

General Purpose Technologies

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Abstract

Electricity and IT are perhaps the two most important GPTs to date. We analyze how the U.S. economy reacted to them. The Electricity and IT eras are similar, but they also differ in important ways. Electrification was more broadly adopted, whereas IT seems to be technologically more revolutionary. The productivity slowdown is stronger in the IT era but the ongoing spread of IT and its continuing precipitous price decline are reasons for optimism about growth in the coming decades.

1 Introduction

The term “general-purpose technology,” or GPT, has seen extensive use in recent treatments of the role of technology in economic growth, and is usually reserved for changes that transform both household life and the ways in which firms conduct business. Steam, electricity, and information technology (IT) are often classified as GPTs for this reason. They affected the whole economy.

As David (1991) pointed out some years ago, a GPT does not deliver productivity gains immediately upon arrival. Figure 1 shows the evolution of the growth in output per man hour in the U.S. economy over the past 130 years, with periods of rapid diffusion of the two major GPTs shaded and the dashed line representing long-term trends as generated with the Hodrick-Prescott (H-P) filter.¹ Productivity growth was apparently quite rapid during the heyday of steam power (circa. 1870), but fell as electrification arrived in the 1890s, with the defining moment probably being the

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¹Output per man-hour in the business, non-farm sector is from John Kendrick [U.S. Bureau of the Census (1975, Series D684, p. 162)] for 1889-1947, and from the Bureau of Labor Statistics (2002) for 1948-2001. For 1874-1889, we use Kendrick’s decadal averages for 1869-79 and 1879-89, and assume a constant growth rate from 1874-84 and 1885-89.

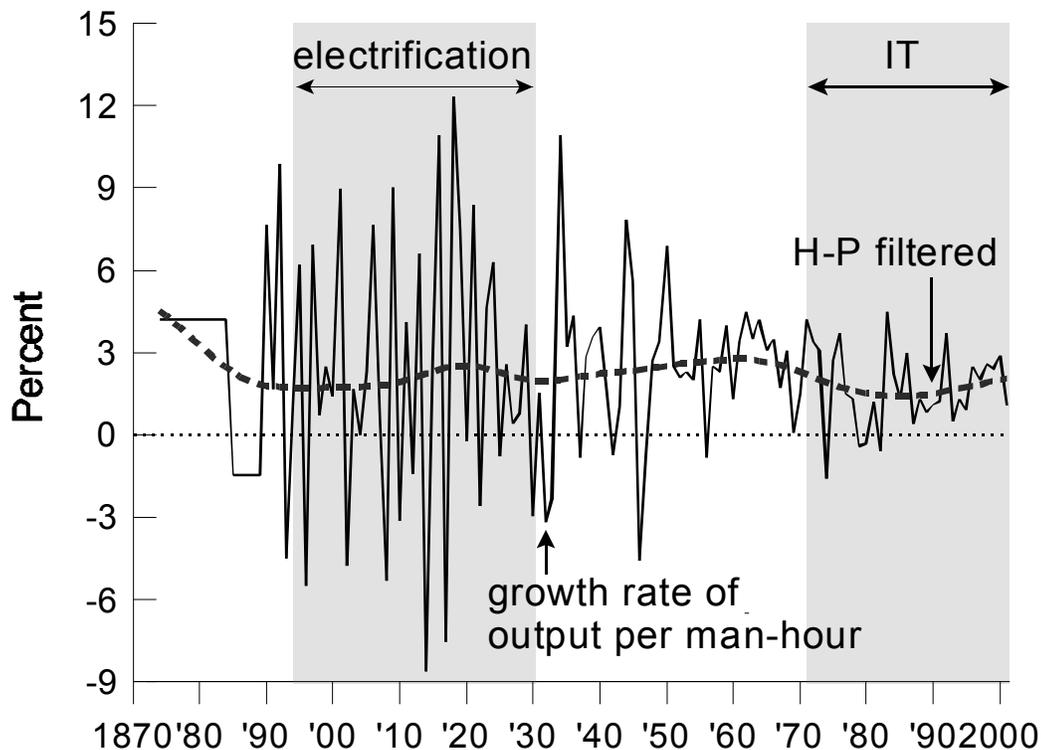


Figure 1: Annual growth in output per man-hour.

startup of the first hydro-electric facility at Niagara Falls in 1894. It was only in the period after 1915, which saw the diffusion of secondary motors and the widespread establishment of centralized power grids, that electricity finally pervaded businesses and households more generally and the productivity numbers began to rise. Figure 1 also shows that the arrival of IT, which we date with Intel’s invention in 1971 of the “4004 computer chip” (the key component of the personal computer), did not reverse the decline in productivity growth that had begun more than a decade earlier. To some extent it seems that we are still waiting for computers to show up in the productivity figures.

But it is not obvious that the startup of the Niagara Falls dam in 1894 and Intel’s invention of the 4004 chip in 1971 should define the birth of the two GPTs. Indeed, the reader may wonder how we choose the dating for the two GPT eras. In fact, the dates do coincide with periods of adoption: Net adoption of the two GPTs picks up about where the shading begins and, in the case of electrification, adoption reaches a plateau in 1929, whereas new adoption of IT is still rising today so that, on that criterion, the IT era still continues.

1.1 What is a GPT?

Each shaded area in Figure 1 contains a growth slowdown. Will the growth slowdown of the current IT era be followed by a rise in growth in the first half of the 21st century? If the second shaded area in Figure 1 is in some “fundamental” respects like the first shaded area, then we can expect growth to pick up over the next several decades. In Jovanovic and Rousseau (2002a) we have argued that the first half of the 21st century will have higher growth than, say, the 1950s and 1960s. Gordon (2000), on the other hand, is pessimistic, arguing that IT does not measure up to electricity and that it will not have such positive results. This chapter will conclude that the two eras are indeed similar.

So, what are these “fundamental” features of the two GPTs that we may attempt to compare? More generally, what criteria can one use to distinguish a GPT from other technologies? Bresnahan and Trajtenberg (1995) argue that a GPT should have the following three characteristics:

1. *Pervasiveness*: The GPT should spread to most sectors.
2. *Improvement*: The GPT should get better over time and, hence, should keep lowering the costs of its users.
3. *Innovation spawning*: The GPT should make it easier to invent and produce new products or processes.

Most technologies possess each of these characteristics to some degree, and therefore a GPT cannot differ qualitatively from these other technologies. Moreover, this is a short list which we shall later broaden. Nevertheless, we shall begin with measures of these three characteristics in the next section. But first, we summarize our findings:

1.2 Summary of findings

The evidence shows similarities and differences between the electrification and the IT eras. Electrification was more pervasive (#1), whereas IT has a clear lead in terms of improvement (#2) and innovation spawning (#3). Let us list the similarities and differences in more detail.

1.2.1 Similarities between the electrification and IT eras

1. In both of the GPT eras growth is below rates attained in the decades immediately preceding.
2. Measures of reallocation and invention – startups, exits, patents, trademarks, and investment by new firms relative to incumbents – are all higher during the GPT eras.

