Indices that capture creative destruction: questions and implications

Indices That Capture Creative Destruction: questions and implications

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Abstract

The paper argues that micro and macro economists interested in the dynamics of creative destruction can gain important insights by using indices that capture the effect of innovation on the *relative* position of firms. This is due to the uneven and "destructive" effect that radical innovation has on firm rankings. One such index is the *market share instability index*. On the financial side, the *excess volatility* of stock prices and *idiosyncratic risk* also appear to capture the uneven dynamics of creative destruction. The paper concludes by considering the implications of these propositions for economy-wide growth during periods of radical innovation (e.g. GPTs).

Keywords: creative destruction, relative growth, innovation, volatility.

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Introduction

Entry and exit patterns in the microeconomics and industrial organization (IO) literature, and firm turnover rates in the macroeconomics literature, are often used to describe and measure industrial turbulence during periods of Schumpetarian creative destruction. Macro studies on the effect of innovation on the reallocation of resources within and between sectors use such data to study the turbulence underlying this reallocation (Caballero and Hammour 2000, Davis and Haltiwanger 1998). IO studies analyze the relationship between innovation and entry/exit patterns to gain insights on the cause and consequences of the industry "shakeout" common to the early evolution of many industries (Geroski and Mazzucato 2001, Gort and Klepper 1982, Klepper 1996, Utterback and Suarez 1993). And the organizational ecology literature, which lies at the intersection between strategic management and IO, studies the relationship between entry/exit rates (which they use to calculate "firm density") and the dynamic process by which firms gain "legitimation" (Carroll and Hannan 2000).

Yet if one is interested in the turbulence that emerges from the *destruction* side of creative destruction, it is not necessarily entry and exit data, or firm turnover rates, that one should focus on. It is (just as) important to look at measures that capture changes in the *relative* position of firms, i.e. measures that capture the essence of the competitive battle between firms. Schumpeter described this battle as a *"…process of industrial mutation…that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one.*" (Schumpeter 1975: p. 83). Such relative measures include, the rank turnover index (Gort 1963) and the market share instability index (Hymer and Pashigian 1962).

For example, in the personal computer industry, although entry rates were highest during the 1980's, market shares during this period were relatively stable as was also the concentration ratio up until the early 1990's. It was only when "competence destroying" innovations, such as the rise of Wintel and the World Wide Web in the 1990's, destroyed IBM's monopoly of the innovation process that market shares (and market structure) became unstable. This is the period of creative destruction in the industry (Bresnahan and Greenstein 1997).

Due to their focus on the emergence and evolution of inter-firm variety, evolutionary economists have long emphasized the importance of focusing on relative change rather than absolute change. For this reason evolutionary models often use replicator dynamics, or *distance from mean dynamics,* to describe growth processes rather than models that rely on the representative agent (Metcalfe 1994, Mazzucato 2000). In an evolutionary context where growth is a function of how agents differ from the mean, a world of representative agents—no matter how optimal, would be a world without growth. The focus on relative change is also found in "population" based models of organizational ecology.

Yet there are not many empirical applications of these approaches which focus on indices of competition which capture the relative changes between firms. Many continue to rely on standard indices in industrial organization, such as changes in concentration, or proxies of turbulence like entry/exit rates and turnover rates. Using a limited set of empirical examples, our paper concentrates on the ability of some alternative indices, from both the IO literature and the finance literature, to capture creative destruction, or what the strategic management literature calls "competence destroying innovations" i.e. innovations that undermine the advantage of incumbents (Tushman and Anderson 1986, Henderson and Clark 1990). Our main point is that these indices are particularly useful for researchers that want to isolate those periods of industry evolution that undergo the most turbulence due to the dynamics of creative destruction.

The paper is organized as follows: Section I uses examples from the personal computer and automobile industry to prove that the turbulence caused by radical innovation is not (always) well captured by entry and exit data. Section II shows how market share instability captures such periods of competence-destroying innovations at the core of Schumpeter's notion of creative destruction. Section III proposes that IO economists interested in such instability can gain important insights by evaluating indicators of stock price volatility since these indicators also appear to capture (indirectly) the effects of creative destruction. Section IV emphasizes the aggregation problems that arise when industry level indicators of turbulence are not derived using firm level data. Section V explores some possible implications of these points for our understanding of growth led by general purpose technologies (GPTs). Section VI summarizes the main points in the paper.

An important note: the points made in Sections I-IV arise from previous empirical work on the computer industry and the automobile industry (Mazzucato 2002; 2003) as well as an analysis of volatility in 34 different industries (Mazzucato and Tancioni 2004). Our aim here is to draw out new insights, important to both micro and macroeconomists, which these specific examples suggest. We are in the process of investigating whether the points can be made more *generally*—theoretically through a model of learning under different knowledge regimes, and empirically through a study of a larger number of firms and industries. Data sources are listed in the Appendix. `

I. Periods of high entry/exit do not always coincide with periods of radical innovation.

Entry and exit patterns in both the automobile industry and the PC industry follow the standard pattern highlighted by industry life-cycle studies (Jovanovic and MacDonald 1994; Klepper 1996, Utterback and Suarez 1993). Figure 1[1] illustrates that in both industries, firm numbers rose very quickly during the first two decades—reaching just under 300 after 15 years, and then began to steadily fall. 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.

Faithful to the standard life-cycle story, in both industries the shakeout began shortly after product standardization[2]. In the auto industry the timing of the shakeout coincided with Ford's introduction in 1910 of the industry's first branch assembly plant to

[1] In Figures 1 and 3 "industry age" on the horizontal axis begins with the year that the industry began. The US auto industry began in 1899 and by 1926 it had already attained an equal importance to shipbuilding and railroads (Epstein 1928). The PC industry began in 1974 with the introduction of the first mass produced minicomputer, the Altair 8800, produced by Micro Instrumentation and Telemetry Systems (the IBM PC emerged later in 1981).

[2] Although there are some differences between the different life-cycle approaches (see Klepper and Simons 1997 for a review), they all emphasize that the shakeout begins with the emergence of a standardized product. One of the main differences between these approaches is the emphasis in Klepper 1996 on increasing returns to R&D that occurs simultaneously with product standardization, a more continuous process than the emphasis in Utterback and Suarez (1993) on a single discontinuous event.

produce the first standardized car, the Model T[3]. 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's introduction of the 32-bit 386 processor in 1985 and Microsoft's introduction of Windows 3.0 in 1990—both of which made consumers care more about what was inside the box than who was the maker of the box (Bresnahan and Greenstein 1997).

Yet the study of innovation dynamics in the two industries reveals that the similarities in entry and exit patterns hide an important qualitative difference between the two industries: whereas the period of high entry rates in the auto industry was also the period of radical technological change, this is not the case in the PC industry. Empirical studies on technological change in the auto industry suggest that the most radical innovations occurred in the very early years, when entry rates were the highest (i.e. before 1925). Abernathy et al. (1986) list all process and product innovations in the auto industry from 1893-1981, weighting them— via a "transilience" scale— 1 to 7 according to how much they affected the production process: 7s represent radical innovations (e.g. the advent of the assembly line in 1910) and 1s incremental ones (e.g. new paint procedure). During these 88 years, there were only 18 innovations that received a 6 or 7, and nine of these occurred *before* 1917. After 1940, only four innovations received such high weights. Figure 2, which displays the innovation index over time (the number of product and process innovations multiplied by their weights), illustrates that the intensity of innovation fell over time. Filson's (2001) "quality change index" (a proxy for technological change, derived by dividing actual prices by hedonic prices) confirm these dynamics.

