emergence of a dominant design which could be mass-produced. In the auto industry, the greatest exits occurred between 1907-1912, which coincides with the advent of the Model T that introduced mass production techniques to the industry. In the PC industry, most of the exits occurred between 1987-1993, coinciding with two developments which allowed the production of PCs to be standardized and “commoditized”: Intel introduction of the 32-bit 386 processor in 1985 and Microsoft’s introduction of Windows 3.0 in 1990.

In the auto industry, the extraordinarily high exit rate in 1910 was due to the large fall in demand for high-priced cars that occurred in that year and the fact that those firms not able to adapt to the new cheaper cars (lighter-weight, four cylinder vehicles) were forced to exit (Epstein, 1926). Ford’s Model T was the embodiment of the lighter car that could be sold for cheaper. The fall in exit rates after 1912 was due to the growth of the industry, which facilitated the purchase, and use of standardized parts. For example, between 1905 and 1923 sixteen standardized parts replaced 800 different sizes of lock washers, and less than fifty alloy steels replaced 1600 different types of steel being used (Epstein, 1927, p.170).

In both industries, the main effect of economies of scale was to allow costs and prices to radically fall. Between 1906 and 1940 the inflation adjusted prices of automobiles dropped almost 70% (Raff and Trajtenberg, 1997, p. 77). Figure 5 illustrates the fall in auto prices using the hedonic price index created by Raff and Trajtenberg (1997). Most of the real change in automobile prices that occurred between 1906-1982 was concentrated in the period 1906-1940. Within that period most of the change occurred

between 1906-1918. Between 1906-1940 hedonic prices fell at an average annual rate of 5%. Figure 5 illustrates that while in the auto industry prices fell most rapidly in the first decade of its evolution, in the PC industry prices fell most rapidly during the third decade of its evolution. Hedonic PC prices fell by an average of 18% between 1983-89, an average of 32% between 1989-94, and an average of 40% between 1994 and 1999 (Berndt and Rappaport, 2000). This faster fall of prices in the 1990's coincided with the replacement of the IBM OS/2 platform with the Wintel platform—ending the period of IBM compatibility which had until then constrained the depth and breadth of the innovation process. In the 1990's, the commercial rise of the Internet also contributed to the increased sales and fall in prices of PCs.

FIGURE 5

In both industries, falling prices reflect the radical changes in technology, the diffusion of mass production, and the general expansion of the market. Different studies on technological change in the auto industry have emphasized that the most radical innovations in the auto industry occurred in the very early years. For example, firm-level data on process and product innovations in the auto industry from 1890-1980, reveal that those innovations that affected the production process the most occurred prior to 1940 (Abernathy et al. 1993). Furthermore, Filson (2001) finds that most quality improvements in the auto industry occurred in the early phase of the auto industry's life-cycle—with innovation dying down significantly towards the end of the growth phase. His quality change index is computed by dividing actual BEA price ratios by quality adjusted price ratios (the latter computed by Raff and Trajtenberg, 1997). Figure 6 displays his results. Dividing the early stage of the industry into three different periods, he finds that the first decade witnessed the highest percentage of quality change: 25% between 1895-1908, 3.1% between 1909-1922 and 3.2% between 1923-1929.

FIGURE 6

The differences between the two industries in terms of when prices fell the quickest reflect the differences in terms of when quality changed the most. Unlike in the auto

industry where most of the price and quality change occurred in the first decade, in the PC industry most of the price and quality change occurred in the third decade of its evolution: 34% quality change between 1975-1986, 17% between 1987-1992 and 38% in the period 1993-1999 (Filson, 2001). Bresnahan (1998) attributes the higher degree of competitive innovation in the last decade to the “vertically disintegrated” structure of innovation in that period: innovation has been spread out between the makers of the PCs (e.g. Dell), the makers of microprocessors (e.g. Intel), the makers of the operating systems (e.g. Microsoft), and the makers of application software (e.g. Lotus).

Changes in industry structure: market share instability and concentration

In both industries, those periods in which there was the most radical innovation were also those periods in which market shares were the most unstable. This is because technological change has the most effect on market structure when innovations are competence destroying ones, i.e. ones that render the competencies of the incumbents obsolete (Tushman and Anderson, 1986). The ability of technological change to destroy monopoly rents is, in fact, the essence of Schumpeterian “creative destruction.” From 1980-1990, innovation in the PC industry was more of the competence-enhancing type: it served to enhance the existing competencies and lead of IBM. From 1990-2000, innovation in the PC industry was more of the “competence-destroying” type: new innovations destroyed the lead of IBM.

This process of creative destruction is captured here through an instability index, I , which tracks absolute changes in market shares:

$$I = \sum_{i=1}^n [|s_{it} - s_{i,t-1}|] \tag{1}$$

where s_{it} = the market share of firm i at time t (Hymer and Pashigian, 1962). The larger the value of I , the riskier the environment for any given firm: current growth is not a guarantee of future growth. To prevent the changing number of firms to affect this index, I is calculated here using only the market shares of the top 10 firms in each industry^{ix}. In the auto industry, these are: Ford, GM, Chrysler, Studebaker, Packard, Hudson, Nash, Willys, Kaiser and American Motors. In the PC industry, these are: IBM, NCR, Apple,

Hewlett-Packard, Compaq, Dell, Gateway, Toshiba, Wang, and Unisys (different compositions of firms were experimented with to ensure that I is not sensitive to the particular firms included in the calculation). Table 2, which contains the average value of I during different decades (and also the volatility of stock prices to be compared with I in Section IV), indicates that the levels of market share instability in the two industries were very similar during their early phases.

Table 2 and Figure 7 indicate that in the auto industry market share instability was highest during the period 1900-1928, with most of the action occurring between 1918-1928. This latter period was particularly unstable since it includes the years when GM began challenged Ford as the industry leader (achieved in 1927). The period of highest market share instability was also the period in which sales were the most volatile—although the average growth rate of sales was higher in the previous decade when the industry was first taking off. From 1940 onwards, market share instability steadily decreased as did also innovation and entry. Market share instability increased in the 1970s, when foreign firms entered the US auto market, but the level was still much lower than that experienced during the industry's early stage.

In the PC industry, market share instability rose with the entry of new firms in the 1980's, but became especially high in the late 1980's and early 1990's when IBM lost control of the innovation process, allowing the new firms (that had entered earlier) to gain more market share and to have a greater influence over the innovation process. Table 2 indicates that although PC sales were the most volatile in the first decade of industry evolution, market share instability was highest in the decade 1990-2000. The fact that market shares in both industries were the most unstable in periods of competence-destroying innovations, not necessarily during the very early period of growth, indicates that market share instability is indeed a result of Schumpeterian creative destruction.

FIGURE 7

How does market instability affect the level of inequality between firms, i.e. market concentration? Figure 8 indicates that in periods of high market share instability concentration tends to be low, and vice versa. In the US auto industry, concentration was initially low— since all firms were de novo entrants— and then increased during and after the shakeout period. The strong economies of scale that developed in the 1920's, and the associated fall in price-cost margins, caused the industry to become increasingly concentrated. Concentration stopped increasing in the 1970's when the entry of foreign firms in the US market stimulated more competition.

In the PC industry, concentration instead began high due to the power of the pre-existing incumbents and then decreased when that power was challenged in the 1990's. Vertical disintegration in the 1990's allowed the co-existence of different firms and kept the level of concentration relatively low. However, the severe slowdown of industry growth in the last 2-3 years has stimulated fierce price wars (led by Dell), turning attention away from innovation towards more zero-sum type strategies which have begun to increase concentration. Industry analysts have warned that if this continues, the industry might soon be composed of only 2-3 giant firms—not dissimilar to the auto industry^x.