3. Private consumption rose gradually during each GPT era.
4. Real interest rates are about the same during the two GPT eras, and about three percentage points higher than in the middle 40 years of the 20th century.

1.2.2 Differences between the electrification and IT eras

1. Innovation measures are growing much faster for IT than for Electrification – patents and trademarks surge much more strongly during the IT era, and the price of IT is falling 100 times faster, at least, than did the price of electricity.
2. IT is spreading more slowly than did electrification, and its net adoption still continues to rise in the United States.
3. The productivity slowdown is stronger in the IT era.
4. No comparable sudden collapse of the stock market occurred early on in the Electrification era.
5. The Electrification era saw a surplus in the U.S. trade balance, in part surely because Europe had to finance a string of wars, whereas the IT era finds the United States in a trade deficit

The differences seem to outnumber the similarities. Yet the overall evidence clearly supports the view that technological progress is uneven, that it does entail the episodic arrival of GPTs, that these GPTs bring on turbulence and lower growth early on and higher growth and prosperity later.

2 Measuring the three characteristics of a GPT

As suggested in Figure 1, we shall choose electricity and IT as our candidate GPTs, and the measures that we provide will pertain mostly to these two technologies. In passing, we shall also touch upon steam and internal combustion. The three subsections below report, in turn, various measures of each characteristic – pervasiveness, improvement, and innovation – for the two GPTs at hand.

2.1 Pervasiveness of the GPT

The first characteristic is the technology’s pervasiveness. We begin with the aggregates and then look in more detail at industrial sectors.

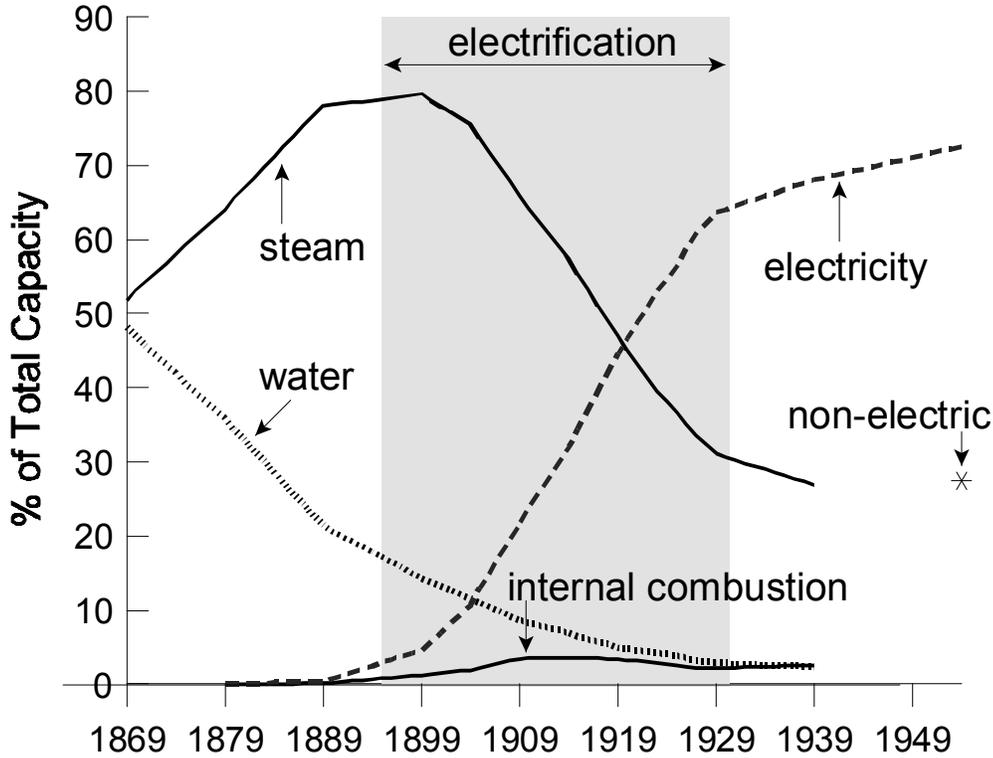


Figure 2: Shares of total horsepower generated by the main sources in U.S. manufacturing, 1869-1954.

2.1.1 Pervasiveness in the aggregate

We would like to track the evolution of GPTs using continuous time series from about 1850 to the present, but we do not have data that consistently cover the entire stretch of time, and thus will need to break this period into two overlapping segments: 1869-1954 and 1947-2001.

Figure 2 shows the shares of total horsepower in manufacturing by power source from 1869 to 1954.² The period covers the fall of water wheels and turbines, the rise and fall of steam engines and turbines, the rise and gradual flattening out of the internal combustion engine, and the sharp rise in the use of primary and secondary electric motors. The symmetry of the plot is striking in that, with the exception

²We construct the shares of total horsepower capacity in manufacturing as ratios of each power source (DuBoff, 1964, table 14, p. 59) to the total (table 13, p. 58). DuBoff estimates these quantities in 1869, 1879, 1889, 1899, 1904, 1909, 1914, 1919, 1923, 1925, 1927, 1929, 1939, and 1954, and we linearly interpolate between these years. This source does not include a breakdown of non-electrical capacity (i.e., water, internal combustion, and steam) after 1939, and so we mark the broader-defined “non-electrical” share for 1954 with an asterisk.

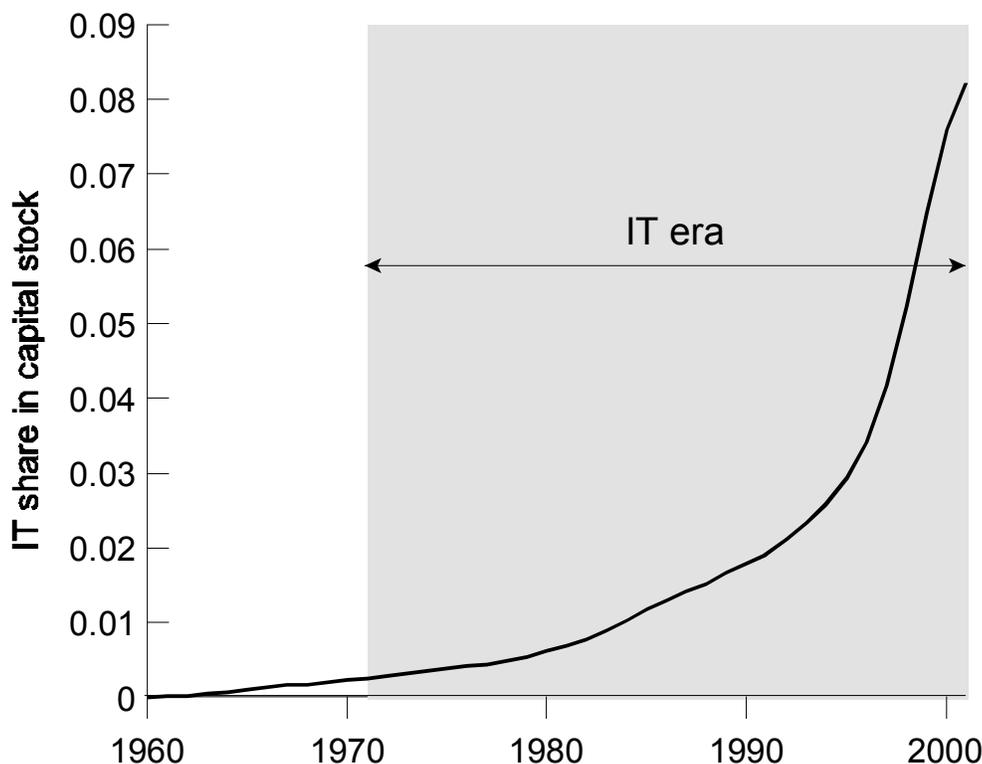


Figure 3: Shares of computer equipment and software in the aggregate capital stock, 1960-2001.