Unlike the auto industry where most of the price and quality changes occurred in the first decade, most of the price and quality changes in the PC industry 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). This third decade includes the rise of the Intel chip (1987), the rise of Windows (1990), and the commercial rise of

[3] 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 standardized cheaper cars (lighter-weight, four cylinder vehicles) were forced to exit (Epstein 1928).

the World Wide Web (1995)—all contributing to the loss of IBM's monopolistic control of sales and the innovation process[4].

- *Main point: The case of the personal computer industry suggests that periods of competence destroying innovations, at the heart of Schumpeter's notion of creative destruction, are not always captured by entry and exit data. What is (also) needed is an index that captures changes in the relative positions of firms. The next two sections propose the use of such indices from the IO literature and the finance literature.*

II. Market share instability captures creative destruction.

As argued above, in both the automobile and PC industries, periods in which innovation was most radical were also the periods in which market shares underwent the greatest change. This supports the literature on "competence-destroying" innovations which emphasizes the effect of radical (or architectural) innovations in upsetting industry structure (Tushman and Anderson 1986; Henderson and Clark 1990). It also supports the focus of evolutionary economics on the *relative* growth, as opposed to the absolute growth, of firms (Dosi and Nelson 1994). The market share instability index, devised by Hymer and Pashigian (1962) is particularly appropriate for capturing this type of change (for further discussion, see Mazzucato 2000):

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

where s_{it} = the market share of firm *i* at time *t*. The higher is *I*, the more competitive is the industry[5].

[4] Bresnahan and Greenstein (1997) attribute the higher degree of competitive innovation in this third decade of the PC industry to the "vertically disintegrated" structure of innovation—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). From 1980-1988, innovation in the PC industry was more of the "competence-enhancing" type: it served to enhance the existing competencies and lead of IBM. From 1989-1996, innovation in the PC industry was of the "competence-destroying" type: new radical innovations destroyed the lead of IBM.

[5] 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). 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. In the auto industry, the 10 firms are: Ford, GM, Chrysler, Studebaker, Packard, Hudson, Nash, Willys, Kaiser and American Motors.

The market share instability index has been deemed, in various studies, to be a more dynamic index of competition than the concentration ratio (Gort 1963, Mazzucato 2000). Even if the concentration ratio is very high, if the instability index is also high (due, for example, to the constant change in identity of the top 4 firms), the industry can be considered competitive. A similar index is the rank order index, which tracks changes in rankings between firms.

Using the instability index, Table 1 and Figure 3 indicate that in the auto industry market share instability was highest during the period 1900-1928. This is supported by Figure 4, which illustrates the constantly changing positions of the 28 leading producers during this period (Epstein 1928). From 1940 onwards, market share instability steadily decreased as did also innovation and new firm entry. Market share instability temporarily 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 creative 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 its monopoly of the innovation process (until then all innovations had to be "IBM compatible"). The new innovations allowed the firms—that had entered earlier—to gain market share and have greater influence over the innovation process. Table 1 indicates that market share instability in the PC industry was highest in the decade 1990-2000. Column 2 in Table 1 indicates that this was not the same period in which *absolute* firm growth was the highest: individual firms and the industry as a whole grew fastest during the decades in which entry rates were highest (1974-1984), but the greatest changes in market shares occurred during the decades with the most radical innovations (Bresnahan and Greenstein 1997).

- *Main point: Measures/indices of competition used in dynamic IO, such as the market share instability index, are useful for capturing the turbulence caused by radical*

In the PC industry, the 10 firms are: IBM, NCR, Apple, Hewlett-Packard, Compaq, Dell, Gateway, Toshiba, Wang, and Unisys. In the PC industry, different compositions of top firms were experimented with to ensure that *I* is not sensitive to the particular firms included in the calculation.

innovation. Such indices are, in our opinion, at times more useful than entry/exit data (or turnover rates) to capture the "destructive" side of creative destruction.

In the next section we consider how measures/indices of stock price volatility are also useful for capturing such turbulence.

III. Stock price volatility appears to capture creative destruction.

When investors value a firm they are comparing the potential future growth of the firm to that of its competitors. What they care most about is not the *absolute* health of the firm, but whether it will win against its competitors. Hence when a firm's stock price goes up, this movement is often associated with the fall in another firm's price (e.g. as was witnessed with the rise of the dot.com firms). And as innovation is a key factor in a firm's future growth, we expect that movements in stock prices will be associated with changes in innovation.

The relationship between innovation and stock market values operates through the effect of the news on innovation on the expected future cash flows of the firm. As indicated in Pakes (1985), the effect of new patents on stock market rates of return operates as follows:

"…changes in the stock market value of the firm should reflect (possibly with error) changes in the expected discounted present value of the firm's entire uncertain net cash flow stream. Thus, if an event [a successful patent application] does occur that causes the market to reevaluate the accumulated output of the firm's research laboratories, its full effect on stock market values ought to be recorded immediately." (Pakes, 1985: p. 392).

Literature on this topic includes Jovanovic and Greenwood (1999) which links stock prices to innovation in a model in which innovation causes new capital to destroy old capital (with a lag). Since it is primarily incumbents who are initially quoted on the stock market, innovations cause the stock market to decline immediately since rational investors with perfect foresight foresee the future damage to old capital. They claim that this explains why 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.

Yet both Pakes (1985) and Jovanovic and Greenwood (1999) focus mainly on (changes in) the *level* of stock prices not on volatility. Why should stock price *volatility* be related to creative destruction? In general, when radical innovations upset the existing market structure, this affects the market valuation process due to the effect of uncertainty (e.g. market share instability) on the ability of investors to predict future rankings. In a study of the auto industry (1898-1998), Mazzucato and Semmler (1999) find a correlation between market share instability and the excess volatility of stock prices, i.e. the degree to which stock prices are more volatile than the present value of discounted future dividends. In a comparative study of autos and personal computers, Mazzucato (2002) finds that both the "excess volatility" of stock prices and "idiosyncratic risk", i.e. the degree to which firm level stock returns are more volatile than market level stock returns (S&P 500), were highest precisely during the decades in which innovation was the most radical and "competence-destroying".

Below, we first explain how excess volatility was calculated in Mazzucato (2002), and then connect the empirical results attained to the core points in this paper. Excess volatility compares the volatility of actual stock prices with those that would be predicted by the efficient market model (Shiller 1981). The efficient market model (EMM) states that the real stock price is equal to the expected value of discounted future dividends:

$$v_t = E_t v_t^* \tag{2}$$

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

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.*

To calculate excess volatility for the auto and computer industry, the perfect foresight price v_t^* is computed using the industry level stock price and dividend data. After dividing the industry level data by the S&P 500 equivalent (e.g. average automobile dividend / S&P 500 dividend), and detrending the data to ensure stationarity, v_t^* is calculated recursively using Equation (4):

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

for which the moving average version is:

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

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.