FIGURE 8

The future: S-shaped market growth?

Figure 9 compares the early years of market growth in the auto industry with that in the PC industry and finds a strikingly similar picture: sales (units) growth increased at a similar rate and it took exactly 24 years for 50% of US households to own the product: in 1923, 50% of US households owned a car, and in 1998 50% of US households owned a PC. Figure 10 illustrates what happened in the auto industry after the early stage that has been the focus until now. The familiar S shaped pattern indicates that fast early growth was followed by (permanent) stagnation around the beginning of the 1960's. Is this the future of the PC industry? In 2000 and 2001, sales for PCs have fallen for the first time since 1985^{xi}. However, just as the rise of the interstate highway prolonged the growth phase of the US auto industry, and just as the rise of the internet gave a new impetus to the PC industry in the early 1990's, new potential developments in the PC industry—such

as real-time communications, note taking and music storage systems—could allow the growth phase to persist for some more decades.

FIGURE 9

FIGURE 10

IV. Stock Price Volatility

The relationship between industrial instability, as described above, and stock price volatility is determined by the effect of uncertainty on stock prices. In a period of high market share instability, current performance is not a good indicator of future performance. Hence, it is especially in such unstable periods that investors will be more likely to be influenced by the speculation of other investors, leading to herd effects and the type of over-reactions emphasized by Campbell and Shiller (1988) in their analysis of excess volatility. Furthermore, the constant corrections that investors must make to their previous predictions in this turbulent period should also increase stock price volatility. Mazzucato and Semmler (1999) find support for this hypothesis in the US auto industry: “excess volatility” was higher in the early phase of the life-cycle when market share instability was highest.

To trace the co-evolution of industrial instability and stock price volatility, three different snapshots of stock price volatility are used.

1. Volatility of actual stock prices vs. volatility of perfect foresight prices

First, the volatility of the average industry stock price in each industry (the industry index calculated by S&P) is compared with the volatility of the market value that emerges from the perfect foresight or efficient market model (from now on the EMM price). The EMM price is used solely as a benchmark. A constant discount rate is used instead of a time-varying one, so that one can clearly observe the movement in the discount rate—the risk premium—that would be needed to allow the perfect foresight model to better track the movements in the actual stock prices? If this movement is supported by the depiction, in

Section III, of how industrial uncertainty evolves over time, then a connection clearly exists between industrial instability and stock price volatility.

The efficient market model (EMM) states that the real stock price is equal to the expected value of discounted future dividends:

$$v_t = E_t v_t^* \quad (2)$$

$$v_t^* = \sum_{k=0}^{\infty} D_{t+k} \prod_{j=0}^k \gamma_{t+j} \quad (3)$$

where v_t^* is the ex-post rational or perfect-foresight price, D_{t+k} is the dividend stream, γ_{t+j} is a real discount factor equal to $1/(1+r_{t+j})$, and r_{t+j} is the short (one-period) rate of discount at time $t+j$.

The perfect foresight price v_t^* is computed here for the two industries, using the industry level stock price and dividend (both indices computed by S&P). After dividing the industry level data by the S&P 500 equivalent (e.g. automobile dividend / S&P 500 dividend), and detrending the data to ensure stationarity, v_t^* is calculated recursively using Equation (4):

$$v_t^* = \frac{v_{t+1} + D_t}{(1+r)} \quad (4)$$

for which the moving average version is:

$$v_t^* = \sum_{k=t}^{T-1} \frac{1}{1+r}^{k-t} D_k + \frac{v_T^A}{(1+r)^{T-t}} \quad (5)$$

where v_T^A is the actual price at the terminal date T (the subscripts for firm i and industry j are not included). Given the lag in Eq. (4), it is not possible to calculate v_t^* at T. Instead, if $T=100$, the value for v_t^* at $t = 99$ is calculated by using v_t at T in place of v_{t+1} in Eq. (4). Then for each other value from $t = 1$ to $t = 98$, Eq. (4) is used.

Figures 11 and 12 compare the volatility of v_t^* and v_t in the auto industry and the PC industry. The standard deviations of both series are taken during a 10-year interval, meaning that the last 10 years cannot be looked at if the interval begins at $t=1$. In the PC industry, the results are tested for their sensitivity to beginning the interval at $t=1$ or at $t=T$. Since the qualitative results are not affected (volatility is highest in the last decade), Figure 12 depicts the results from the method starting at $t=-T$ so that the dynamics in the last 10 years, which exhibit the most industrial turbulence, can be more clearly observed. In the auto industry the interval begins at $t=1$ so that the years of industrial turbulence can be focussed on (again, the qualitative dynamics are found to be insensitive to this procedure).

Automobiles. Figure 11 illustrates that from 1918 to the early 1930's, the volatility of the actual stock price in the auto industry was always greater than that which would have been predicted by the perfect foresight model. However, the difference between the actual and predicted series fell at the end of the 1920's and in the 1930's—precisely when the industry began to stabilize in terms of market shares, entry and exit rates, innovation, and prices. The difference in the volatility of the two series would be much smaller—hence excess volatility lower— if Equation (4) embodied a *time-varying* discount rate r_t that was both higher and more volatile in the period 1918-1930. This would imply that risk was higher and more variable in that period – exactly what the patterns of industrial turbulence and uncertainty suggest.

Personal computers. Figure 12 compares the volatility of v_t^* and v_t in the PC industry. The volatility of the actual stock price is, again, higher than the volatility of the EMM price. Until 1990 the difference in volatility of the two series is more or less constant until 1990. The relative volatility of the actual stock price increases. Excess volatility would be much lower if Equation (4) embodied a time-varying discount rate r_t that was both higher and more volatile in the period from 1990-2000—again, exactly what the patterns of industrial turbulence and uncertainty in Section III suggest.

FIGURE 11

FIGURE 12

The results suggest that the dynamics of financial risk are related to the industry-specific dynamics of creative destruction.

2. Volatility of stock prices versus volatility of units and market shares

The relationship between industrial instability and stock price volatility can be most clearly observed by comparing the standard deviation of the growth rate of stock prices to the standard deviation of the growth rate of units and to the level of market share instability (I). Table 2 displays the results for the industry level data, while results for firm-level data can be found in Mazzucato (2001). The analysis of the auto industry is limited here to that period in which the auto firms were listed on the stock market, i.e. from 1918 onwards (although some data on units and market shares is also provided for the previous years for reference only).

TABLE 2

Table 2 confirms the result found above: stock prices in each industry were most volatile during the same period during which market shares were most unstable: 1918-1928 in the auto industry and 1990-2000 in the PC industry. Most of the volatility in the PC industry occurred in the sub-period 1994-2000—precisely the years commonly used to date the New Economy. While in the automobile industry this was also the period in which units were most volatile, in the PC industry units were instead most volatile in the first decade (1970-1980). The fact that stock price volatility follows market share instability more than sales volatility suggests that stock price volatility reacts to uncertainty in relative growth rates (i.e. market shares) more than to uncertainty in absolute growth rates.

The last column in Table 2, which displays the volatility of the series after they are divided by their S&P 500 equivalents, indicates that stock price volatility is indeed caused by industry-specific factors not economy-wide factors. A comparison with the S-shaped pattern of market growth in Figure 10 indicates that relative stock prices fell in the early 1960s precisely when industry sales fell.

