Two Technological Revolutions

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Abstract:

The IPOs of the Electricity/Internal Combustion revolution created more lasting value than the IPOs of the IT revolution. Stock-market data point to two explanations for this. First, computer prices have been falling much faster than did those of electricity and internal combustion in the 1890-1930 period, and so the value of each generation of computer-intensive entrants is reduced by later entrants. And, second, the pre-1973 vintages reacted to the microcomputer relatively quickly, perhaps because the threat of being taken over is now higher than it was 70-100 years ago.

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1 Introduction

In 116 years of U.S. stock-market history we look for evidence of extended periods of creative destruction. It seems to us that the periods 1890-1930 and 1971-2001 saw more creative destruction than the period 1930-1970. The first epoch saw the rise of electricity and the internal combustion engine, while the second epoch is that of the microcomputer and information technology. One way to measure progress is by how much cheaper a technology becomes. Electricity, internal combustion and – most dramatically – computing all became much cheaper over the periods in question. This is shown by the price indexes displayed in Figure 1.

{FIGURE 1 HERE}

2 What vintages are worth a lot today?

A sharp fall in the price of an input creates new business opportunities. Not all firms can take advantage of new opportunities. Radically new technologies – such as the three depicted in Figure 1 – tend to be taken up disproportionately by new firms. So, did new firms in fact join the stock market disproportionately during periods of sharp decline of the input prices in question? And if so, did they add lasting value?

Figure 2 answers this question with a qualified "yes". The solid line accounts for the value *at the end of 2001* of all firms that were then listed on the three major U.S. stock exchanges, i.e. the New York Stock Exchange (NYSE), the American Stock Exchange (AMEX), and NASDAQ, *by year of listing*. The graph is therefore a 2001 *cross section*, with the value allocated to the various vintages. Vintages vary greatly in their contributions to 2001 stock market value, but is this mainly because aggregate investment was higher in years where lasting value was created? It turns out that the cohorts of the'20s and the '60s retain their strong presence in 2001 even per unit of investment. But the '90s cohort does not.

{FIGURE 2 HERE}

The dashed line in Figure 2 is real non-residential private investment from 1885 to 2001 plotted as the share of this total attributable to each year. In a one-sector

world in which every firm financed its start-up with a stock issue and then simply kept up its capital and paid for all parts and maintenance out of its profits, each firm's current value would be proportional to its initial investment, and the solid and dashed lines would coincide. Using the ratio of the areas under the solid and dashed lines in Figure 2 as an estimate of the relative gap between market value and the start-up investment that produced it, we find a ratio of 3.26 for the '20s compared to 1.20 and 2.12 for the '50s and '60s. Surprisingly, the ratios are only 0.88 and 0.75 for the '80s and '90s. This is puzzling since the computer price index has been falling much faster than the other two indexes in Figure 1.

Relative to investment, why do the '20s account for so much more than the '90s? Several explanations come to mind:

1. *Organization capital*: The entrants of the '20s created "organization capital" that was hard to hire away or imitate by subsequent generations, whereas the subsequent vintages did not. This is an unlikely explanation since teamwork and other components of organization capital probably matter more for new technologies than for the old.

2. *Financing*: The entrants of the '20s may have financed a higher-than-average share of their own investment by issuing shares, or they later bought back more of their debt. But in the time series since 1885, business debt and stock market capitalization are *positively* correlated with a coefficient of 0.85.[1]

3. *Bubbles*? Note that the solid line in Figure 2 is a cross-section plot of values in 2001 and not a time-series plot. It is unthinkable that today there is a bubble on the '20s vintages and not on other vintages of firms.

4. *More total investment after 1970?* Had the rate of investment been higher after 1971 than before, one could expect that the average quality of that investment may have been smaller as relatively poorer projects were undertaken. But the investment rate was not that much higher after 1970 than before, and so this explanation does not work either.[2]

5. *Market power*: The IT vintages are more computer intensive, and Figure 1 shows that the price of their capital has been plummeting. A fall in markups

on old capital induced by the cheapening of new capital is the most likely explanation for the under-performance of the IT-era vintages.