The results on excess volatility in computers and autos are illustrated in Figures 5 and 6. The key point is that in both cases the difference between the standard deviation of efficient market prices (vt*), (prices that reflect the present value of future dividends) and actual stock prices (vt) is highest during the periods that innovation was most radical (Abernathy et al. 1983, Filson 2001, Bresnahan and Greenstein 1997). As discussed above, these are precisely the periods when market shares were most unstable, i.e. when competence destroying innovations upset the ranking between firms. This suggests that the "excess volatility of stock prices", like "market share instability", is useful for (indirectly) capturing changes in relative growth of firms.

Another measure of stock price volatility which captures the effect of creative destruction on the relative growth of firms is "idiosyncratic risk". Idiosyncratic risk is measures the degree to which firm-specific (or industry-specific) returns are more volatile than general market returns (Campbell et al. 2000). The stock return of firm *i* at time *t* is defined as:

$$r_{i,t} = \frac{P_{i,t} + D_{i,t}}{P_{i,t-1}} - 1 \qquad (6)$$

where P_{it} is the stock price of firm *i* at time *t,* D_{it} is the dividend of firm i at time t. Idiosyncratic risk is calculated by dividing the standard deviation (denoted in brackets) of firm *i*'s stock return by the standard deviation of the stock return of the general market *M* (the average for the S&P 500 firms):

$$IR_{i,t} = \frac{\langle r_{i,t} \rangle}{\langle r_{M,t} \rangle} \tag{7}$$

Using cointegration analysis between firm specific stock returns and market returns, Mazzucato (2002) finds that idiosyncratic risk in both industries under invetigation, like excess volatility, was highest during the periods of radical innovation.

The fact that both market share instability and stock price volatility are correlated with periods of radical innovation, suggest that both types of turbulence are related to real production factors. This is important since in both the industrial organization literature and the finance literature, volatility is often discussed in terms of “random” and/or transient factors (Evans 1987; Shiller 1981). An understanding of how patterns of innovation in both industries are related to different types of turbulence and volatility provides an alternative, innovation-based, understanding of volatility and idiosyncratic risk.

- *Main point: Here we have suggested that indices of excess volatility and idiosyncratic risk, like the market share instability index discussed above, are highest during periods of radical innovation and are thus relevant to the analysis and measurement of creative destruction. Like market share instability, they are helpful for capturing changes in the relative growth of firms.*

IV. A*ggregate* industry data hides the dynamics of creative destruction.

In this section we consider whether the results in Section III can be generalized across different industries. That is, given the finding that periods of radical innovation exhibit high excess volatility of stock prices and idiosyncratic risk, we test whether industries which are deemed to be *highly innovative* exhibit more volatility of stock prices than those that are deemed to be less innovative. Idiosyncratic risk is studied at the industry level so that in Eq. 7 above firm *i* is replaced with industry *j* (i.e. the volatility of the stock returns of industry *j a*re compared with the volatility of the stock returns of the general market). Thirty four industries are studied: Table 2 includes the list of these industries along with their descriptive statistics. Using R&D intensity data (R&D spending/total sales for each industry), the industries are first divided into the following three categories: “very innovative”, “innovative” and “low innovative”. The categorization supports that found in Marsili (2001), which builds on Pavitt’s (1984) sectoral taxonomy of innovation.

To study whether idiosyncratic risk is higher in innovative industries than in less innovative industries, we use different statistical and econometric tools: basic descriptive statistics; deterministic and stochastic trend analysis of volatility (Augmented Dickey Fuller tests for unit roots); Granger causality analysis to see whether the general market returns have predictive capabilities for the innovative industries (i.e. we expect the general market returns to have no predictive capabilities for the innovative industries’ stock returns); variance decomposition analysis to study the relative contributions of unit-specific and unspecific variances to the single units volatilities; and regression analysis with the CAPM model to evaluate the degree to which the average market return explains the industry level returns. In each case the null hypothesis is that there is no relation between innovation and idiosyncratic risk (both measured at the industry level). Detailed results can be found in the working paper by Mazzucato and Tancioni (2004).

The main result is that, at the industry level, no coherent pattern emerges between innovation and idiosyncratic risk. While some of the innovative industries conform to the predicted behavior (more idiosyncratic risk), other innovative ones do not. The same holds for the low innovative industries. In fact, our expectations seem to be only fulfilled in the extremes of the categorization (e.g. semiconductors on the innovative side). These results suggest that calculating volatility with aggregate industry level data (average stock prices and dividends for the industry as a whole) does not permit us to capture volatility behavior that is specific to innovative industries.

In a preliminary analysis of firm level data, Mazzucato and Tancioni (2004) try to get beyond the aggregation problems by looking at firm level dynamics for a select group of 34 firms in five different industries which have very different levels of innovativeness: computers, biotechnology, pharmaceuticals and textiles[6]. The

[6] The reason that data for only 34 firms was studied is that to conduct the firm level panel analysis we had to use a select group of firms that were available for the entire time period, 1974-2002. We recognize that this is very limiting and while it serves our preliminary explorative purpose, we intend to look at a much greater number of firms in the future.

firms (about 7 for each industry) were chosen to represent a balanced group of large and small firms in each industry. We take annual firm-level R&D intensity data and see whether at the firm level this variable can explain observed changes in firm level volatility of stock returns. Panel estimation procedures are used to test for the relationship between the volatility of stock returns and R&D intensity (R&D/sales)[7]. Employing monthly observations on stock returns, the annual volatility figures are calculated as 12 term (monthly returns) standard deviations. Given the small time dimension of the sample obtained, the preferred estimators are the pooled OLS and GLS, both with the common constant (C) and Fixed Effects (FE) versions. In order to control for the effects of dimensionality on volatility, the firms' relative capitalization weights are also entered in the different specifications. The idiosyncratic elements can thus be captured by the GLS weighting, the FE specification and the relative weights in capitalization. The best results are obtained when the R&D intensity measure is entered with 5-year lags.

Table 3 shows the results of the analysis under different specifications. The hypothesis of a positive relationship between volatility and R&D intensity is not rejected by the data. The innovation effect is statistically meaningful[8]. These results are encouraging and suggest that a more direct consideration of innovation activity, for example using patent data, may improve the results (this is the focus of our work in progress).

- *Main point: In this section we have asked whether some of the results concerning innovation and stock price volatility discussed in Section III can be generalized across different industries (thirty four industries with different levels of innovativeness). Preliminary analysis suggests that the relationship between*

[7] R&D intensity is of course an imperfect proxy for innovation since it is only the *input* to innovation. Patent data is a better proxy for innovative *output*. However, we leave this to our work in progress where we connect NBER patent citations data with industrial and financial volatility data (Mazzucato and Tancioni 2005).

[8] It is interesting to note that the relationship tends to be weakened by considering different firm-specific factors. In particular, jointly controlling for cross-sectional heteroskedasticity via GLS and for Fixed Effects makes the R&D intensity coefficient statistically meaningless. This potentially happens because the covariation between R&D intensity and volatility may be captured by the two sectional corrections (FE and GLS). The same occurs to the coefficient on the weight for capitalization, resulting statistically meaningless only when entered in a FE-GLS specification. The possibility that the joint consideration of both the corrections for the sectional specificities is responsible for this result is also signaled by the fact that the percentage of variance explained by the regression does not improve when moving from a FE OLS to a FE GLS, while the GLS correction resulted highly effective when the a common constant restriction was imposed.

innovation and volatility, discussed in Section III, does not appear when aggregate industry data is used to calculate volatility (e.g. average stock prices and average dividends). This should act as a warning for researchers looking at creative destruction with aggregate industry level data (this of course does not apply to industry level indices that are calculated using firm level data as in Sections I-III above). In fact, when firm level data is used, a relationship between R&D intensity and volatility is found. These results are being explored further in current work using patent citation data.