The average stock price in the computer industry fell relative to that of the general market beginning in the 1980's, shortly after the advent of the IBM PC. Table 2 indicates that it began to rise again only in 1993: 1994-2000 is the only period in which there is a positive average growth rate for the relative computer stock. The late rise may be due to the fact that the firms that innovated the most in the industry did not enter until relatively late and did not get listed on the stock market until even later—for example, Compaq was first quoted in 1988, Dell in 1996, and Gateway in 1996. IBM has, instead, been included in the S&P computer stock index since 1918. Some large firms like NCR were removed by S&P from the index before the relative rise: NCR was removed in 1991, Xerox in 1987, and Wang in 1992. Jovanovic and Greenwood (1999) claim that the computer stock fell relative to the S&P500 in the 1980's because the computer firms that were quoted on the market at that time were the incumbents whose capabilities and competencies would be made obsolete by the radical innovations in the 1990's.

3. Industry age and co-movement with the general market

How does idiosyncratic risk evolve over the industry life-cycle? The capital asset pricing model (CAPM) measures *idiosyncratic risk* through the covariance between the firm-level (or industry-level) stock return and the market-level stock return: the lower is this covariance the higher is the unsystematic or idiosyncratic level of risk. Unsystematic risk in an industry might be higher in early periods of growth since idiosyncratic factors affecting both supply and demand are stronger in this phase: consumers' tastes for the new product are still adjusting and the product has yet to settle around a standardized version, often undergoing hundreds of model changes. In fact, Campbell et al. (2000) claim that individual stock returns have become more volatile since the 1960's because companies have begun to issue stock earlier in their life-cycle when there is more uncertainty about future profits. This is similar to the finding in Morck et al. (1999) that volatility is higher in emerging markets due the effect of undeveloped institutional structures on the uncertainty about future profits. However, it is also possible that in periods of uncertainty, an industry is less settled and hence more vulnerable to economy-wide shocks—which would imply higher covariance between industry-specific returns and the market return in the early phase.

To observe the changing level of firm and industry-specific risk in the two industries, a cointegration test is used to see to what degree the movements in firm and industry stock returns are correlated with movements in the market level stock return (S&P500). A stock's return is defined as:

$$r_t = \frac{P_t + D_t}{P_{t-1} - 1} \quad (6)$$

where P_t and D_t are the stock price and dividend (in logs) at time t . To test for cointegration, the two stage Engle and Granger (1997) test is used, based on an augmented Dickey-Fuller test for cointegration (CRADF)^{xii}.

TABLE 3

Automobiles. Cointegration tests were conducted only on the returns of those firms that were available for most of the sample: GM, Ford, Chrysler, Studebaker and American Motors. The results for the firm-level returns were qualitatively the same as that for the industry level return—not surprising given that these same firms were used by S&P to calculate the average industry index. Table 3 displays the results for the average industry return, while firm-level results are available in Mazzucato (2001). The first part of Table 3 indicates that the auto industry return cointegrates with the S&P500 return only after 1956: after 1956 the CRADF value in Table 3 is larger than the 95% critical value and the residual of the data generating process (Res. DGP in Table 3) is integrated of the order 0 (I(0)). Before the 1950's, the individual stock returns did not cointegrate with the market return. This means that in this earlier period, which coincides with the “introductory” phase of the industry life-cycle and the end of the “growth” phase, firm-level and industry-level returns were determined by idiosyncratic factors specific to the auto industry. The result is confirmed by the relatively high standard error of the residual in the pre-war period (SER in Table 3). The negative coefficient on the Trend variable in Table 3 indicates that the industry return declined over time with respect to the average market return—a fact that is confirmed in Figure 13.

The second part of Table 3 contains the results from the error correction representation of the cointegration regression. Since the coefficient on the value of the lagged residual is

significant and negative, this means that the long run cointegration relationship is strong. The recursive coefficients for the error correction model solutions display the short-run solution of the long-run relations from the Engle and Granger two stage analysis. Plots of these coefficients confirm that the industry cointegrated with the general market around 1956. Firm-level coefficients for GM, Chrysler and Ford indicate the same date, while American Motors cointegrated later, most likely because it entered the industry much later. A comparison of these results with Figure 10, reveals that cointegration with the general market occurred exactly when the growth of the auto industry began to permanently slow down, i.e. when it reached the plateau on the S-shaped growth curve.

Personal Computers. Table 4 indicates that in the PC industry, the industry return never cointegrated with the market return: the CRADF value is always lower than the 95% critical value. Hence, returns in the PC industry are still idiosyncratic--as they were during the first 30 years of the auto industry. If/when growth in the PC industry reaches a similar plateau to that experienced in the auto industry in 1960, the level of idiosyncratic risk may fall.

TABLE 4

Thus, preliminary analysis suggests that firm and industry-specific returns are correlated with the market return only once the industry in question has entered its mature stage, i.e. when growth begins to stagnate. Prior to that, firm-specific and industry-specific returns are determined by idiosyncratic factors, such as consumers' discovery if they like the product, uncertainty over what standard to adopt, high business failure rates, and the size of the market. Thus, idiosyncratic risk should be looked at over the course of industry evolution, not in selected time frames, since the latter will coincide with the early stage in some industries and the mature stage in others. For example, Campbell et al. (2000) find that since the 1960's idiosyncratic risk in many industries, including the auto industry, has increased and conclude from this that economy-wide changes have taken place, most likely related to the emergence of IT. However, a study of the entire history of the

industry reveals that idiosyncratic risk in the post-1960 period is lower than that which existed prior to 1940—making it harder of course to argue that a new era has begun.

V. Conclusion

The present study has compared the co-evolution of industrial and financial dynamics during the early development of an old high-tech industry and a new high-tech industry: the US auto industry from 1899-1929 and the US PC industry from 1974-2000. On the industrial side, both industries experienced a high degree of turbulence during the first 30 years: high entry and exit rates, short firm life-spans, radical innovation, and rapidly falling prices. On the financial side, both industries experienced the most stock price volatility during those periods in which the forces of creative destruction were the strongest. While in the auto industry this occurred straightaway, in the PC industry, it took a longer time because the innovation process was for the first decade and a half dominated by the incumbents from the pre-existing mainframe and minicomputer industries.

Different provocative lessons emerge from the study. First, the fact that those characteristics often used to describe new economy industries—innovative, entrepreneurial, dynamic, unstable, speculative—depict just as well the early development of an industry which is today considered old and sluggish, suggests that perhaps it is not the economy that is “new” but the industries that are driving its growth. Second, changes in the relative growth rates of firms lie at the heart of economic growth more so than changes in absolute growth rates—a claim long argued by evolutionary economists (Nelson and Winter, 1982). Third, financial risk is related to the industry-specific dynamics of creative destruction. It is this feedback between risk and strategic innovation that led the pioneer of the study of risk to state: “*Without uncertainty it is doubtful whether intelligence itself would exist.*” (Knight, 1921, p. 268).