{FIGURE 3 HERE}

The puzzle of the late '60s is due partly to how we treated the *en masse* addition of NASDAQ to the CRSP files in 1972. We reassigned this artificial spike back, but most of it only a *few* years back because most of the NASDAQ firms were, in 1972, only a few years old. In Figure 3 we consider versions of the solid line in Figure 2 that would obtain if none of the entering AMEX and NASDAQ firms were assigned to earlier years. The solid (top) line in Figure 3 is the same as in Figure 2, and so is the investment line. The upper dashed line shows the entry shares of 2001 stock market value that we obtain by removing the 1962 AMEX entrants from the data-set entirely (i.e., not redistributing their capital into earlier years). The dotted line reflects removal of the 1972 NASDAQ entrants.[3] Figure 3 shows that the prominence of the late '60s is indeed partly due to the NASDAQ adjustment, but that the entry of the AMEX in 1962 had a smaller effect. The ratios of the areas beneath the stock market and investment lines from 1960-70 are 2.12 with re-assignment of the 1972 spike and 1.31 without the re-assignment. In this sense, the '60s do not look quite as strong.

3 What sectors led the way for IPO's of the '20s, '60s and '90s?

For the '20s, electricity and internal combustion are the likely "general purpose" technologies. IT is the likely explanation for the post-'85 surge. But what of the '60s? Let us now consider some of these technologies in the context of some of the firms cited in Figure 2.

- *Electricity.* Two of today's giants, General Electric (listed in 1892) and AT&T (vintage 1901) both applied electricity – arising from the invention of the incandescent light bulb in 1880 and the telephone in 1876. The film industry

emerged with the founding of Warner Brothers in 1922, though the company did not formally list on the NYSE as Time-Warner until 1964.

- *Internal Combustion Engine.* General Motors listed on the NYSE in 1917 and accounted for more than 4 percent of stock market value by 1931. Caterpillar and Boeing produced the gas-driven tractor and airplane.

- *Computer/IT*: Firms at the core of the IT revolution, such as Intel, Microsoft, and Amazon, quickly rose to prominence.

This discussion does not explain the '60s. What, then, were the sectors that led the way in terms of IPO activity in the key decades? Table 1 confirms that entry in the '20s and '90s were driven by technology: Utilities such as electricity led in the '20s, and services (including health and professional) and communications technologies rose to preeminence in the '90s. The '60s have machinery (including office equipment) and chemicals as the leading sectors.

{TABLE 1 HERE}

4 Replacement among the leaders

In Hopenhayn (1982), when an industry is in a long-run stochastic equilibrium, the age distribution of an industry's leadership is invariant. That is, the average age of, say, the top 5% or top 10% of the firms is fixed. Some leaders hold on to their positions and this tends to make the leading group older, but others are replaced by younger firms, and this has the opposite effect. In equilibrium the two forces offset one another and the age of the leadership stays the same. Keeping the age of the leaders flat requires, in other words, constant replacement.

{FIGURE 4 AND FIGURE 5 HERE}

Figures 4 and 5 show that, overall, the age of the leaders is anything *but* flat. It sometimes rises faster than the 45^0 line, indicating that the age of the leaders is rising faster than the passage of time. At other times it is flat or falling, indicating replacement. Both figures show, however, that during the electricity and the IT

revolutions, the lines are flat or falling, so that replacement was then high. This is best seen in Figure 5.

Figure 4 plots the value-weighted average age of the largest firms whose market values sum to 5 percent of GDP. "Age" is from incorporation and from exchange listing. We label some important entries and exits from this group (with exits denoted by "X"). Based upon years from incorporation, the leading firms were being replaced by *older* firms over the first 30 years of our sample, because the solid line is then steeper than the 45° line. In the two decades after the Great Depression the leaders held their relative positions as the 45° slope of the average age lines shows. The leaders got younger in the '90s, and their average ages now lie well below the 45° line. The shake-out of 1999-2001 comes from Microsoft's huge rise in 1999, when it was worth more than 5 percent of GDP on its own, and its rapid decline in 2000, which transferred the full 5 percent share to GE. The two firms split the 5 percent share in 2001. The slopes of regression lines in Figure 4 (estimated with constant and time trend) are 0.62 for years since incorporation and 0.67 for years since exchange listing.

Figure 5 is similar to Figure 4 but shows the top 10 percent of firms. The regressions have slopes of 0.62 (using age since incorporation) and 0.60 (using age since listing). This figure shows that the top 10% did not age at all in the periods 1896-1928 and 1980-1999, which are right in the middle (and form the bulk of) the electrification and IT epochs. Thus, the two epochs seem to have had high rates of creative destruction.