V. Possible implications for growth theory.

This section explores some possible implications of the results found in Sections I to IV for our understanding of the causes and consequences of economic growth during periods of radical technological change. The discussion is intended as exploratory, making a new link between the macro literature on growth and the IO literature on innovation and market structure.

Recent growth literature has linked TFP growth to the advent of General Purpose Technologies or GPTs (Helpman and Trajtenberg 1998). Some of this literature has focused on the effect that such large innovations have on sectoral, cyclical and aggregate volatility (e.g. Caballero and Hammour 2000, Imbs 2002). The underlying assumption in this work is that radical innovations (often introduced by new firms) lead to increases in firm-level productivity and growth and the summation of the growth of individual firms leads to increases in industry growth (and productivity)[9]. Since innovation causes intra and inter sectoral reallocation, this also leads to greater volatility in growth rates[10]. When these innovations are GPTs this can lead to economy wide growth and volatility, such as that experienced during the New Economy years (late 1990's) which were driven by the IT revolution (David and Wright 1999, Gordon 2000). Aggregate volatility, in this framework, arises from the economy re-adjusting itself to the new technological paradigm. In general, the macro literature on Schumpetarian waves and growth predicts a positive correlation

[9] For example, Imbs (2002) states: "A direct implication is that the link between sectoral volatility and growth should vary systematically with the sectoral rate of (total factor) productivity. In particular, the higher productivity growth, the higher the positive correlation between growth and volatility".

[10] Caballero and Hammour (2000) argue that productivity growth arises from factors shifting from low to high productivity areas. They also show that most of the increase in productivity occurs from reallocation occurs *within* not between sectors.

between the growth of firms and industries introducing the new technologies, the productivity and volatility of these industries, and the growth, productivity and volatility of the aggregate economy.

The data and arguments provided in Sections I to IV above suggest that the above logic may contain some erroneous assumptions. In some situations, such as the PC story describd above, the causation is not from changes in absolute firm growth to industry and economy wide growth but instead from changes in *relative* firm growth to industry volatility to aggregate economic growth. The difference is important since it means that we might not be able to associate periods of aggregate economic growth with periods of individual firm growth. What we might instead observe is a relationship between changes in the relative growth rates of firms (e.g. measured directly or also indirectly via the market share instability index, or in a theoretical model via replicator dynamics), increases in industry level productivity and increases in aggregate economic growth.

The connection with economic growth occurs of course only if the industries under question are fundamental to economic growth, e.g. industries embodying a new GPT. Given that autos and personal computers were the industries that most embodied the GPTs of the 1920's and 1990's (the proliferation of the internal combustion engine in the 1920s and the combined advances in the microchip and internet technology in the late 1980's/early 1990's) we can use the early history of these industries to test this tentative proposition about growth. The results are found in Table 4.

Table 4 compares the dynamics of autos and PCs (innovation, market share instability, output growth and multi-factor productivity growth-MFP) to that of the general economy (MFP growth and GDP growth). As predicted in the discussion above, the period in which the PC industry's MFP growth was highest was not the same as that when firm and industry growth rates were highest (detailed firm level absolute and relative growth data can be found in Mazzucato 2003). Firm and industry growth rates were highest when entry rates were highest, i.e. during the first 10 years of the industry when production grew the most. Instead, productivity grew the most when market shares were the most unstable, in the 1990's, the decade of creative destruction. *This was the same period that aggregate economy MFP and GDP growth was highest* (the New Economy period led by IT). It is this fact that provides the most support to our exploratory proposition about growth.

The economy's GDP growth was highest precisely during the decades in which quality change and market share instability in both industries was highest. For the years for which industry level MFP data is available (only the early evolution of computers), we see that this was also the period when both industry and economy wide MFP growth was highest. If we calculate simple productivity figures for autos (output over labor input) we get a similar result. Although GDP growth was marginally higher in the period 1923-1929, it is surprising that it was nearly as high in that first decade prior to the mass-production revolution of the 1920's.

The results provide some preliminary insights regarding the relationship between firm, sectoral and economy wide growth during Schumpetarian waves. Of course general conclusions cannot be drawn from the study of only two industries. It is important to test these hypotheses on as many different GPT driven industries as possible (our work in progress is dedicated to biotechnology and pharmaceuticals). Nevertheless, the detailed history of these two particular industries (as well as the more extensive, albeit less qualitative, analysis of the cross section of industries in Section IV), has highlighted the importance of understanding the relationship between innovation, inter-firm variety and volatility in both micro and macro investigations of growth.

- *Main point: When creative destruction occurs through competence destroying innovations, we should expect to see a correlation between economy wide growth and market share instability. Since this does not always occur in the period of high entry and output growth (as argued in Section I), it is possible that the common assumption that economy wide growth occurs bottom up from firm and industry growth is misplaced. Due to the uneven nature of technological change, what matters is relative change (and the associated instability) not absolute change.*

VI. Conclusion

The paper has explored different propositions which suggest that micro and macro economists interested in the dynamics of creative destruction can benefit from paying attention to indicators of turbulence that highlight changes in the relative position of firms, a dynamic not well captured by entry and exit data. It was proposed that some more appropriate indicators of the effect of creative destruction on market structures include the market share instability index (Hymer and Pashigian 1962) due to its ability to capture changes in relative growth rates at the core the creative destruction dynamic. In fact, in both the case of autos and computers, this index was very high during periods of radical innovation. In the case of the personal computer industry, radical innovation and high market share instability occurred *after* the peak in entry rates.

The paper also showed that measures of financial volatility tend to be correlated with the outcomes of creative destruction. Since market valuation is to a large extent a process of valuing firms against each other in the competitive battle, it is not surprising that market share instability is correlated with both the "excess volatility" of stock prices and "idiosyncratic risk".

The paper also showed that this correlation is hard to capture when aggregate financial data is used (i.e. average industry stock prices and dividends). To capture the effect of creative destruction on financial volatility it is necessary to look at firm level data since average industry data smoothes out the very uneven process (between firms) at the center of our investigation.

Finally, we have suggested the possibility of a relationship between these indices of creative destruction and economy wide growth. We have suggested that what matters for economic growth is not (only) firm and industry growth, but *uneven growth*, which allows some firms to survive and some to fail. This uneven growth is the result of radical technological change and productivity increases which, as described above, (often) undermine the leads of the incumbents (Tushman and Anderson 1986).