Figure 1

Number of Firms and Industry Age

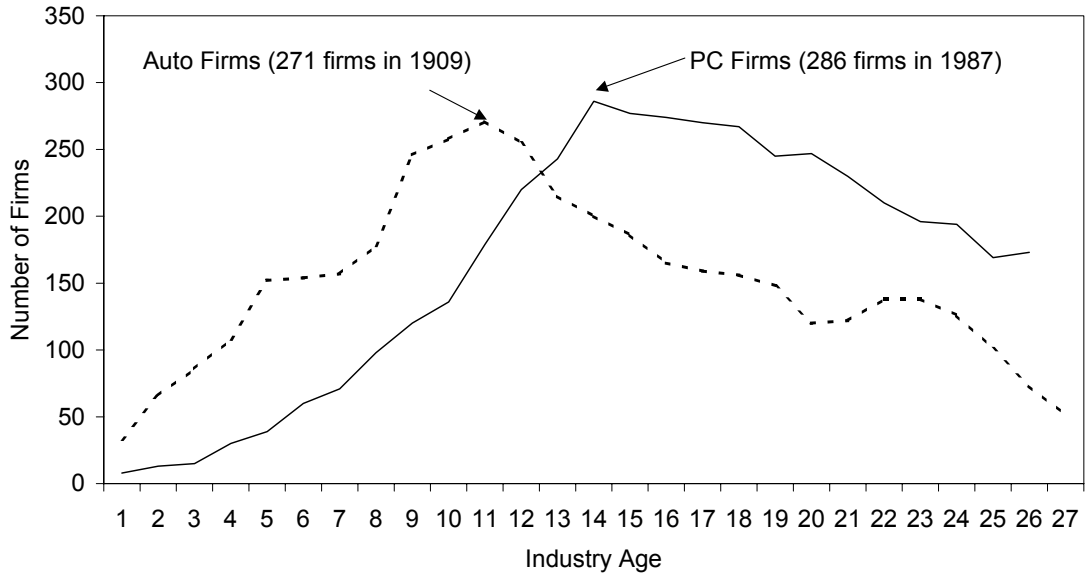


Figure 2

Entry and Exit in the Auto Industry

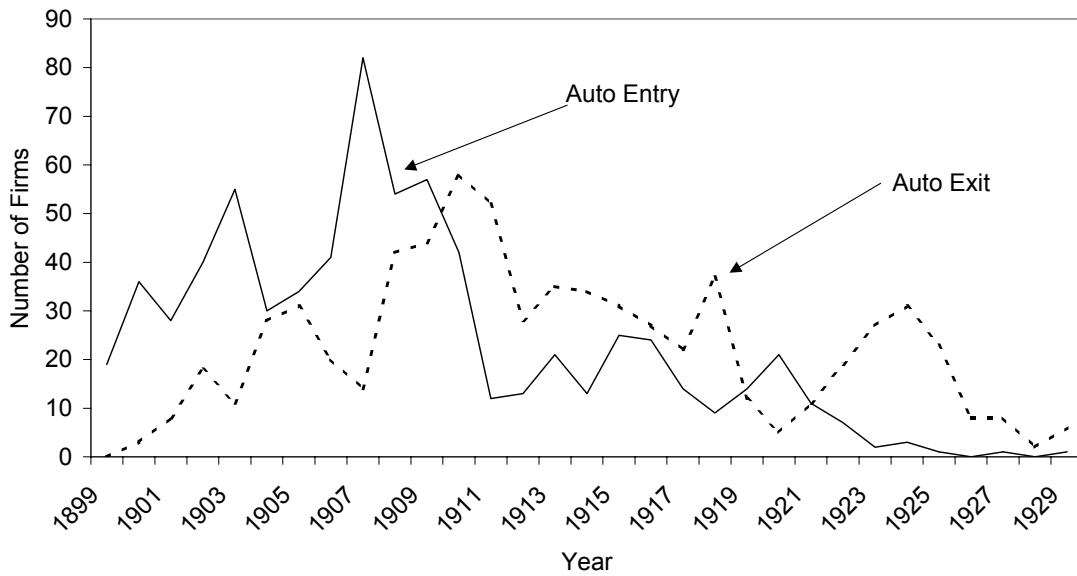


Figure 3

Entry and Exit in the PC Industry

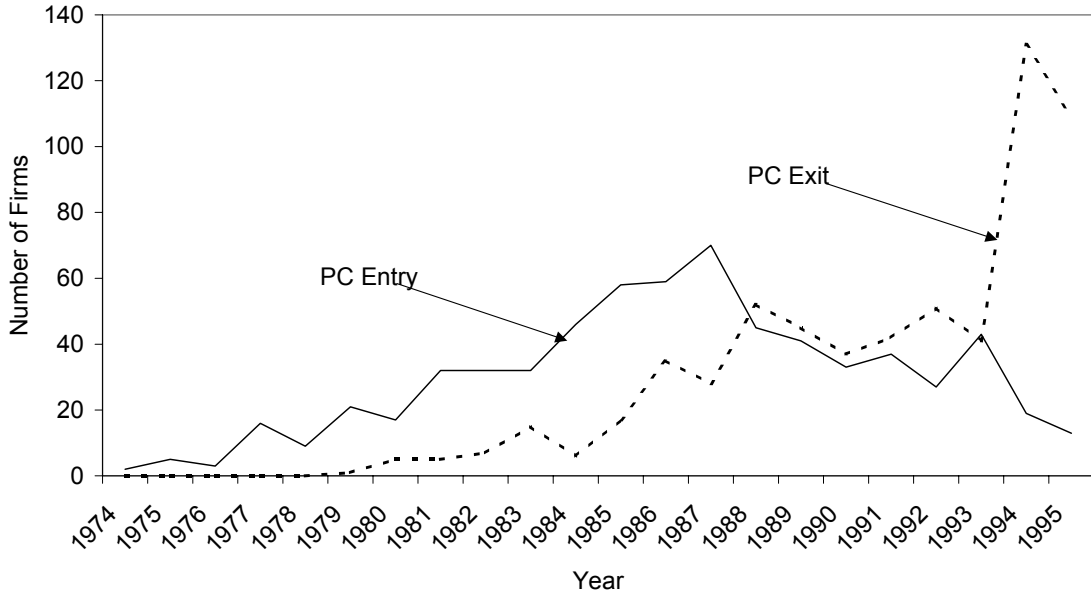


Figure 4

Length of Life of 180 Auto Firms (1895-1924) and 668 PC Firms (1970-2000)