of internal combustion, power-generating technologies seem to have led for the most part sequential existences. The relative brevity of the entire steam cycle, which rises and falls within a period of 50-60 years, suggests that the technology that replaced it, Electricity, was important enough to force change quickly among manufacturers. In contrast, the decline of water power was more gradual. Moreover, if we could continue the graph to the present, electricity would surely still command a very high share of manufacturing power as a new source (e.g., solar power?) has not yet emerged to replace it. The persistence of electricity as the primary power source, even though its diffusion throughout the manufacturing sector was complete decades ago, helps to identify it as one of the breakthrough technologies of the modern era.

Figure 3 shows the diffusion of computers in the U.S. industrial sector as measured by the real share of IT equipment and software in the real aggregate capital stock.³

³We build the ratio plotted in Figure 3 by summing the capital stocks of 62 industrial sectors from the detailed non-residential fixed asset tables in fixed 1996 dollars made available by the Bureau of Economic Analysis (2002). IT capital includes mainframe and personal computers, storage devices, printers, terminals, integrated systems, and pre-packaged, custom, and own-account software. The total capital stock is the sum of all fixed asset types.

Computer and software purchases appear to have reached the first inflection point in their "S-curve" more slowly than Electrification in the early years of its GPT-era, but it is striking how much faster the IT share has risen over the past few years. Moreover, while the diffusion of electricity had slowed down by 1930, the year which we mark as the end of the Electrification "era," yet computer and software sales continue their rapid rise to this day.

The scaling of the vertical axes in Figure 2 and Figures 3 is different. The vertical axis in Figure 2 measures the shares of total horsepower in manufacturing, whereas the vertical axis in Figures 3 is the real share of IT equipment and software in the real aggregate capital stock. But scaling aside, the diffusion process appears to be much more protracted for IT than for Electrification insofar as a comparison of the shape of the diffusions in the two figures suggests that the IT era will last longer than the 35 years of Electrification. The acceleration in adoption, which was over by about 1905 for Electrification, did not end until about 1997 for IT.

Why did electricity spread faster than IT seems to be doing? We do not know if this is because it was more profitable, or because the rapid price decline of computers and peripherals makes it optimal to wait and adopt later, or still for some other reason.

2.1.2 Pervasiveness among sectors

Cummins and Violante (2002, p. 245) classify a technology as a GPT when the share of new capital associated with it reaches a critical level, and that adoption is widespread across industries. Electrification seems to fit this description. Figure 4 shows the shares of total horsepower electrified in manufacturing sectors at ten-year intervals from 1889 to 1954.⁴ Electrical adoption was very rapid between 1899 and 1919 but slowed considerably thereafter, with the dispersion in the adoption rates largest around 1919.

The main message in Figure 4 is that electrical technology affected individual manufacturing sectors with a striking degree of uniformity. Moreover, Table 1, which shows the rank correlations of electricity shares across sectors and time, indicates that there was little change in the relative ordering of the manufacturing sectors either. This means that the sectors that were the heaviest users of electricity in 1890 remained among the leaders as adoption slowed down in the 1930s. Indeed, the adoption of electricity was sweeping and widespread.

It was not practical to set up the wiring required to electrify households early on. This is apparent from the peculiar two-stage adoption process that many factories chose in adopting electricity: Located to a large extent in New England factory towns, textile firms around the turn of the century readily adapted the new technology by using an electric motor rather than steam to drive the shafts which powered looms,

⁴The shares of electrified horsepower include primary and secondary electric motors, and are computed using data from DuBoff (1964, tables E-11 and E-12a through E-12e, pp. 228-235).

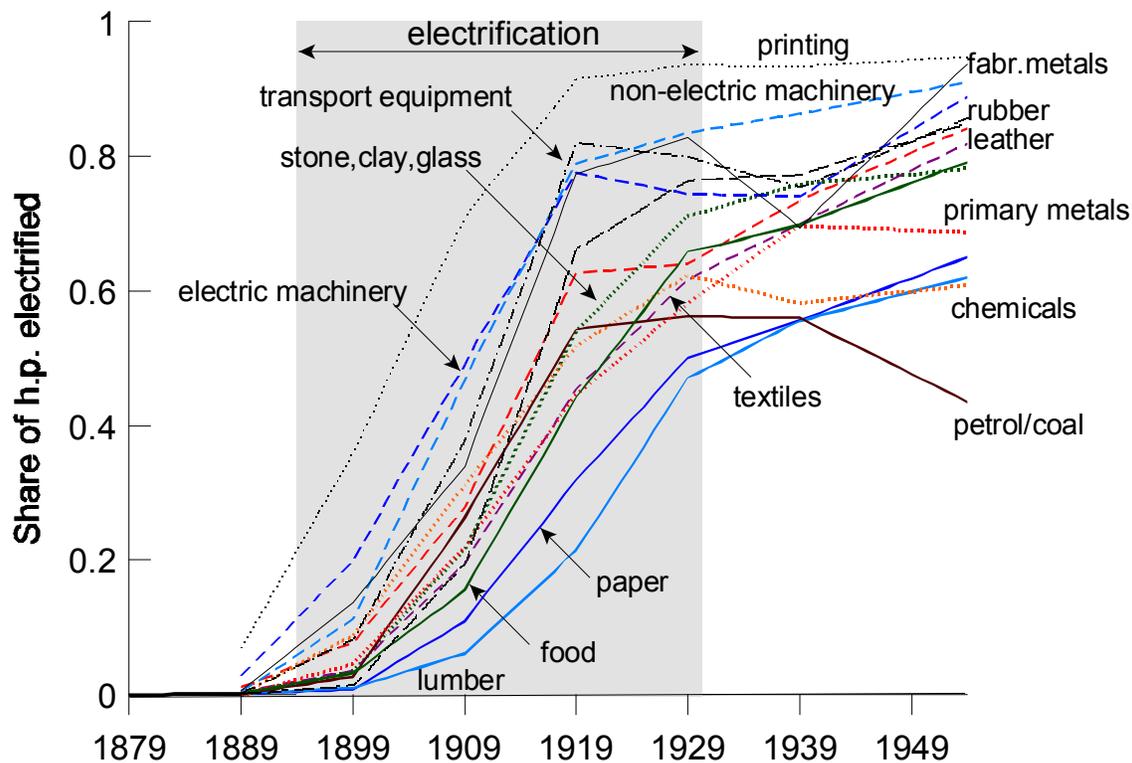


Figure 4: Shares of electrified horsepower by manufacturing sector, 1890-1954.

spinning machines and other equipment [see Devine (1983)]. Further delays in the distribution of electricity made it more costly to electrify a new industrial plant fully.