5 Small *vs.* large firms

If "creative destruction" does indeed mean that old firms give way to young firms, then we should see signs of it in Figure 6, which depicts the relative appreciation of *total* market value of small versus large firms since 1885 with NBER recessions shaded. We define "small" firms as those in the lowest quintile of CRSP, and "large" firms as those in the upper quintile. The figure shows that small firms outperform large ones in the long run and that the growth premium is about 7.5 percent per year. But the two technological epochs do not show a faster rise than the other epochs, and this is puzzling. The IT episode shows, in particular, that the large firms regrouped

after 1983. Surprisingly, recessions do not seem to hurt the long-term prospects of small firms. The relative index rises in 10 of the 23 NBER recessions that are shaded in Figure 6.

{FIGURE 6 HERE}

6 Conclusion

All in all, evidence does point to two technological revolutions. But we do not yet know why the IT era did not produce more lasting value for the firms that IPO'd at the time. Instead, most of the large run-up in stock-market values since 1983 seems to have been collected by *large* firms of *pre*-IT-era vintage. This IT-era adaptability of older and larger firms may well explain why the phenomenal success of the '20s vintage was not repeated in any subsequent decade, and, in particular, for why no comparable success awaited the post-'70 IPOs. But a second force was the rapid cheapening of computers – it probably caused a fall in markups on old capital and may further explain why the computer-intensive post-'70 vintages have not done so well.

7 Data Appendix

Figure 1.—We describe the data and methodology for constructing the price indexes in Jovanovic and Rousseau (2002, footnotes 3, 5, and 6, pp. 350-351).

Figures 2 and 3.—The data are from the stock files distributed by University of Chicago's Center for Research in Securities Prices (CRSP) for 1925-2001, which we extended backward to 1885 with year-end observations from contemporary newspapers. The data-set, which includes 24,475 firms, is described in detail in Jovanovic and Rousseau (2001a, footnote 1, p. 1).

(*i*) *Treatment of the '62 and '72 spikes*: AMEX and NASDAQ join CRSP in July of 1962 and December of 1972, respectively. But NASDAQ firms traded over-the-counter before 1972 and the AMEX's predecessor (the New York Curb Exchange)

dates back to at least 1908. To reassign the capital from these two years to the years of its "true entry," we assume that the waiting time from incorporation to unobserved listing in the over-the-counter market for the 1972 NASDAQ entrants is the same as that for years between incorporation and NASDAQ listing *after* 1972. We consider the implications of this assumption for the apparent entry wave of the late '60s when building Figure 3. See Jovanovic and Rousseau (2001a, footnote 2, p. 1-2) for a complete description of the adjustment.

(*ii*) *Treatment of mergers*: Many of the 2001 CRSP survivors obtained large portions of their value through mergers and acquisitions. Since mergers usually imply a combination of assets among firms that entered the market at different times, we recursively traced back the merger history of the survivors who ever acquired other CRSP firms to apportion their 2001 equity capital between the entry years of the survivor, its (often multiple) targets, and any of their predecessors, using the share of combined market value attributable to each partner in the year before the merger. Figure 2 reflects this processing for 6,410 mergers. Jovanovic and Rousseau (2001a, footnote 4, p. 3) describe the procedure in more detail.

(*iii*) *Choice of investment series*: The series for private domestic fixed investment and its price deflator for 1929-2001 are from the August 2002 issue of the *Survey of Current Business* (Table 1, pp. 123-4, and Table 3, pp. 135-6) and exclude non-farm residential investment. We use Kendrick (1961, Table A-IIa, column 7) for 1889-1928, and worksheets underlying Kuznets (1961, Table T-8) for 1885-1888, and then subtract residential nonfarm construction from Kuznets (1961, Table T-11). The deflator for 1885-1928 is the quotient of the nominal and real investment series that result. We then join the Kuznets-Kendrick figures for 1885-1928 with the official figures for 1929-2001.

Figures 4 and 5.—Our data on incorporation dates include more than 5,983 CRSP firms, and are described in Jovanovic and Rousseau (2001b). The "5 percent" and "ten percent" groups actually account for more than these shares of stock market capitalization because we add firms to each group until the thresholds are passed.

Figure 6.—Because the CRSP files contain occasional but obvious errors involving changes in market value of an order of magnitude or more from one year to the

next, we exclude observations from the indexes when the data indicate an appreciation of more than 500 percent. To build the indexes, we compute the value-weighted average change in market capitalization for all CRSP firms in the appropriate quintile with observations in a given year and the next, and use the weighted average to update an index number for that quintile that is set to unity in 1885. We re-form the quintiles in each year. Figure 6 is the quotient of the small and large cap indexes.