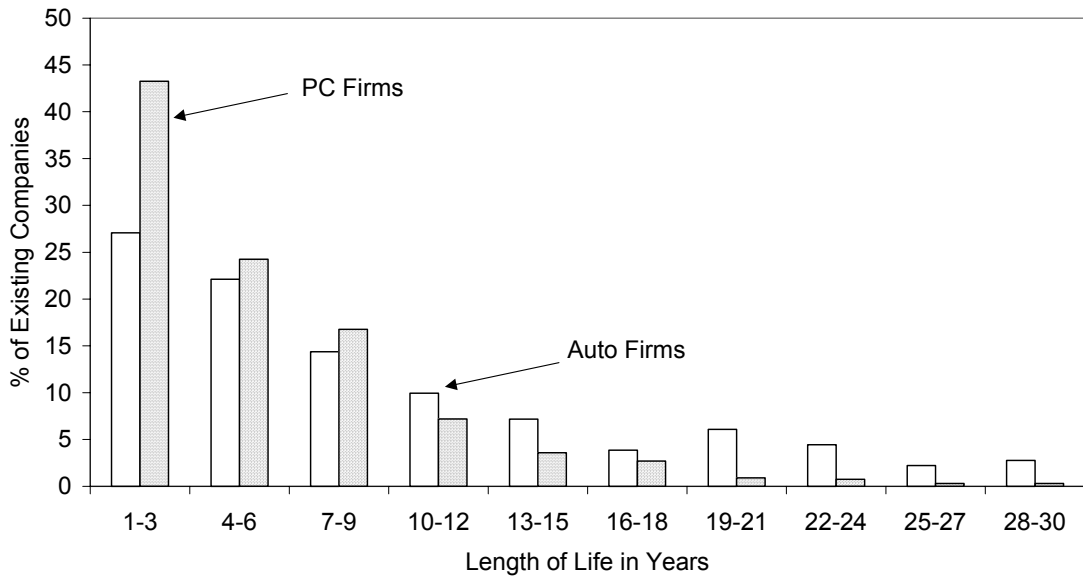


Figure 5

Hedonic Prices and Industry Age

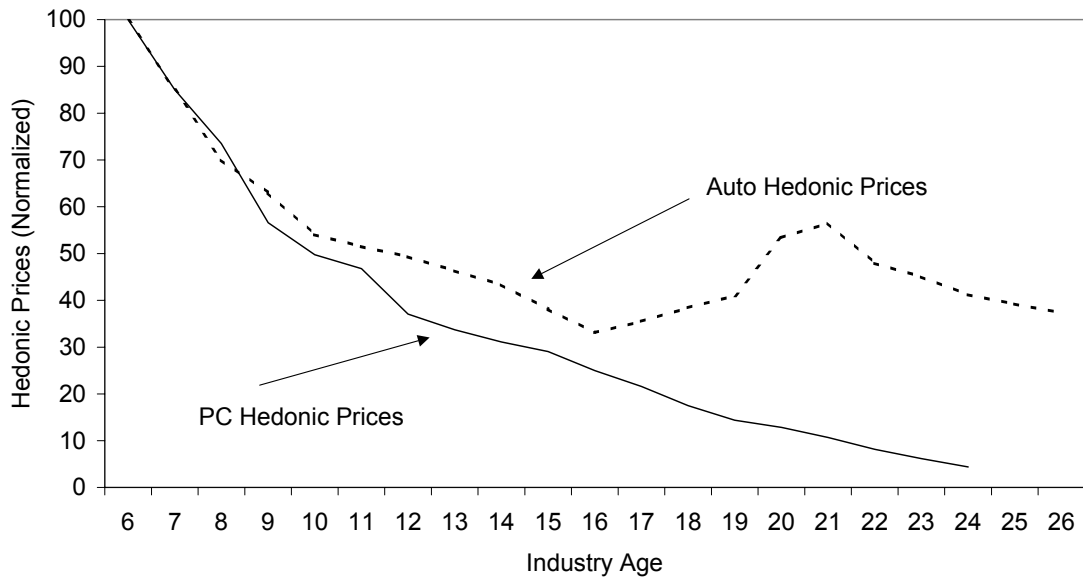


Figure 6

Quality Change and Industry Age

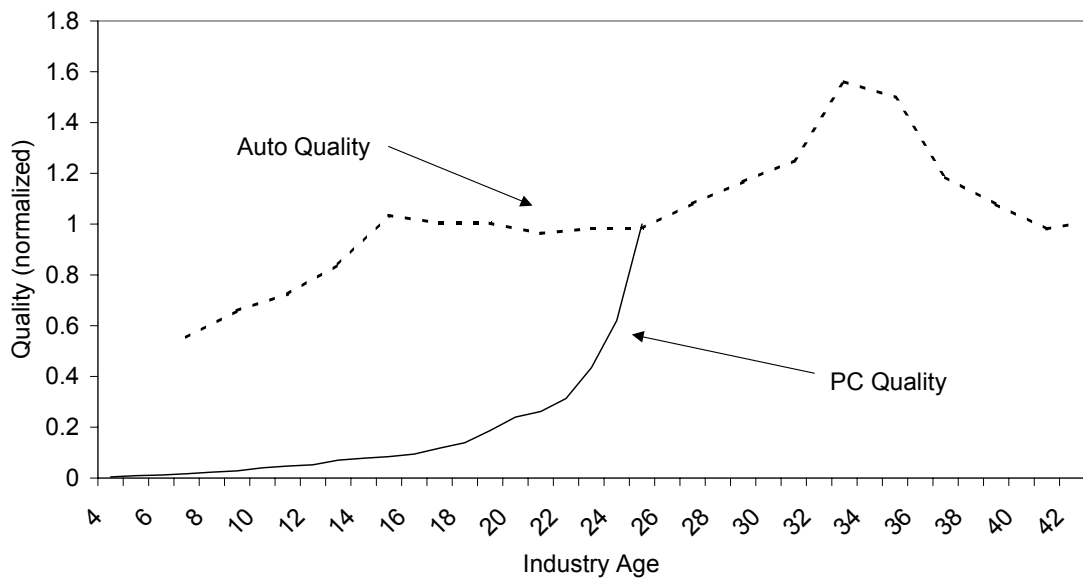


Figure 7

Market Share Instability and Industry Age

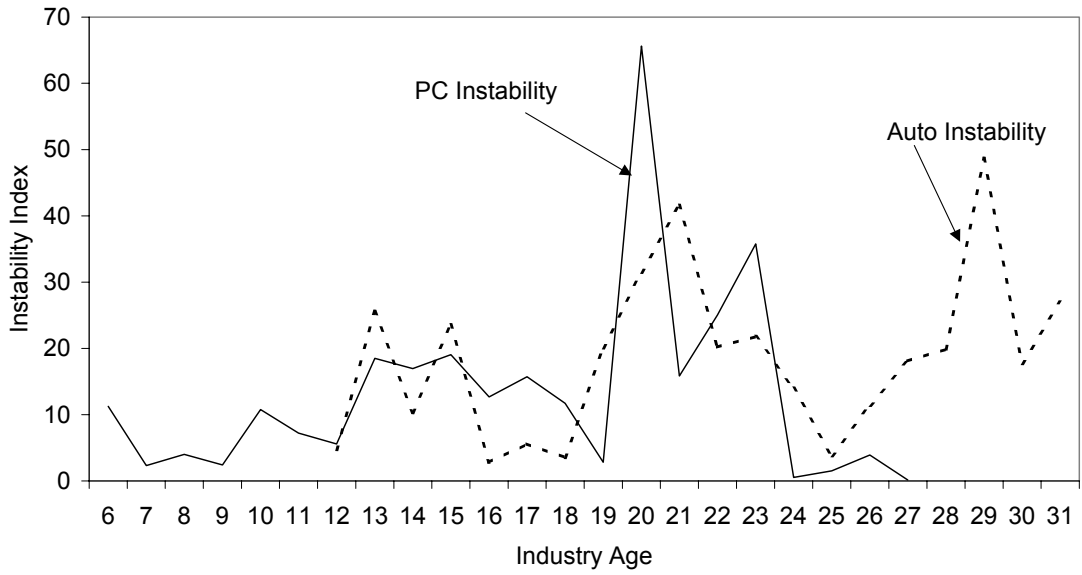


Figure 8

Concentration and Industry Age

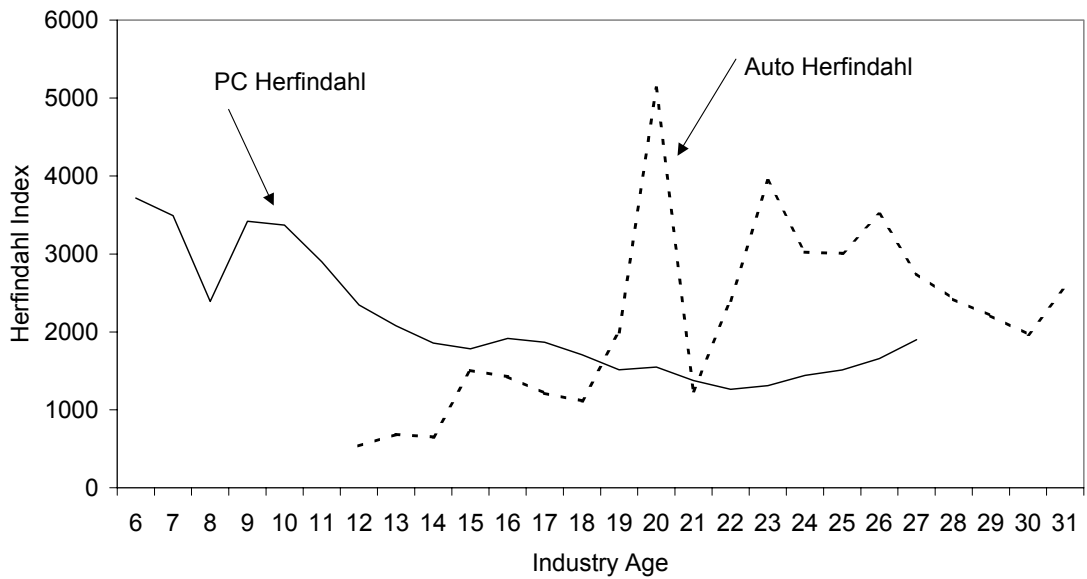


Figure 9

Market Growth, Household Penetration, and Industry Age

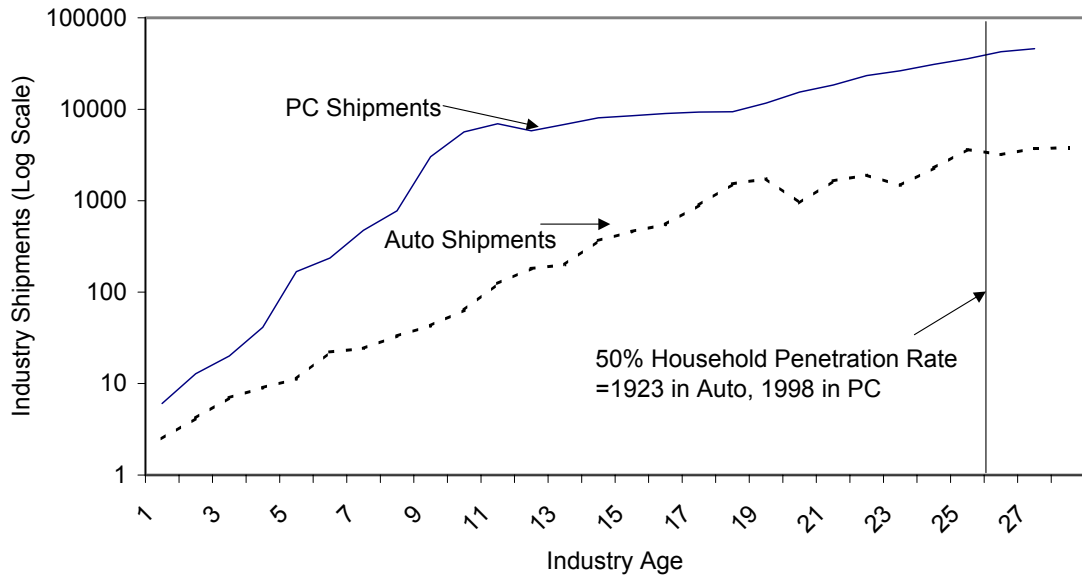


Figure 10

S-Shaped Market Growth in the Auto Industry

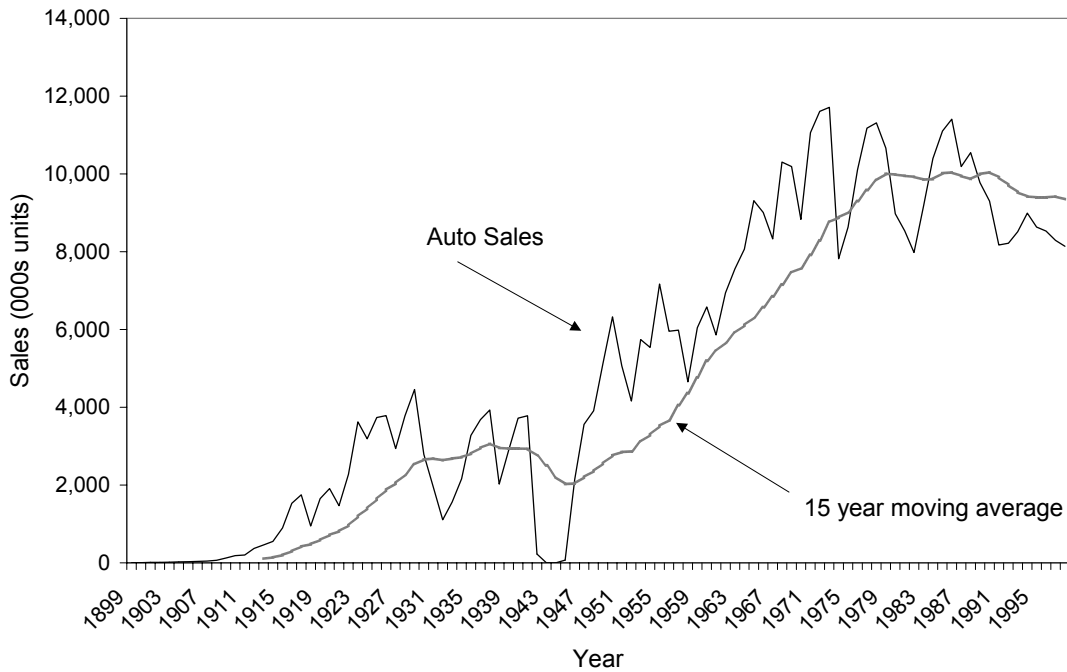


Figure 11

Standard Deviation of Actual Stock Price and EMM Price in the Auto Industry

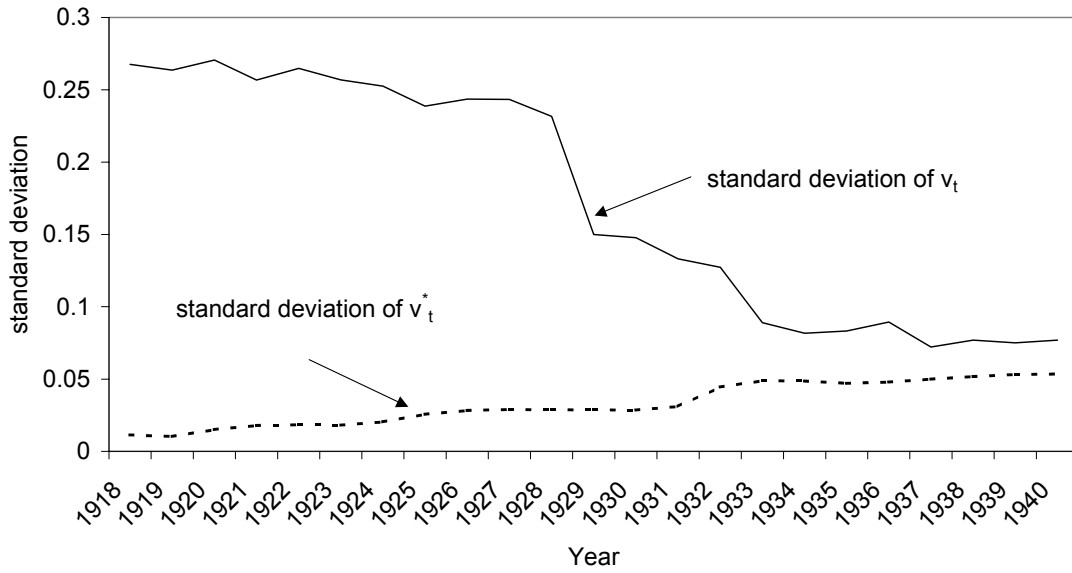


Figure 12

Standard Deviation of Actual Stock Price and EMM Price in the PC Industry

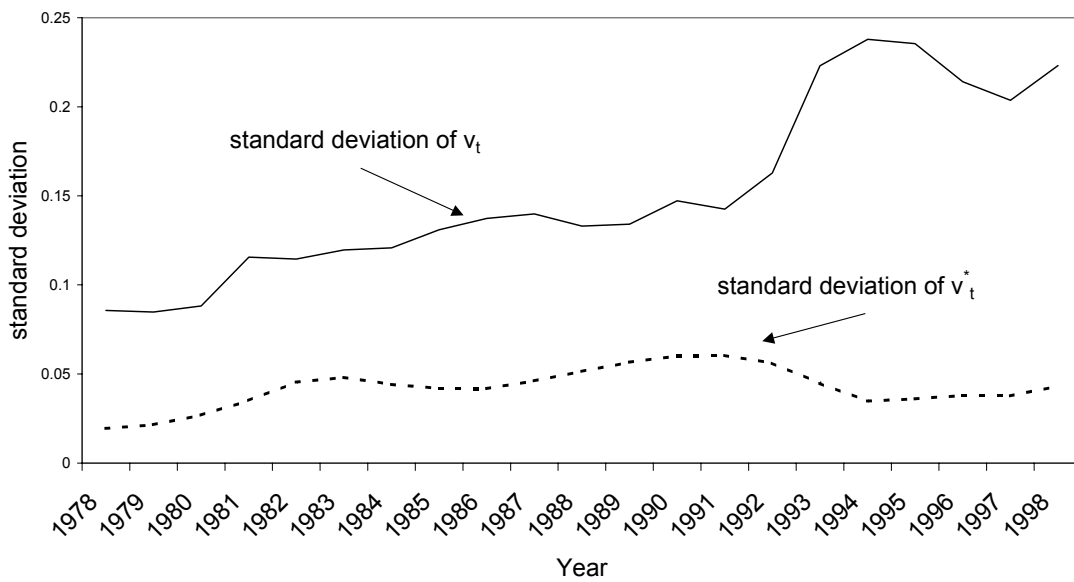


Figure 13

Industry Age and Relative Stock Price

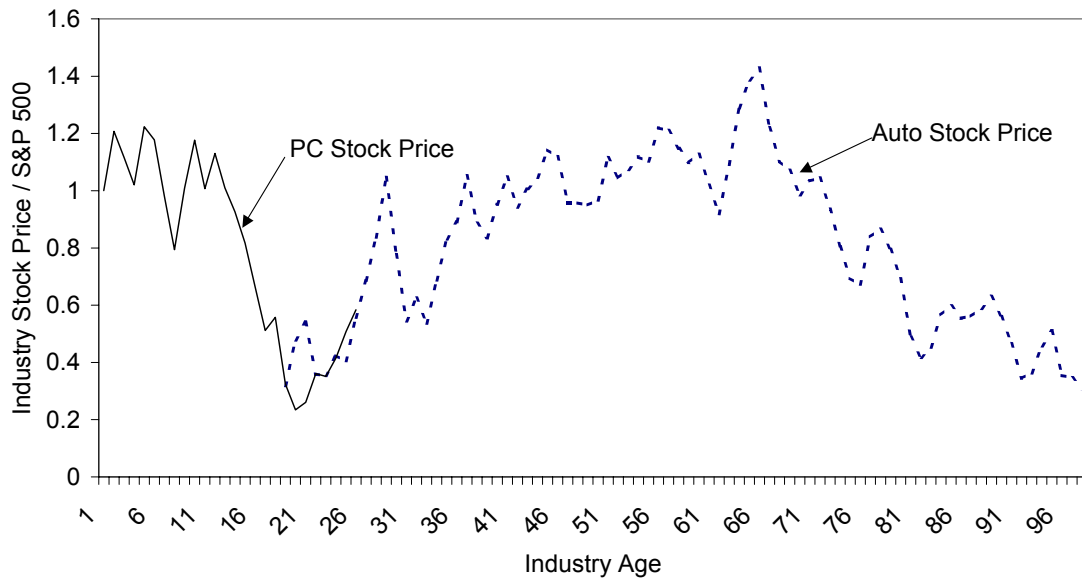


Table 1