Table 1
Rank correlations of electricity shares in total horsepower
by manufacturing sector, 1889-1954

	1889	1899	1909	1919	1929	1939	1954
1889	1.000						
1899	0.707	1.000					
1909	0.643	0.918	1.000				
1919	0.686	0.746	0.893	1.000			
1929	0.639	0.718	0.739	0.871	1.000		
1939	0.486	0.507	0.571	0.750	0.807	1.000	
1954	0.804	0.696	0.650	0.789	0.893	0.729	1.000

Figure 5 shows the same data as Figure 4, but now in percentile form. We build them by sorting the electricity shares in each year and, given that only 15 sectors

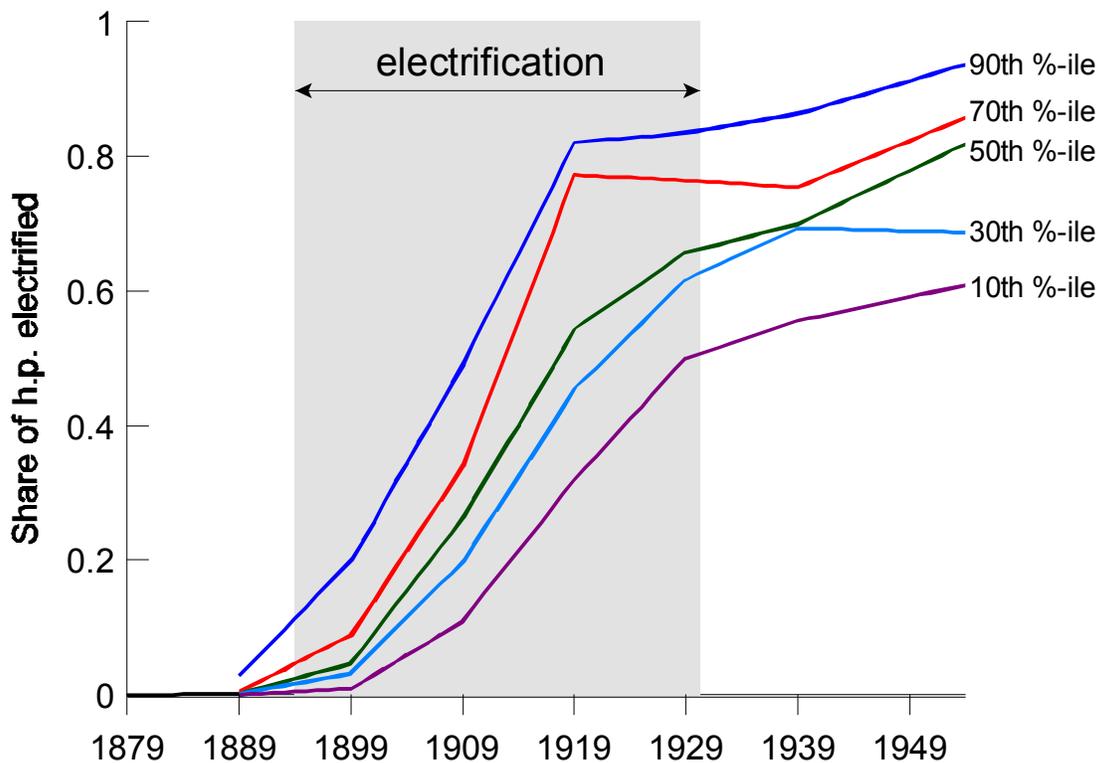


Figure 5: Shares of electrified horsepower by manufacturing sector in percentiles, 1890-1954.

are represented, plotting the 2nd, 5th, 8th, 11th and 14th largest shares in each year. The percentile diffusion curves will be useful when drawing comparisons with the IT era. They also help us in dating electricity as a GPT. Linear extrapolation between the years 1890 and 1900 suggests that in 1894, about one percent of horsepower equivalents in the median industry was provided by electricity. Whether or not this is the right percentage for dating the start of the Electrification era, we shall use the same percentage for the median industry to date the beginning of the IT era, thereby using a common standard for choosing the left-end points of the two shaded areas.

In the century before the Electricity revolution, the technology that primarily drove manufacturing was steam. Figure 6 shows just how slowly steam was replaced between 1899 and 1939.⁵ It is natural that industries such as rubber, primary metals, non-electric machinery, and stone, clay, and glass, which saw such rapid increases in electricity use over the same period, would withdraw from steam most rapidly.

⁵The sectoral shares of manufacturing horsepower driven by steam were computed from DuBoff (1964, tables E-12a through E-12e, pp. 229-233), and include steam engines and turbines. These shares are available on a decade basis from 1899 until 1939 only, which is why the time coverage in Figure 6 is shorter than that in Figure 4.

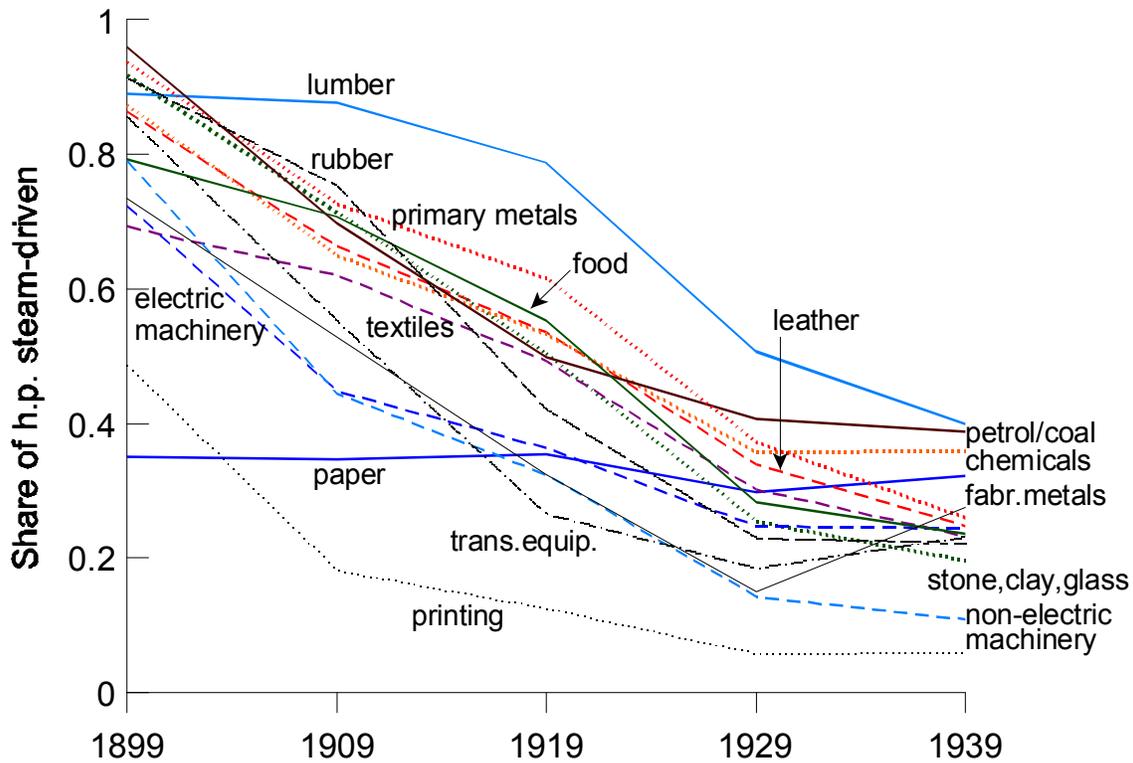


Figure 6: Shares of steam-driven horsepower by manufacturing sector, 1899-1939.