References

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Table 1. Leading sectors for newly-listing firms by percent of entrant value

	1920's		1960's		1990's	
Rank	Sector	%	Sector	%	Sector	%
1	utilities	12.1	machinery	11.7	services	22.7
2	retail	11.3	chemicals	9.1	communications	15.2
3	food/tobacco	10.9	mining	6.8	machinery	13.0
4	metals	9.9	utilities	6.7	chemicals	5.0
5	chemicals	7.8	communications	5.8	mining	4.6

Source: Extended CRSP stock files (see Data Appendix).

Footnotes:

1- Jovanovic and Rousseau (2001b, p. 341) build a series for business debt from 1885 to 2000 by summing the market value of corporate bonds and commercial and industrial bank loans. Stock market capitalization is the sum of firm values for each year in our extended CRSP database.

2- The average ratio of private non-residential domestic investment in GDP was 9.4 percent from 1885-1970, and 11.6 percent from 1971-2001. The investment rate reached 10.7 percent from 1890-1930, and was 9.7 percent in the '20s.

3- When removing either group of entrants, we leave the surviving 1962 NYSE and 1972 AMEX and NYSE entrants in the figure after correcting for their post-entry mergers.

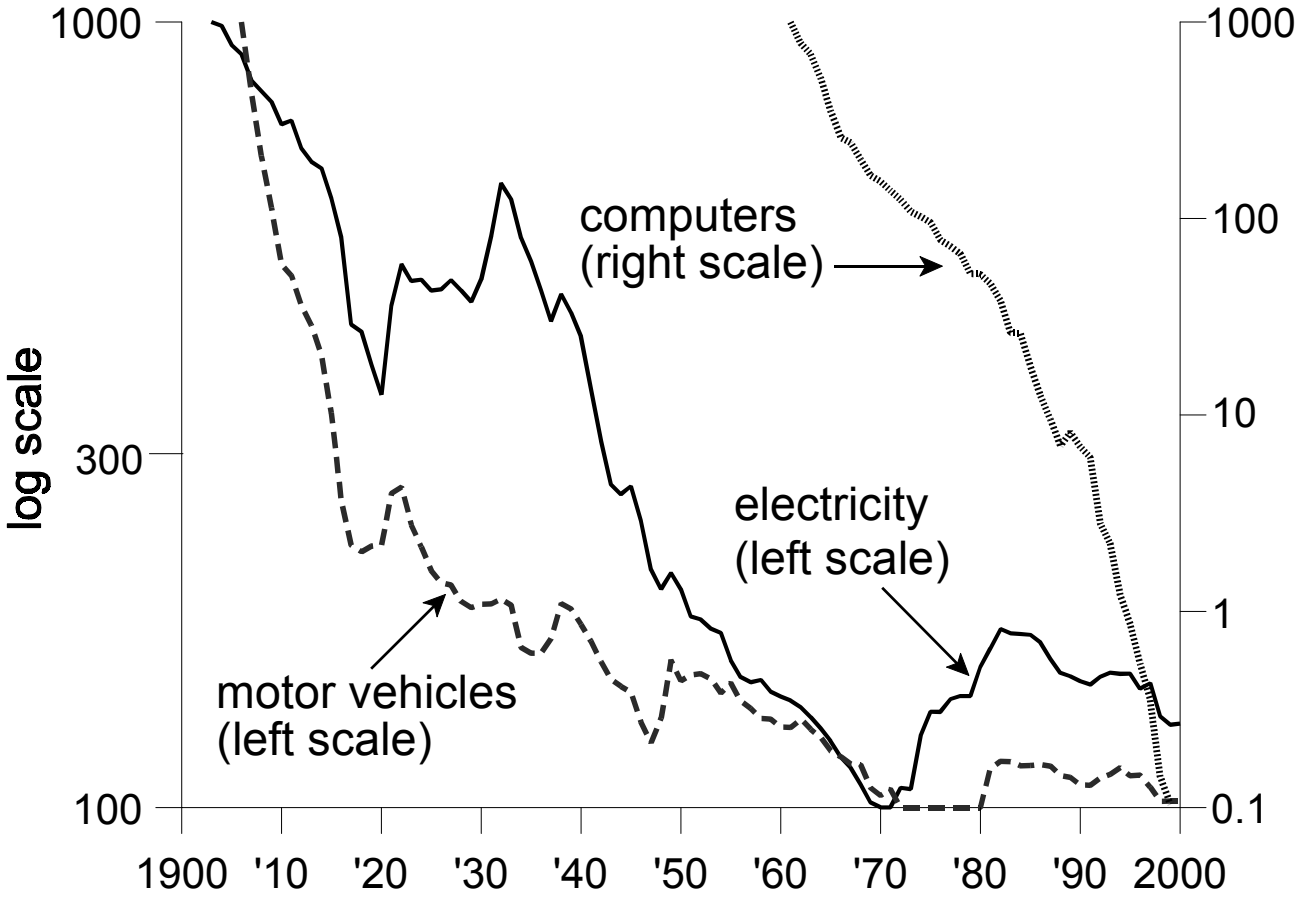

Figure 1. Price indexes for products of two technological revolutions.