Aggregate Business Failure Rate (%) vs. Failure Rate in Autos and PCs.

	Economy	Auto		Economy	PC
1903	0.9	4	1984	0.9	3.4
1904	0.9	3	1985	1.0	7.7
1905	0.8	5	1986	1.1	14.0
1906	0.7	2	1987	1.0	8.7
1907	0.8	0	1988	0.9	18.4
1908	1.1	4	1989	0.8	15.7
1909	0.8	1	1990	1.0	13.3
1910	0.8	26	1991	1.4	14.2
1911	0.8	4	1992	1.5	20.4
1912	0.9	12	1993	1.3	15.4
1913	0.9	10	1994	1.1	88.2
1914	1.0	9	1995	1.1	50.5
1915	1.0	7	1996	1.1	21.7
1916	1.0	9	1997	1.2	12.7
1917	0.8	7	1998	na	9.3
1918	0.6	7	1999	na	5.6
1919	0.4	5	2000	na	12.2
1920	0.5	6			
1921	1.0	1			
1922	1.2	10			
1923	1.0	15			
1924	1.0	19			

Table 2

Volatility of Market Shares, Units and Stock Prices

	MS Inst.	Units	Stock	Stck/SP500
AUTO				
1908-1918	16.3	0.1273 <i>0.1356</i>		
1918-1928	22.6	0.1569 <i>0.0304</i>	0.1458 <i>0.0939</i>	0.1257 <i>0.0617</i>
1918-1941	17.9	0.1500 <i>0.0378</i>	0.1393 <i>0.0620</i>	0.1089 <i>0.0352</i>
1948-2000	7.6	0.0638 <i>0.0070</i>	0.0791 <i>0.0298</i>	0.0352 <i>-0.0020</i>
1948-1970	10.3	0.0759 <i>0.0171</i>	0.0671 <i>0.0335</i>	0.0372 <i>0.0002</i>