TABLE 1

Standard Deviation (and Mean in Italics) of Market Share Instability, Units and Stock prices

	MS Inst.	Units	Stock	Stck/SP500
AUTO				
1908-1918	**25.2**	**0.1620**	na	na
		0.0401	na	na
1918-1928	22.6	0.1569	**0.1458**	**0.1257**
		0.0304	*0.0939*	*0.0617*
1918-1941	17.9	0.1500	0.1393	0.1089
		0.0378	*0.0620*	*0.0352*
1948-2000	7.6	0.0638	0.0791	0.0352
		0.0070	*0.0298*	*-0.0020*
1948-1970	10.3	0.0759	0.0671	0.0372
		0.0171	*0.0335*	*0.0002*
1970-2000	5.6	0.0523	0.0881	0.0335
		-0.0030	*0.0243*	*-0.0036*
PC				
1970-1980	1.4	**0.2062**	0.0708	0.0294
		0.2431	*-0.0047*	*-0.0039*
1980-1990	11.5	0.1884	0.0662	0.0324
		0.1450	*0.0154*	*-0.0136*
1990-2000	**17.9**	0.0357	**0.1196**	**0.0445**
		0.0646	*0.0585*	*-0.0003*
1970-2000	28.9	0.1758	0.0905	0.0349
		0.1504	*0.0258*	*-0.0038*

top = standard deviation, bottom italics=mean value
bold number=decade with highest value
MS Inst.= instability index from Eq. (1)
Units=units produced
Stock=industry-level stock price
Stck/SP500= industry-level stock price divided by S&P500 stock price
na= not available since auto industry first publicly quoted in 1918

Table 2

Industry level stock returns: descriptive statistics

Industry	Mean	Maximum	Minimum	Std. Dev.	Industry	Mean	Maximum	Minimum	Std. Dev.
TRANSPORT	0.1007	3.4089	-0.2685	0.3831	FOREST PROD. PUBL.	0.0690	0.3300	-0.2166	0.1074
SEMICONDUCTORS	0.0768	1.6463	-0.6776	0.2619	HOSPITAL SUPPLIES	0.0529	0.2607	-0.1699	0.1064
NAT. GAS PIPELINES	0.0798	0.9588	-0.3777	0.1502	INSURANCE MULTIL.	0.0669	0.2992	-0.2170	0.1053
BUILD. MATERIALS	0.0674	0.4662	-0.2613	0.1367	FINANCIAL	0.0705	0.3073	-0.2450	0.1041
ELECTRONIC INSTR.	0.0480	0.5427	-0.2612	0.1367	FOOD CHAINS RETAIL	0.0724	0.3119	-0.1619	0.1014
AUTOMOBILES	0.0782	0.4403	-0.2328	0.1331	INSURANCE PROPERTY	0.0752	0.2985	-0.1443	0.1012
TRUCKER TRANSP.	0.0416	0.3759	-0.2406	0.1275	FOREST PROD. PAPER	0.0599	0.3327	-0.1864	0.1001
BANKS NY	0.0816	0.3975	-0.2884	0.1251	CHEMICALS AND COAL	0.0684	0.3070	-0.1955	0.0992
DEPT. STORE RETAIL	0.0666	0.4930	-0.3635	0.1250	INTEGR. DOMESTICS	0.0678	0.3539	-0.2083	0.0950
AEROSP. DEFENCE	0.0736	0.5037	-0.3964	0.1246	METAL AND GLASS CONF.	0.0676	0.2514	-0.2093	0.0946
PAPER CONFECT	0.0646	0.4118	-0.2364	0.1210	BREWERS AND ALCOOL	0.0573	0.2766	-0.1325	0.0940
ENTERTAINMENT	0.0584	0.3630	-0.2835	0.1196	SOFT DRINKS NON ALC.	0.0758	0.2685	-0.1836	0.0926
ALLUMINIUM	0.0593	0.4188	-0.2328	0.1193	ELECRICAL EQUIPMENT	0.0643	0.2536	-0.2529	0.0870
TOBACCO	0.0930	0.3754	-0.2496	0.1177	COMPOSIT OIL	0.0790	0.2893	-0.1575	0.0800
RETAIL COMP.	0.0523	0.2879	-0.3449	0.1145	ELECTRIC POWER COMP.	0.0992	0.3333	-0.0794	0.0740
PUBLISHING NEWSP.	0.0629	0.4078	-0.2308	0.1128	SP500	0.0657	0.2390	-0.2049	0.0713
RESTAURANTS	0.0525	0.2843	-0.2503	0.1081	PUBLIC UTILITIES	0.0930	0.2724	-0.0650	0.0684

Table 3

Panel estimation of the relationship between volatility and R&D intensity in 34 firms from 5 industries (biotechnology, pharmaceuticals, computers, agriculture, textiles)

Method	Dim. corr.	int coeff	t-stat	dim coeff	t-stat	r&d coeff (-5)	t-stat	Rbar sq
Pooled OLS	n	0.106	23.586	-	-	0.056	5.098	0.055
GLS	n	0.086	34.856	-	-	0.048	3.032	0.143
FE Pooled OLS	n	CS spec	-	-	-	0.023	2.354	0.399
FE GLS	n	CS spec	-	-	-	0.017	0.907	0.395
Pooled OLS	y	0.116	22.672	-0.061	-3.897	0.056	5.264	0.085
GLS	y	0.091	29.611	-0.015	-2.187	0.049	3.130	0.167
FE Pooled OLS	y	CS spec	-	-0.090	-1.007	0.023	2.351	0.399
FE GLS	y	CS spec	-	-0.065	-1.659	0.018	0.957	0.401
Pooled OLS	y CS spec	0.205	19.351	CS spec	-	0.038	3.689	0.311
GLS	y CS spec	0.124	16.181	CS spec	-	0.037	2.207	0.291

Note: CS spec = Cross Section specific

Table 4

Growth: Industry (Autos and PCs) vs. Aggregate Economy

	AUTO				***ECONOMY***	
	QUAL. CH.	MS INS	OUTPUT	MFP	*MFP*	*GDP*
1895-1908	**0.2500**	**0.2000**	**0.1356**	na	*na*	***0.0431***
1909-1922	0.0310	0.1800	0.0304	na	*na*	*0.0312*
1923-1929	0.0320	0.1600	0.0378	na	*na*	***0.0455***
	PC				***ECONOMY***	
	QUAL. CH	MS INS	OUTPUT	MFP	*MFP*	*GDP*
1975-1986	0.3400	0.0340	**0.2431**	0.2142	*0.0892*	*0.0313*
1987-1992	0.1700	0.1150	0.0357	0.2800	*0.0500*	*0.0257*
1993-2000	**0.3800**	**0.2010**	0.0217	**0.6388**	***0.1050***	***0.0373***

notes: QUAL. CH. = quality change index, hedonic prices/actual BEA prices, (Filson 2002)
MS INS= market share instability index, (Hymer and Pashigian 1962)
OUTPUT=average growth of industry output (number of cars and PCs)
MFP=average growth rate of multi-factor productivity
GDP= average growth rate of GDP