Indeed, most of the industries that quickly switched over to electricity had been heavy users of steam. This is clear from Figure 4 and Figure 6, taken together, and from the rank correlations presented in Table 2 which decay quickly and suggest a non-uniformity in the destruction of steam technology across sectors.

Table 2
Rank correlations of steam shares in total horsepower
by manufacturing sector, 1889-1954

	1899	1909	1919	1929	1939
1899	1.000				
1909	0.825	1.000			
1919	0.604	0.800	1.000		
1929	0.525	0.604	0.832	1.000	
1939	0.261	0.282	0.496	0.775	1.000

The spread of information technology was also rapid, but does not appear to have been as widespread as electricity. Figure 7 shows the share of real IT equipment and software in the real net capital stocks of 62 sectors from 1960 to 2001 plotted as

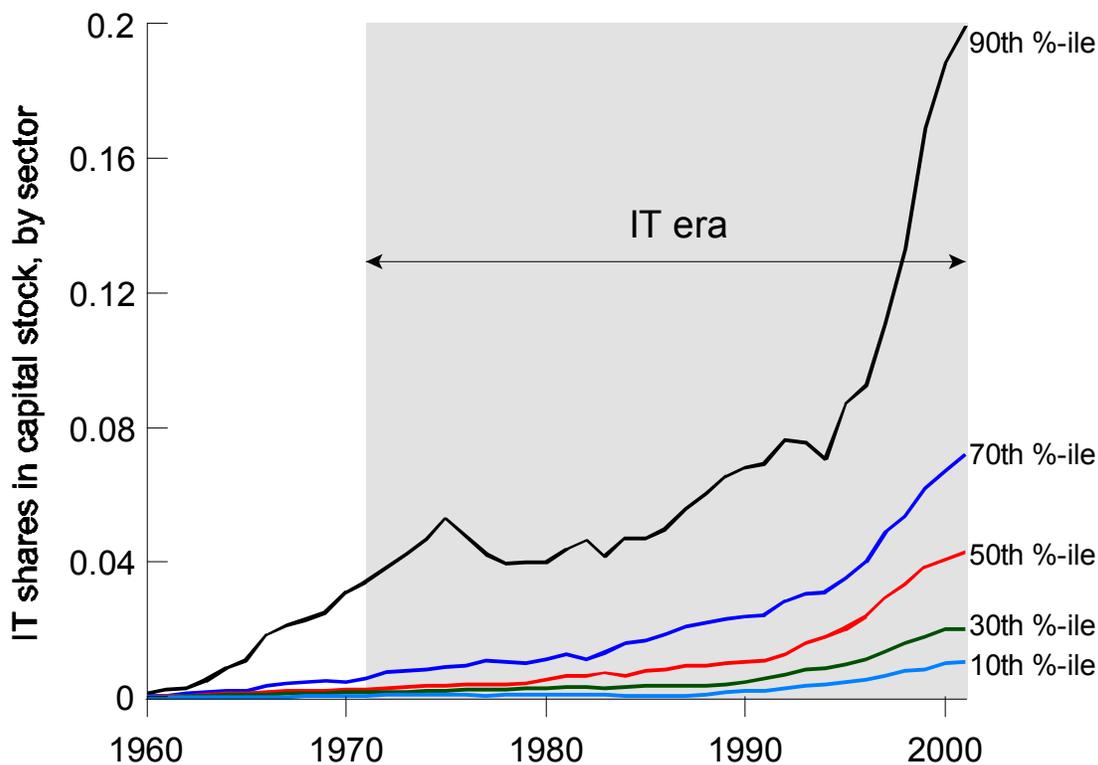


Figure 7: Shares of IT equipment and software in the capital stock by sector in percentiles, 1960-2001.

annual percentiles.⁶ In the case of IT, some sectors adopted very rapidly, and by 1975 six of them (the 90th percentile) had already achieved IT equipment and software shares of more than 5 percent. Other sectors lagged behind, and some did not adopt IT in a substantive way until after 1985.

On the other hand, the rank correlations of the IT shares across sectors, shown in Table 3, are even higher than those obtained for Electrification. On the face of it then, Electrification would appear to have been the more sweeping GPT-type event because it diffused more rapidly in the U.S. economy and all sectors adopted it pretty much at the same time, whereas IT diffused rapidly in some sectors and not-so-rapidly in others. Nonetheless, the recent gains in IT shares show that the diffusion of this GPT has yet to slow down in the way that Electrification did after 1929.

⁶The sectoral capital stocks are from the detailed non-residential fixed asset tables in fixed 1996 dollars made available by the Bureau of Economic Analysis (2002). We present the sectoral shares for the IT epoch in percentile form because the number of sectors covered is much larger than was possible for electrification and steam.

Table 3
Rank correlations of IT shares in capital stocks
by sector, 1961-2001

	1961	1971	1981	1991	2001
1961	1.000				
1971	0.650	1.000			
1981	0.531	0.806	1.000		
1991	0.576	0.746	0.847	1.000	
2001	0.559	0.682	0.734	0.909	1.000

So far we have discussed adoption by firms, and it determines the dating of the two GPT epochs. We turn to households next.

2.1.3 Adoption by households

Households also underwent electrification and the purchase of personal computers for home use during the respective GPT-eras. Figure 8 shows the cumulative percentage of households that obtained electric service and that owned a personal computer in each year following the “arrival” of the GPT.⁷ If we continue to date Electricity as arriving in 1894 and the personal computer in 1971, Figure 8 shows that households adopted electricity about as rapidly as they are adopting the personal computer. By the time the technology is officially 35 years old (in 1929), nearly seventy percent of households had electricity. A comparison with Figure 5 shows that this is just a little higher than the 1929 penetration of electrified horsepower share by the median manufacturing sector. As in the case of firms, the Electrification of households reaches a plateau in 1929, although it resumed its rise a few years later. On the other hand, there is no sign yet that the diffusion of the computer among either households or firms is slowing down.