1970-2000	5.6	0.0523 <i>-0.0030</i>	0.0881 <i>0.0243</i>	0.0335 <i>-0.0036</i>
PC				
1970-1980	1.4	0.2062 <i>0.2431</i>	0.0708 <i>-0.0047</i>	0.0294 <i>-0.0039</i>
1980-1990	11.5	0.1884 <i>0.1450</i>	0.0662 <i>0.0154</i>	0.0324 <i>-0.0136</i>
1990-2000	17.9	0.0357 <i>0.0646</i>	0.1196 <i>0.0585</i>	0.0445 <i>-0.0003</i>
1994-2000	20.1	0.0217 <i>0.0679</i>	0.2887 <i>0.041</i>	0.5990 <i>0.0162</i>
1970-2000	10.3	0.1758 <i>0.1504</i>	0.0905 <i>0.0258</i>	0.0349 <i>-0.0038</i>

all variables are in logs and differenced

italics=mean value under the standard deviation

bold number=decade with highest value

MS Inst.= average instability index from Eq. (1)

Units=standard deviation and mean of units produced

Stock=standard deviation and mean of industry-level stock price

Stck/SP500= industry-level stock price divided by S&P500 stock price

Table 3

Regression in the levels of the variables and residuals cointegration tests (Auto industry)