Figure 1

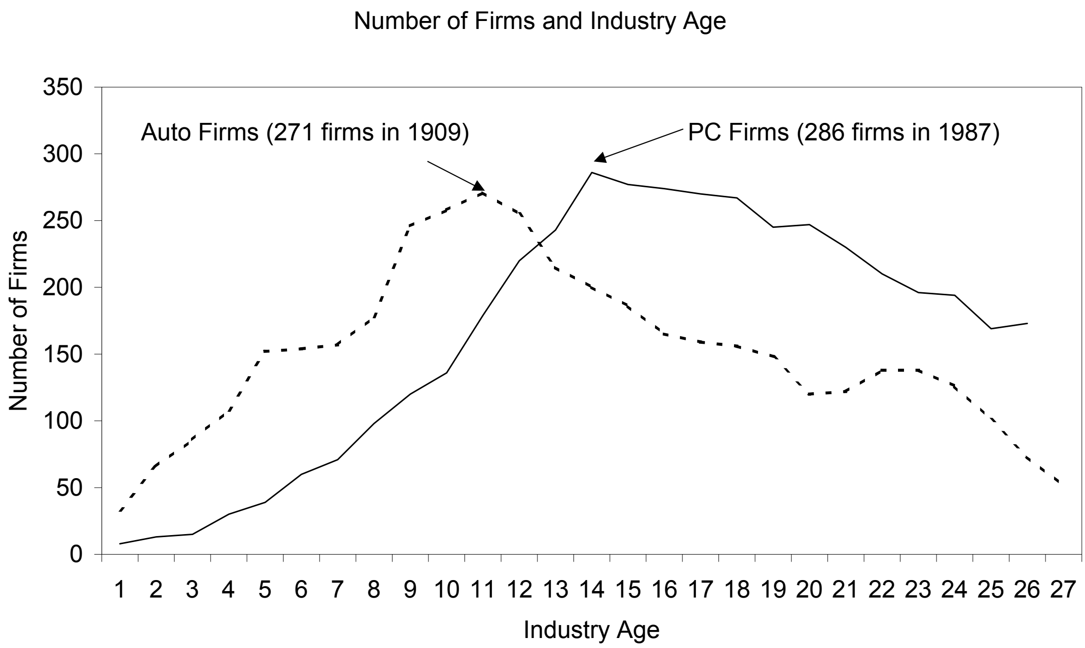


Figure 2

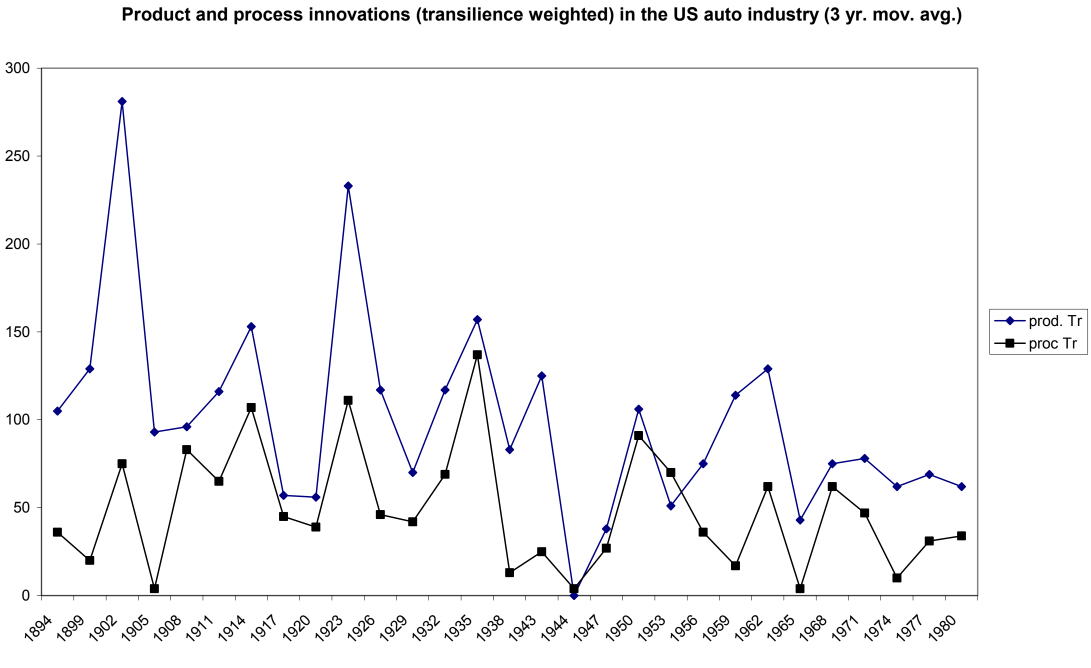


Figure 3

Market Share Instability and Industry Age

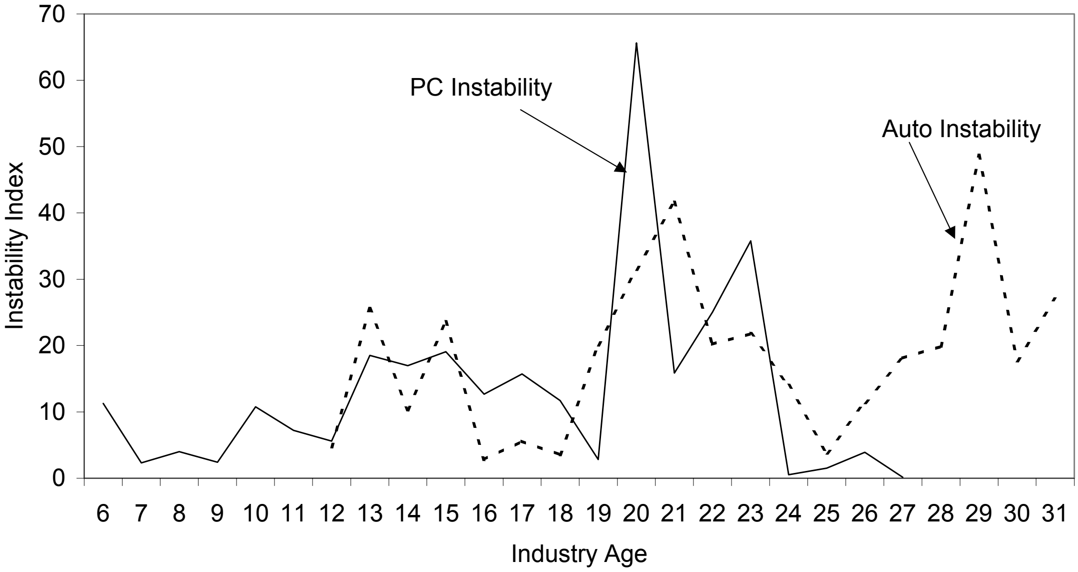


Figure 4

Movement of 28 Leading Auto Producers Ranked According to Places in Production
(source: Harvard Business Review, Epstein, 1928)