With households, as with firms, diffusion lags seem to arise for different reasons for the two technologies. Rural areas were difficult to reach for Electricity, but not so for the PC, for which the main barrier is probably the cost of learning how to use it. This barrier seems to have more to do with human capital than was the case with Electricity.

In some ways it is puzzling that the diffusion of the PC has not been much faster than that of Electrification. The price of computing is falling much faster than the price of Electricity did. Affordable PCs came out in the 1980s, when the technology was some 15 years old. On the other hand, households had to wait longer for affordable electrical appliances. Only after 1915, when secondary motors begin to spread widely,

⁷Data on the spread of electricity use by consumers are approximations derived from U.S. Bureau of the Census (1975) *Historical Statistics of the United States* (series S108 and S120). Statistics on computer ownership for 1975 through 1998 are from Gates (1999, p. 118), and from the Census Bureau’s *Current Population Survey* thereafter.

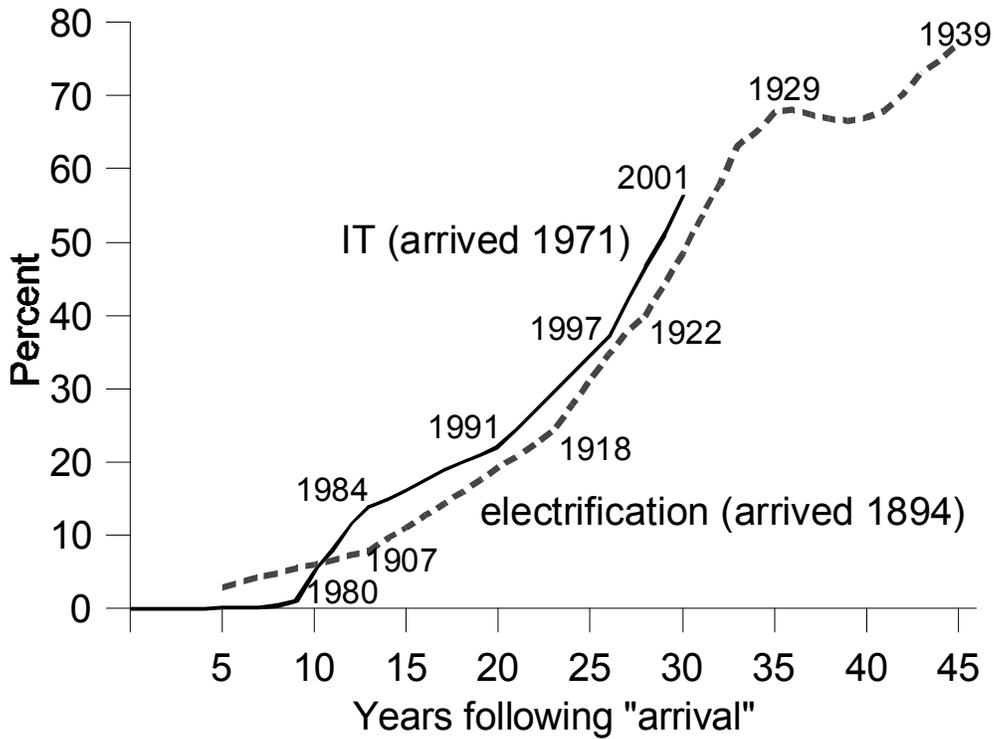


Figure 8: Percent of households with electric service and personal computers during the two technological epochs.

and electrical appliances began to be invented, did the benefits of Electrification outweigh the costs for a majority of households. Greenwood, Shesadri and Yorukoglu (2001) document the spread of electrically powered household appliances and argue that their diffusion helped raise female labor-force participation by freeing up their time from housework.

2.1.4 On dating the endpoints of the era of a GPT

Our dating procedure reflects net adoption rates by firms, but the dates would not change much if we had instead used net adoption by households. The shaded areas are periods when the S-shaped adoption curves are, for the most part, rising. Whether or not they start to fall later should not affect the designated adoption eras. For instance, electricity has not yet been replaced in the same way that steam was phased out in the first half of the twentieth century, but the “Electrification era” still ends in 1930 because adoption as measured in Figures 2, 4, and 5 flattens out. Figures 2 and 6 show that the steam era must have ended sometime around 1899 because net adoption is already negative.

Net adoption is endogenous and it should reflect the profitability of the technology at hand compared to that of other technologies. The Niagara Falls dam in 1894 and the development of alternating current made it possible to produce and distribute electricity more cheaply at greater distances. Figures 4 and 5 show that at the outset, some sectors (like printing) raced ahead of others in terms of how quickly they adopted. Later on, as the technology matures, its adoption becomes more universal. Eventually, the lagging sectors tend to catch up a bit, in relative terms, but not completely. Inequality of adoption is highest in the middle of the adoption era. We also see such a temporary rise in inequality in Figure 6 about the same time.

2.2 Improvement of the GPT

The second characteristic that Bresnahan and Trajtenberg suggested is an improvement in the efficiency of the GPT as it ages. Presumably this would show up in a decline in prices, an increase in quality, or both. How much a GPT improves can be therefore measured by how much cheaper a unit of quality gets over time. If technology is embodied in capital, then presumably, capital as a whole should be getting cheaper faster during a GPT era, but especially capital that is tied to the new technology.

To answer these questions, we first look at the prices of capital as a whole and then at the prices of its components. Figure 9 is a quality-adjusted series for the relative price of equipment as a whole, p_k/p_c (i.e., relative to the consumption price index), since 1885, constructed from a number of sources, with a linear time trend included.⁸ The figure shows that equipment prices declined most sharply between 1905 and 1920, and again after 1975. The 1905-1920 period is also the one that showed the most rapid growth of electricity in manufacturing (see Figure 4) and in the home (see Figure 8). The post-1975 period follows the introduction of the PC.

Figure 10 aims to look at the components of the aggregate capital stock; specifically, the components tied to the two GPTs. Because deflators for electrically powered capital are not available in the first half of the twentieth century, Figure 10 compares the declines in relative prices associated with three GPT's – electricity, internal com-

⁸Krusell et al. (2000) build such a series from 1963 using the consumer price index to deflate the quality-adjusted estimates of producer equipment prices from Gordon (1990, table 12.4, col. 2, p. 541). Since Gordon's series ends in 1983, they use VAR forecasts to extend it through 1992. We start with Krusell et al. and work backward, deflating Gordon's remaining estimates (1947-62) with an index for non-durable consumption goods prices that we derive from the National Income Accounts. Since we are not aware of a quality-adjusted series for equipment prices prior to 1947, we use the average price of electricity as a proxy for 1902-46, and an average of Brady's (1966) deflators for the main classes of equipment for 1885-1902. We deflate the pre-1947 composite using the Bureau of Labor Statistics (BLS) consumer prices index of all items [U.S. Bureau of the Census (1975, series E135)] for 1913-46 and the Burgess cost of living index [U.S. Bureau of the Census (1975, series E184)], which has greater precision than the BLS series, for 1885-1912.