<i>Dep var.</i>	<i>Sample</i>	<i>Intercept</i>	<i>MKT return</i>	<i>trend</i>	<i>S.E. of R.</i>	<i>CRADF</i>	<i>CRADF order</i>	<i>95% crit. val</i>	<i>Res. DGP</i>
IND return	1919-98	1.5801	0.0911	-0.00462	0.18933	-3.7088	3	-3.9092	I(1)
IND return	1919-41	0.7936	1.4532	-0.02531	0.20778	-2.2102	4	-4.3508	I(1)
IND return	1948-98	0.9266	0.9722	-0.01419	0.08935	-2.8878	0	-4.0542	I(1)
IND return	1956-98	0.9216	0.4039	-0.00314	0.06811	-4.1512	1	-4.1366	I(0)
IND return	1956-98	0.9544	0.2229	-	0.06843	-4.5819	1	-3.5622	I(0)

Error-Correction Model representation for the cointegration regression (Auto industry)

Coefficients:			Diagnostics:						
<i>Dep var.</i>	<i>Sample</i>	<i>Intercept</i>	<i>dMKT return</i>	<i>res(-1)</i>	<i>Rbar-sq</i>	<i>F-stat</i>	<i>D-W</i>	<i>LMA</i>	<i>LMN</i>
dIND return	1957-98	-0.0053	0.5764	-0.60253					
	<i>t-value</i>	<i>-0.5068</i>	<i>3.8931</i>	<i>-3.8375</i>	<i>0.5179</i>	<i>17.656</i>	<i>1.6162</i>	<i>3.279</i>	<i>0.2016</i>
									<i>LMO</i>
									<i>1.9232</i>

Note:
 DW = Durbin-Watson statistic for first-order autocorrelation
 LMA = Lagrange Multipliers test for Autocorrelation
 LMN = Lagrange Multipliers test for Normality
 LMO = Lagrange Multipliers test for Homoskedasticity

Table 4

Regression in the levels of the variables and residuals cointegration tests (PC industry)

<i>Dep var.</i>	<i>Sample</i>	<i>Intercept</i>	<i>MKT return</i>	<i>trend</i>	<i>S.E. of R.</i>	<i>CRADF</i>	<i>CRADF order</i>	<i>95% crit. val</i>	<i>Res. DGP</i>
IND return	1974-99	1.4021	0.11229	-	0.11609	-2.2162	0	-3.6421	I(1)

Note:
 S.E. of R. = Standard Error of Regression
 CRADF = Cointegration Rank Augmented Dickey-Fuller (critical values from McKinnon)
 CRADF order = number of lagged dep variables in the auxiliary regression selected on the base of AIC
 Residual DGP = Data Generating Process for residuals
 t-values, F-stats and R-bar statistics are not reported because spurious for the presence of all I(1) variables in the regressions in levels

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End Notes

ⁱ Entries were calculated as the number of firms that were recorded as producers in the year indicated, but that were not recorded as producers in the previous year. Exits were calculated as the number of firms that were not recorded as producers in the year indicated, but that were recorded as producers in the previous year.

ⁱⁱ The firms used by the S&P to create the automobile index are (dates in parentheses are the beginning and, if relevant, the end dates): Chrysler (12-18-25), Ford Motor (8-29-56), General Motors (1-2-18), American Motors (5-5-54 to 8-5-87), Auburn Automobile (12-31-25 to 5-4-38), Chandler-Cleveland (1-2-18 to 12-28-25), Hudson Motor Car (12-31-25 to 4-28-54), Hupp Motor Car (1-2-18 to 1-17-40), Nash-Kelvinator Corp (12-31-25 to 4-28-54), Packard Motor Car (1-7-20 to 9-29-54), Pierce-Arrow (1-2-18 to 12-28-25), Reo Motor Car (12-31-25 to 1-17-40), Studebaker Corp. (10-6-54 to 4-22-64), White Motor (1-2-18 to 11-2-32), and Willy's Overland (1-2-18 to 3-29-33).

ⁱⁱⁱ To make sure that the different sources for the pre-war and post-war financial data were consistent, results in the post-war period were checked for their sensitivity to whether the aggregate industry data (provided by S&P) was used or whether the industry data that was averaged from the firm-level data was used. The results proved robust to this check.

^{iv} The computer industry was first labelled by S&P as *Computer Systems* and then in 1996 changed the name to *Computer Hardware*. Firms that are currently included in this index are: Apple Computer (4-11-84), COMPAQ Computer (2-4-88), Dell Computer (9-5-96), Gateway, Inc. (4-24-98), Hewlett-Packard (6-4-95), IBM (1-12-19), Silicon Graphics (1-17-95), and Sun Microsystems (8-19-92). Firms that were included in the past include: Digital Equipment Corp. (10-15-75 to 6-11-99), NCR Corp (12-31-25 to 9-19-91), Pitney Bowes (8-3-55 to 10-7-87), Prime Computer (12-26-84 to 8-23-89), Unisys Corp (12-31-25 to 6-28-96), and Wang Lab. (8-27-80 to 8-19-92).

^v It should be noted that the larger total number of firms listed in the PC industry (more than 600 by IDC) than in the auto industry (about 350 in most case studies) is not due to structural differences between the two industries, but due to the more advanced data gathering methods that are available today. These methods allow market researchers to trace the evolution of very small-sometimes insignificant- firms. Nevertheless, some sources for the number of firms in the early auto industry, like Carroll and Hannan (2000) who count “pre-producers” as well, report a total count of firm numbers much larger than that found in the PC industry (up to 3,000!). Given these differences, the emphasis of the paper is on the dynamics of firm numbers over time (increasing then decreasing), not on the actual number in any given year.

^{vi} In 2000, the leading market shares were: Compaq 13%, Dell 12%, IBM 8%, Hewlett-Packard 7.3%, and Fujitsu-Siemans 5.1%.

^{vii} In a similar vein, Klepper and Simons (2000) describe how those firms in the television transmitter industry that had pre-existing competencies in the radio industry, were the ones that developed an early lead.

^{viii} The higher percentage of early failures in the PC industry than in the auto industry is due principally to the fact that more firms were included in the sample of PC firms, as explained in Section II and in endnote V.

^{ix} Although the index might be affected by the number of firms, it is empirically not very sensitive to it because small firms do not contribute greatly to the value of the index. This is because they account for such a small share of the industry and because they tend to grow no faster on average than large firms (Hymer and Pashigian, 1962, p. 86).

^x “A price war is hitting PC makers hard. Many well-known names could disappear from the high street. ... But not all the problems are due to the downturn in the economy or the bursting of the Internet bubble. Much of the suffering has been caused by Dell computer

which started a price war to gain market share.” Trouble at the top for PC giants, *The Guardian*, September 13, 2001.

^{xi} “Personal computer shipments suffer first fall in 15 years”, *The Financial Times*, July 21/22, 2001.

^{xii} The first step involves a regression in the levels of the variables: individual firm (and industry) stock returns are regressed on the S&P 500 stock return. Unit root tests are then run on the residuals from this regression to test for cointegration. In the tables, if the CRADF critical values from Mackinnon are larger than the 95% critical value, then the residual is $I(0)$, i.e. stationary and the two variables are cointegrated. Furthermore, although with $I(1)$ variables the standard error of the residuals (called *S.E. of R* in the tables) is not an exact measure, this standard error can be interpreted (lightly) as the firm-specific and industry-specific degree of risk: the larger it is the more unsystematic risk there is. The second step involves the Granger Representation Theorem which states that a cointegrated relationship always admits a representation in terms of an Error Correction Model (ECM) with the variables in differences. The coefficient on the lagged residual (called *RES -1* in the tables) in this equation must be statistically meaningful and negative for the cointegration relationship to hold. The strength of the long run relation is captured by the dimension of this parameter.