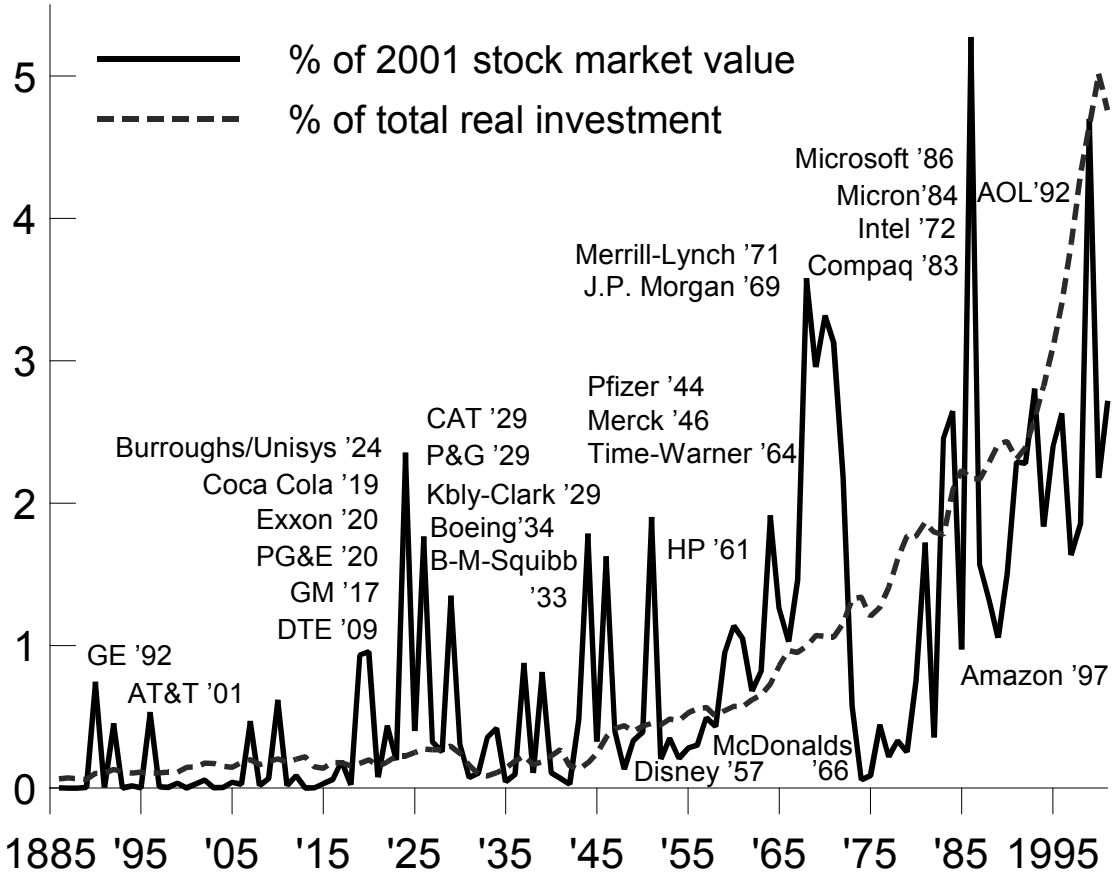

Figure 2. Total non-residential private investment and stock market capitalization in 2001 distributed by year of expenditure or exchange listing.