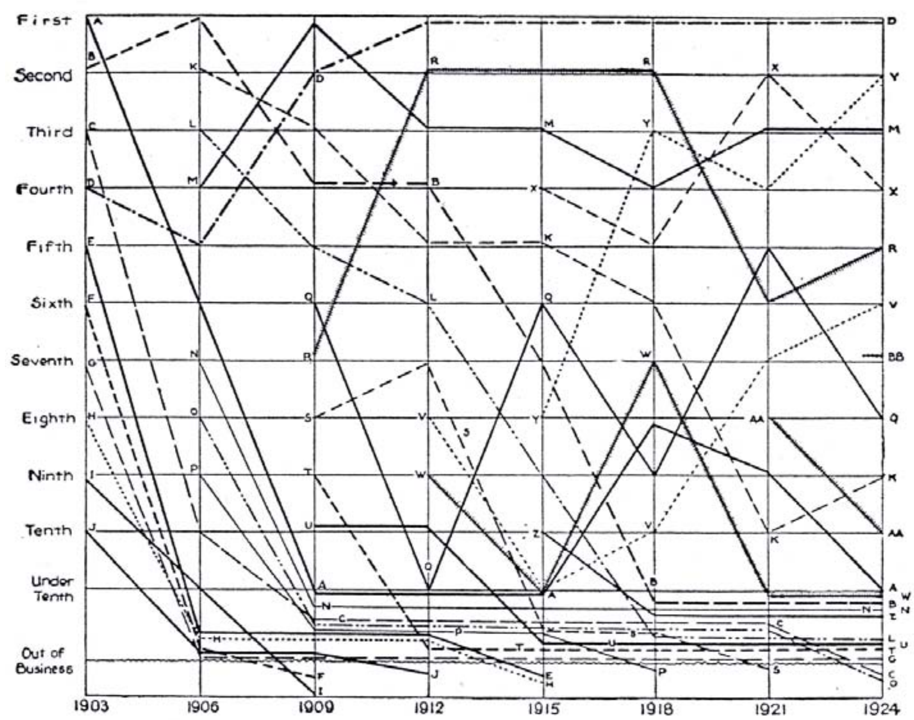


Figure 5

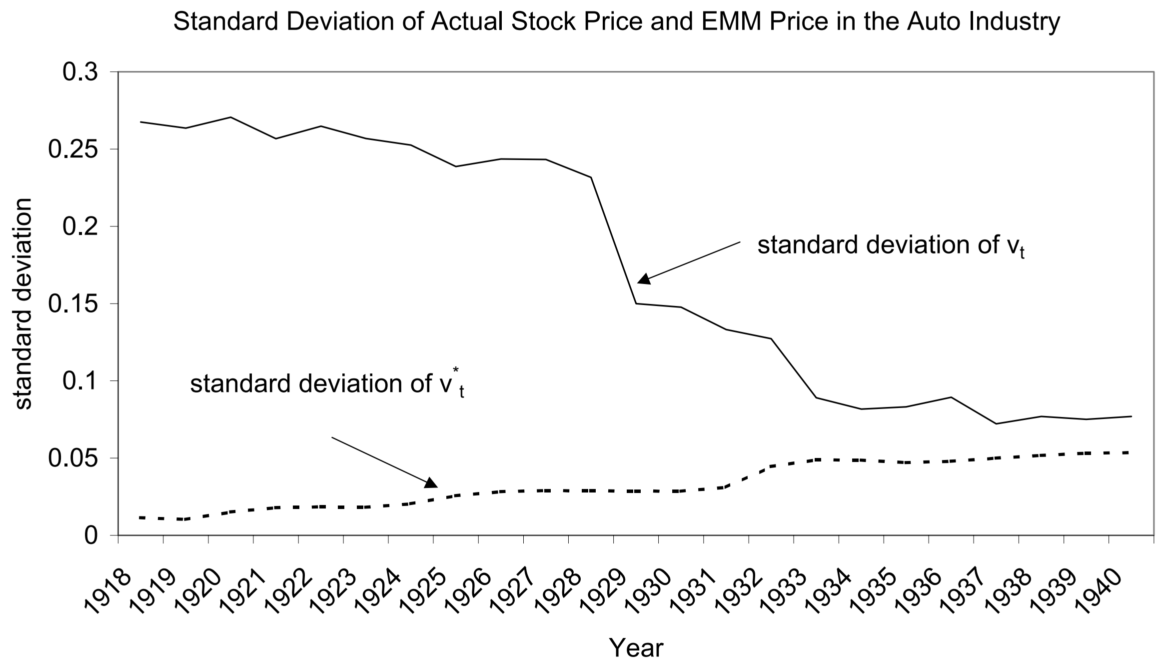
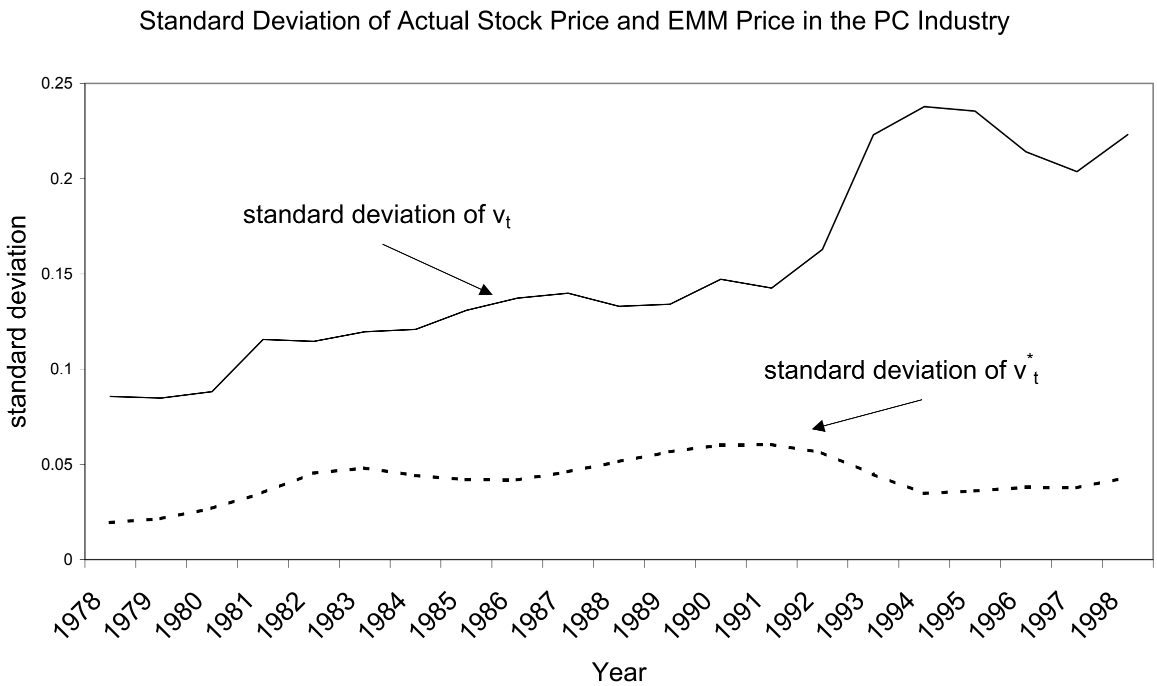


Figure 6



Appendix: Data Sources

Automobiles: Individual firm units and total industry units from 1904-1999 were collected from annual editions of *Wards Automotive Yearbooks* (first editions, reporting data starting in 1904, are published in 1924). Firm-specific stock prices, dividends, and earnings/share figures were collected from annual editions of *Moody's Industrial Manual*. Industry-specific per share data was collected from the *Standard and Poor's Analyst Handbook*[11] (the firms included to calculate that index are listed in endnote 11). Hedonic prices and data on changes in quality are from the series used in Raff and Trajtenberg (1997).

Personal Computers: Annual firm-level data on the total number of personal computers produced from 1973-2000 was obtained from the International Data Corporation (IDC), a market research firm in Framingham, Massachusetts. Firm-level stock price, dividend, and earnings per share data were obtained from *Compustat.* Industry-level financial variables were obtained, as for the post-war auto industry, from the Standard and Poor's *Analyst's Handbook* (2000). The firms which define this index (listed in endnote 12 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)[12]. Hedonic prices and data on changes in quality are from the series used in Berndt and Rappaport (2000) and Filson (2001).