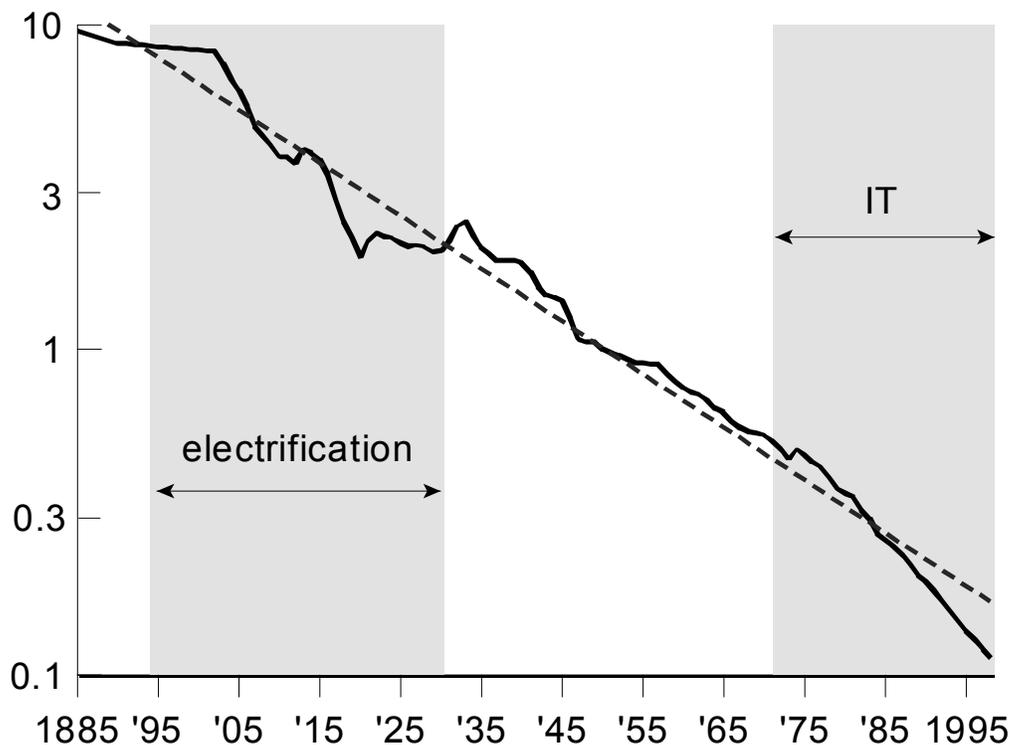


Figure 9: The relative price of equipment.

bustion, and computers – once again relative to the consumption price index.⁹ The

⁹To construct a quality-adjusted price index, we join the “final” price index for computer systems from Gordon (1990, table 6.10, col. 5, p. 226) for 1960-78 with the pooled index developed for desktop and mobile personal computers by Berndt, Dulberger, and Rappaport (2000, table 2, col. 1, p. 22) for 1979-99. Since Gordon’s index includes mainframe computers, minicomputers, and PCs while the Berndt et al. index includes only PCs, the two segments used to build our price measure are themselves not directly comparable, but a joining of them should still reflect quality-adjusted prices trends in the computer industry reasonably well. We set the index to 1000 in the first year of the sample (i.e., 1960).

Electricity prices are averages of all electric energy services in cents per kilowatt hour from the *Historical Statistics of the United States* (U.S. Bureau of the Census, 1975, series S119, p. 827) for 1903, 1907, 1917, 1922, and 1926-70, and from the *Statistical Abstract of the United States* for 1971-89. We interpolate under a constant growth assumption between the missing years in the early part of the sample. For 1990-2000, prices are U.S. city averages (June figures) from the Bureau of Labor Statistics (<http://www.bls.gov>). We then set the index to equal 1000 in the first year of the sample (i.e., 1903).

Motor vehicle prices for 1913-40 are annual averages of monthly wholesale prices of passenger vehicles from the National Bureau of Economic Research (Macrohistory Database, series m04180a for 1913-27, series m04180b for 1928-40, <http://www.nber.org>). From 1941-47, they are wholesale prices of motor vehicles and equipment from *Historical Statistics* (series E38, p. 199), and from 1948-2000 they are producer prices of motor vehicles from the Bureau of Labor Statistics (<http://www.bls.gov>).

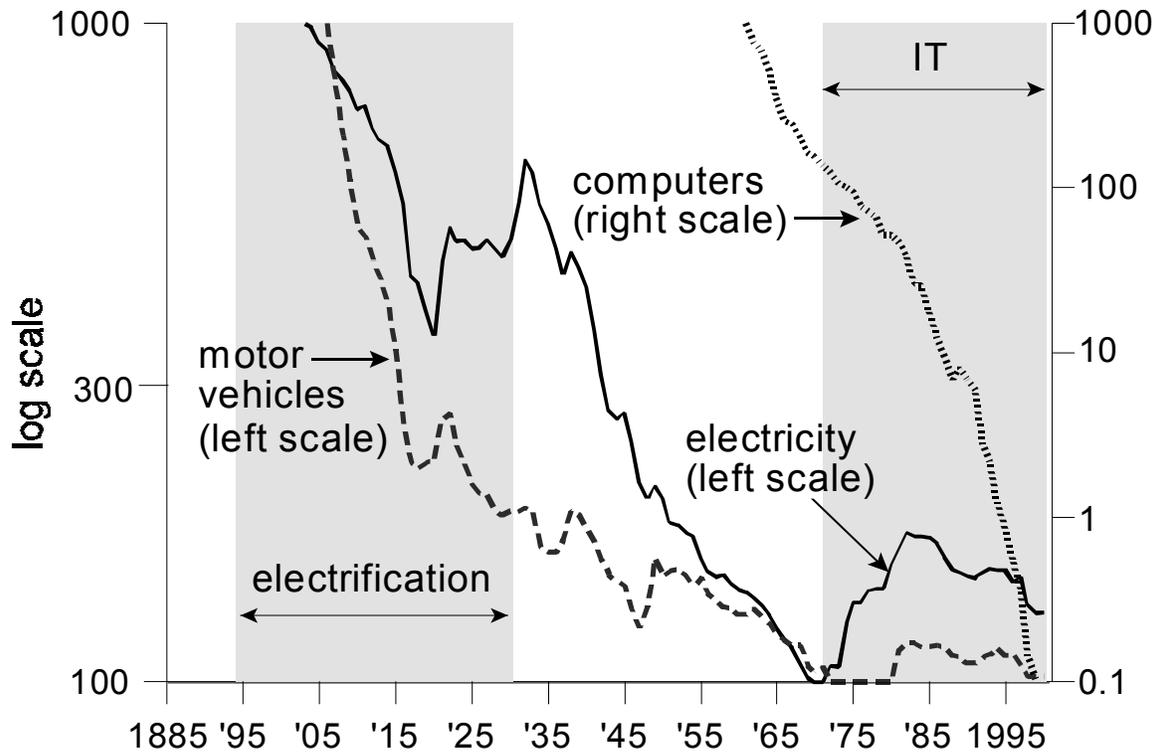


Figure 10: Price indexes for products of two technological revolutions.

use of the left-hand scale for electricity and motor vehicles and the right-hand scale for computers underscores the extraordinary decline in computer prices since 1960 compared to the earlier technologies. While the electricity and the automobile indexes fall by a factor of 10, the computer index falls by a factor of 10,000.