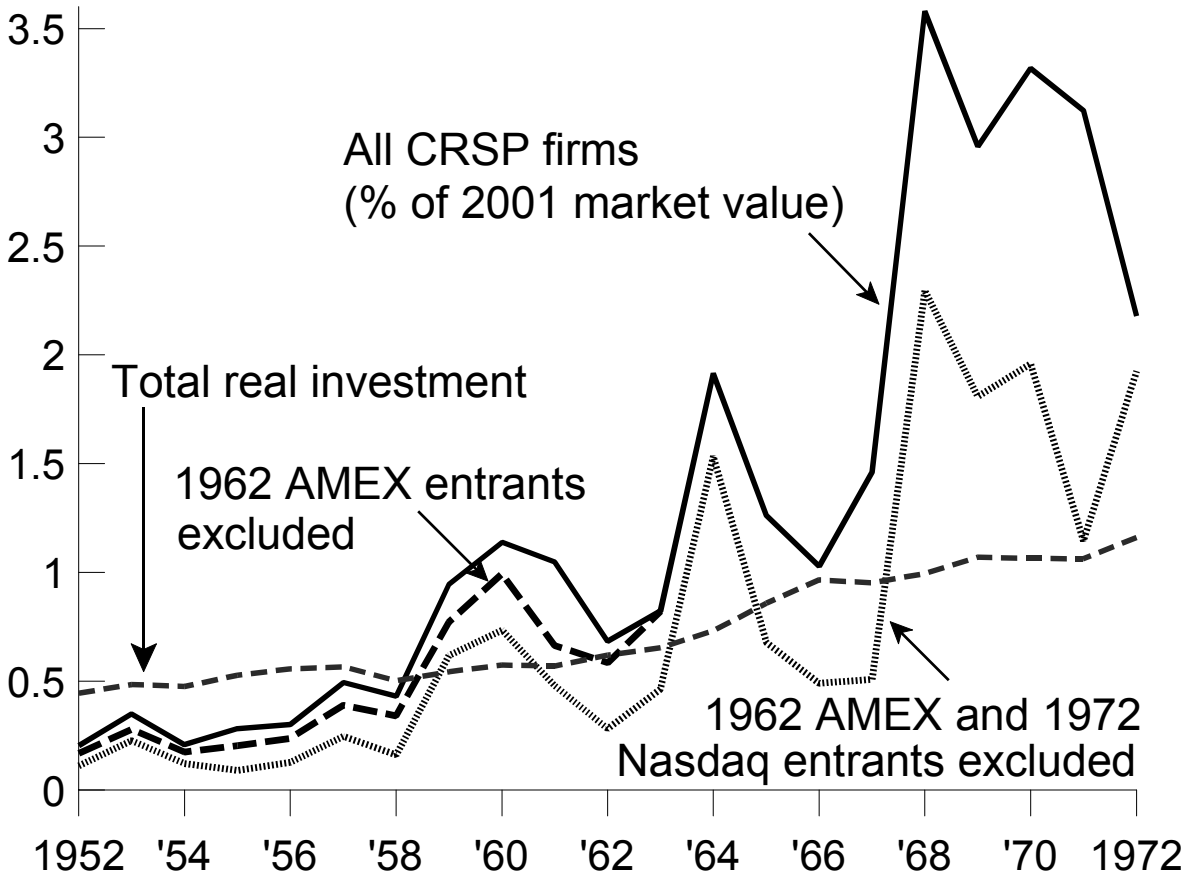

Figure 3. Shares of 2001 stock market value attributable to entry years from 1952-1972 under alternate corrections for 1962 AMEX and 1972 NASDAQ entrants.