Economy: GDP data and industry and aggregate MFP data was obtained from the BLS (http://www.bea.gov/).

[11] The firms used to create the S&P index for automobiles are (dates in parentheses are the beginning and 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).

[12] The computer industry was first labeled by S&P as *Computer Systems* and then in 1996 changed to *Computer Hardware*. Firms 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).

References

Abernathy, W.J., K. Clark and A. Kantrow 1983. *Industrial Renaissance: Producing a Competitive Future for America*, Basic Books, New York

Berndt ER, Rappaport N. 2000. Price and Quality of Desktop and Mobile Personal Computers: A Quarter Century of History. Paper presented at the National Bureau of Economic Research Summer Institute 2000 session on Price, Output, and Productivity Measurement. Cambridge, MA. July 31, 2000.

Bresnahan TF, Greenstein S. 1997.Technological Competition and the Structure of the Computer Industry. *Journal of Industrial Economics* **47** (1): 1-40.

Caballero, R. ,Hammour, M. 2000. Creative Destruction and Development: Institutions, Crises and Restructuring, *NBER Paper* No. 7849.

Campbell JY, Lettau M, Malkiel BG, Yexiao X. 2000. Have Individual Stocks Become More Volatile? An Empirical Exploration of Idiosyncratic Risk. *Journal of Finance* **56**: 1-43.

Carroll G.R. , Hannan, M. 2000. *The Demography of Corporations and Industries*, Princeton University Press, Princeton, NJ.

David, P. , G. Wright (1999), General Purpose Technologies and Surges in Productivity: Historical Reflections on the Future of the IT Revolution, *University of Oxford Discussion Papers in Economic and Social History*, Number 31, September 1999.

Davis, D. , Haltiwanger, J. 1998. Gross Job Flows, in O. Aschenfelter and D. Card, eds. Handbook of Labour Economics.

Dosi G, Nelson R. 1994. An Introduction to Evolutionary Theories in Economics. *Journal of Evolutionary Economics* **4**: 153-72.

Engle, R.F., Lilien, D.M., Robins, R.P. 1987. Estimating Time Varying Risk Premia in the Term Structure: the ARCH-M Model. *Econometrica*, **55,** 391-407.

Epstein R. 1928. *The Automobile Industry; Its Economic and Commercial Development*. Arno Press: New York, NY.

Evans D. 1987. The Relationship between Firm Growth, Size and Age: Estimates for 100 Manufacturing Industries," *Journal of Industrial Economics,* **35**: 567-581.

Filson D. 2001. The Nature and Effects of Technological Change over the Industry Life Cyle. *Review of Economic Dynamics* **4**(2):460-94.

Geroski P, Mazzucato M. 2001. Modelling the Dynamics of Industry Populations. *International Journal of Industrial Organization*, **19**: 1003-1022

Gordon, R.J. 2000. "Does the New Economy Measure Up to the Great Inventions of the Past?" *CEPR Discussion Papers* No. 2607.

Gort M, Klepper S. 1982. Time Paths in the Diffusion of Product Innovations. *Economic Journal* **92**: 630-653.

Gort M. 1963. Analysis of Stability and Change in Market Shares. *Journal of Political Economy,* **62**: 51-61.

Greenwood J., Jovanovic B. 1999. The IT Revolution and the Stock Market. *American Economic Review*, **89**(2): 116-122.

Helpman, E. , Trajtenberg, M. 1998. A Time to Sow and a Time to Reap: Growth based on General Purpose Technologies, in Helpman, E., ed. *General Purpose Technologies and Economic Growth*, Cambridge: MIT Press.

Henderson R, Clark K. 1990. Architectural Innovation: The reconfiguration of existing product technologies and the failure of established firms. *Administrative Science Quarterly* **35** (1):9-30.

Hymer S, Pashigian P. 1962. Turnover of Firms as a Measure of Market Behavior. *Review of Economics and Statistics* **44**: 82-87.

Imbs, J. 2002. Why the Link between Volatility and Growth is both Positive and Negative. *London Business School Working Paper* (April 2002).

International Data Corporation. 2001. *PC Database*, Framingham, Massachusetts.

Jovanovic B, MacDonald G. 1994. The Life-cycle of a Competitive Industry. *Journal of Political Economy* **102** (2): 322-347.

Klepper, S. 1996. Exit, Entry, Growth, and Innovation over the Product Life cycle. *American Economic Review* **86**(3): 562-583.

Klepper, S., Simons, K. (1997). "Technological Extinctions of Industrial Firms: An Inquiry into their Nature and Causes," *Industrial and Corporate Change,* **6** (2): 379-460

Marsili, O. 2001,"The Anatomy And Evolution of Industries", Northampton, MA, Edward Elgar.

Mazzucato, M. 2000. *Firm Size, Innovation and Market Structure: the Emergence of Industrial Instability and Concentration*. Edward Elgar: Northampton, MA.

Mazzucato M. 2002. The PC Industry: New Economy or Early Life-Cycle? *Review of Economic Dynamics* **5**: 318-345.

Mazzucato M. 2003. Risk, Variety and Volatility: Growth, Innovation and Stock Prices in Early Industry Evolution," *Journal of Evolutionary Economics*, **13**(5): 491-512.

Mazzucato, M. , Semmler, W. 1999. Stock Market Volatility and Market Share Instability during the US Auto industry Life-Cycle. *Journal of Evolutionary Economics*, **9**

(1): 67-96.

Mazzucato, M. , Tancioni, M. 2004. Creative Destruction and Idiosyncratic Risk, *Open University Working Paper, no. 2004-50.*

Metcalfe, J.S. 1994, Competition, Fisher's Principle, and Increasing Returns in the Selection Process, *Journal of Evolutionary Economics*, **4**(4): 327-346.

Pakes, A. 1985. On Patents, R&D, and the Stock Market Rate of Return. *Journal of Political Economy*, **93** (2): 390-409.

Pavitt, K. 1984. Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory. *Research Policy*, **13**: 342-373.

Raff DMG, Trajtenberg M. 1997. Quality-Adjusted Prices for the American Automobile Industry: 1906-1940. in Bresnahan TF, Gordon RJ. 1997. *The Economics of New Goods*. NBER Studies in Income and Wealth **58**. University of Chicago Press: Chicago: 71-107.

Ramey, V. , Ramey, G. 1995. Cross Country Evidence on the Link Between Volatility and Growth, *American Economic Review*, **85**(5):1138-1159.

Schumpeter, J. A. 1975. *Capitalism, Socialism and Democracy*, Harper, New York (orig. 1942).

Shiller, R.J. 1981. Do Stock Prices Move Too Much to be Justified by Subsequent Changes in Dividends. *American Economic Review*, **71**: 421-435.

Tushman M, Anderson P. 1986. Technological Discontinuities and Organizational Environments,. *Administrative Science Quarterly* **31**: 439-465.

Utterback, J.M., Suarez, F. 1993. Innovation, Competition, and Industry Structure, *Research Policy,* **22**: 1-21.

Wards Automotive Yearbook 1936-1995. Detroit: Ward's Communications.