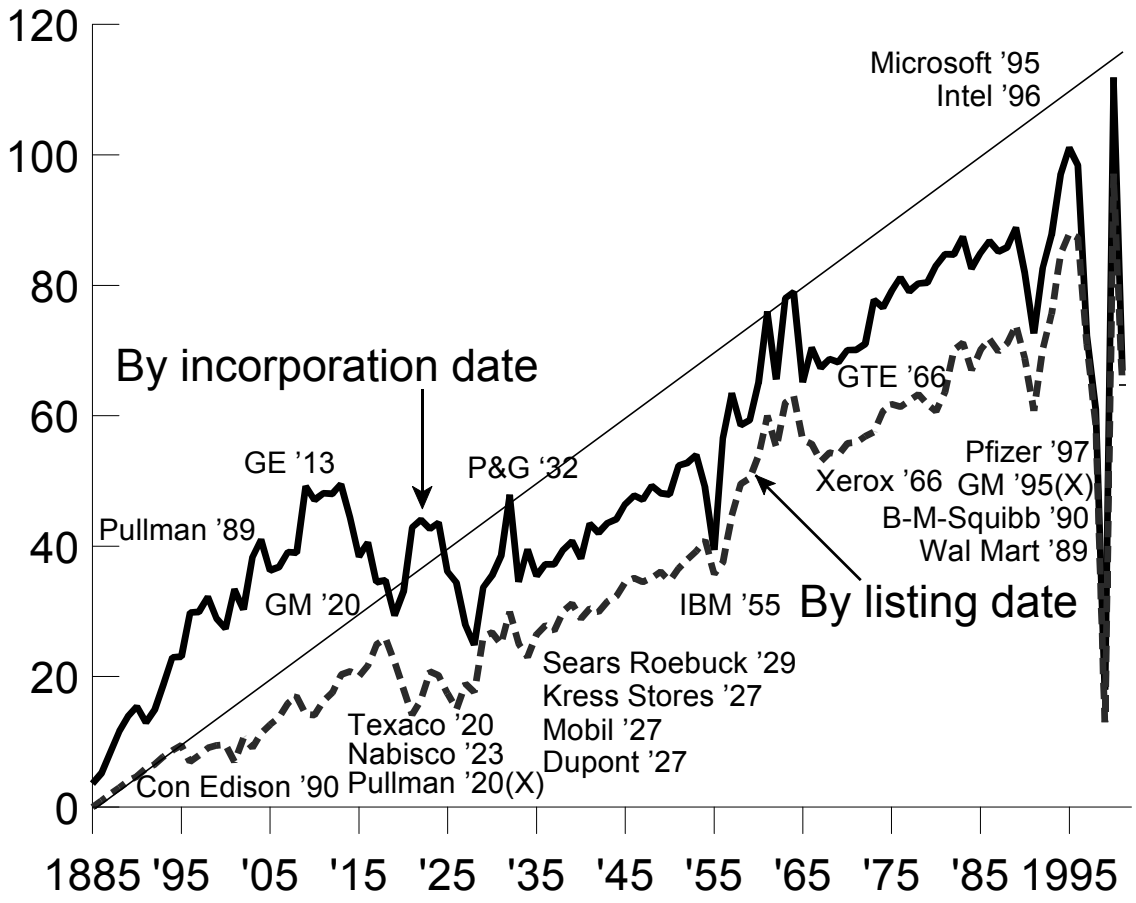

Figure 4. Average age (in years) of the largest firms whose market values sum to 5 percent of GDP.

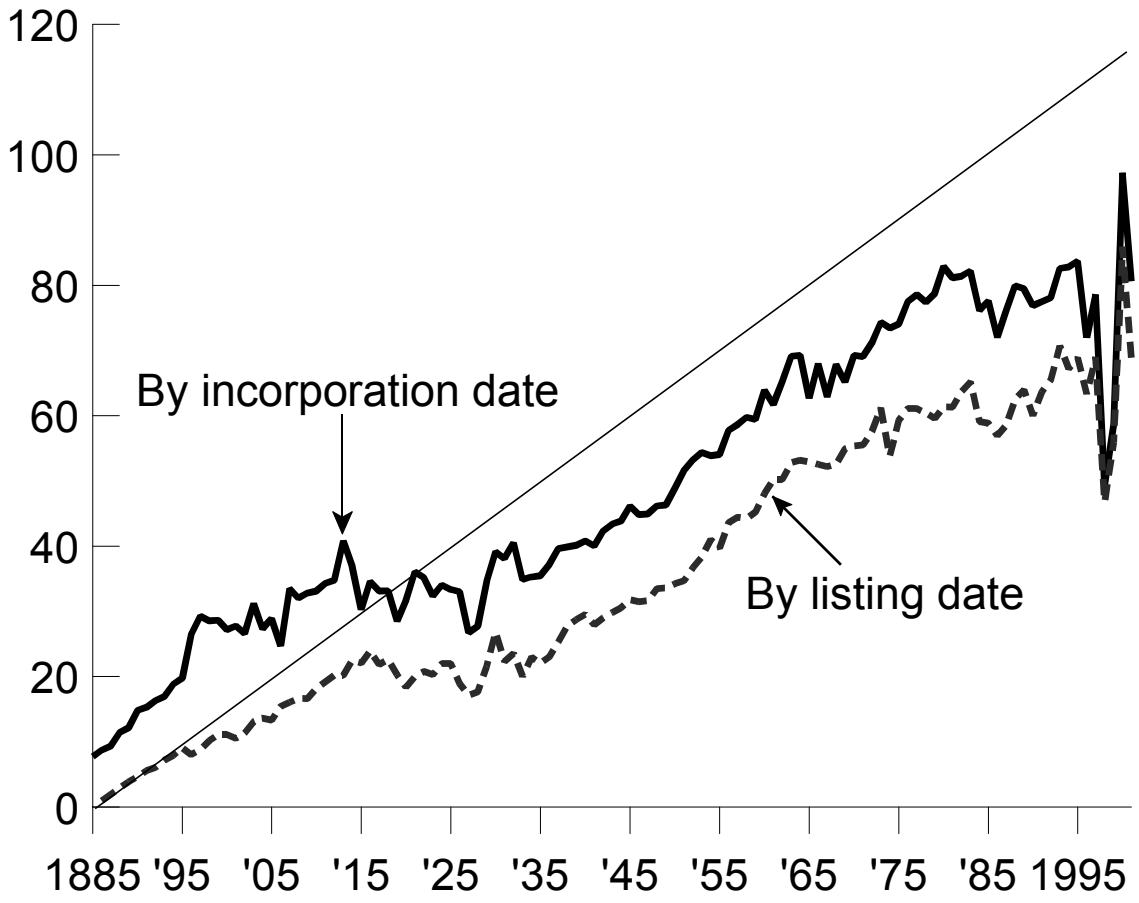

Figure 5. Average age (in years) of the largest firms whose market values sum to 10 percent of GDP.

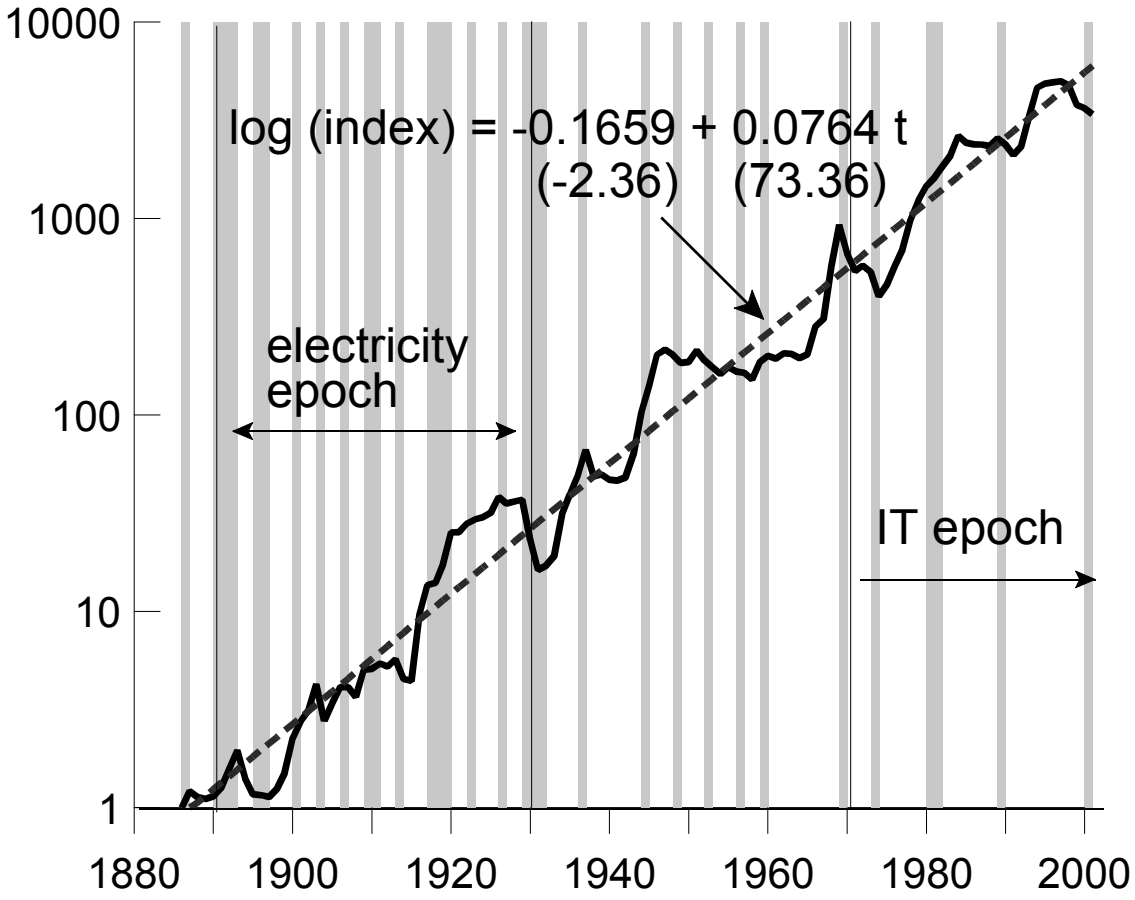

Figure 6. The relative capital appreciations of small vs. large firms.