The more important question, however, is how the general decline in equipment prices compares to the declines associated more directly with the GPTs of each epoch. Figure 11 makes this comparison by plotting the relative prices of all three GPT's along with the general equipment index on the same logarithmic scale, with the starting point for each of the GPTs normalized to the level of the general equipment price index in that year. By this measure, it is clear that electricity and motor vehicle prices declined at about the same pace as that of equipment generally until the start of the IT price data, though it is also interesting that motor vehicle prices appear to have declined faster than electricity prices. After 1960, declining computer prices and rising shares of computers in equipment stocks seem to have drawn the general index downward, while computing prices fell thousands of times faster than the general

To approximate prices from 1901-1913, we extrapolate assuming constant growth and the average annual growth rate observed from 1913-24. We then join the various components to form an overall price index, and set it to equal 1000 in the first year of the sample (i.e., 1901).

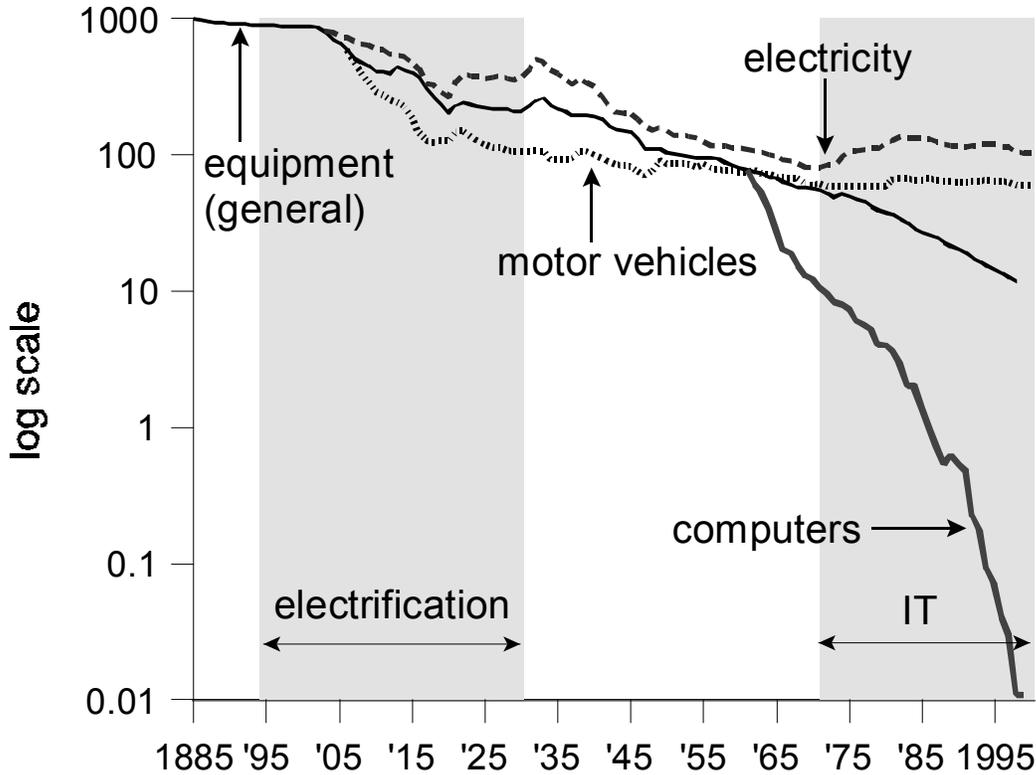


Figure 11: Comparison of the decline in general and GPT-specific equipment prices.

equipment index.

It can be said that the electricity index, being the price of a kilowatt hour, understates the accompanying technological change because it does not account for improvements in electrical equipment, and especially improvements in the efficiency of electrical motors. Such improvements may be contained in the price series for capital generally. Yet based on the price evidence in figures 10 and 11, electricity, motor vehicles, and computers might all qualify as GPTs, but computers are clearly the most revolutionary of the three.

2.3 Ability of the GPT to spawn innovation

The third characteristic that Bresnahan and Trajtenberg suggested was the technology's ability to generate innovation. Any GPT will affect all sorts of production processes, including those for invention and innovation. Some GPTs will be biased towards helping to produce existing products, others towards inventing and implementing new ones. An example of a more specific technology that was heavily skewed towards future products was hybrid corn. Griliches (1957, p. 502) explains why hy-

brid corn was not an invention immediately adaptable everywhere, but, rather, that it was the invention of a method of inventing, a method of breeding superior corn for specific localities.

Electricity and IT have both helped reduce costs of making existing products, and they both spawn innovation, but IT is more skewed towards the latter. The 1920s especially saw a wave a new products powered by electricity, and the computer is now embodied in many new products as well. But as the patenting evidence will bear out, IT seems to have more of a skew towards contributing to further innovation – the role of the computer in simulation should be known to many of us writing research papers. Feder (1988) describes how computers play a similar role in the invention of new drugs.

2.3.1 Patenting

Patenting should be more intense after a GPT arrives and while it is spreading due to the introduction of related new products. Figure 12, which shows the per capita numbers of patents issued on inventions annually from 1790 to 2000 and trademarks registered from 1870 to 2000, shows two surges in activity – between 1900 and 1930, and again after 1977.¹⁰ Is it mere chance that patenting activity was most intense during our technological revolutions? Moreover, it appears that patenting activity picks up after the end of the U.S. Civil War in 1865, and again at the conclusion of World War II in 1945. The slowdown in patenting during the wars and acceleration immediately thereafter suggest that there is some degree of intertemporal substitution in the release of new ideas away from times when it might be more difficult to popularize them and towards times better suited for the entry of new products.

Does the surge in patenting reflect a rise in the number of actual inventions, or was the surge prompted by changes in the law that raised the propensity to patent? This question is important because, over longer periods of time, patents may reflect policy rather than invention: Figure 13 analyzes data described in detail in Lerner (2002) and shows that worldwide, changes in patent policy changes are correlated with the patent series in Figure 12. It is possible, therefore, that the U.S. series reflects court-enforcement attitudes. Kortum and Lerner (1998) analyze this question and found that the surge of the 1990s was worldwide, but not systematically related to country-specific policy changes, and they conclude that technology was the cause for the surge.

¹⁰We use the total number “utility” (i.e., invention) patents from the U.S. Patent and Trademark Office for 1963-2000, and from the U.S. Bureau of the Census (1975, series W-96, pp. 957-959) for 1790-1962. The number of registered trademarks are from the U.S. Bureau of the Census (1975, series W-107, p. 959) for 1870-1969, and from various issues of the *Statistical Abstract of the United States* for later years. Population figures, which are for the total resident population and measured at mid-year, are from U.S. Bureau of the Census (1975, series A-7, p. 8) for 1790-1970, and from the Bureau of Economic Analysis thereafter.

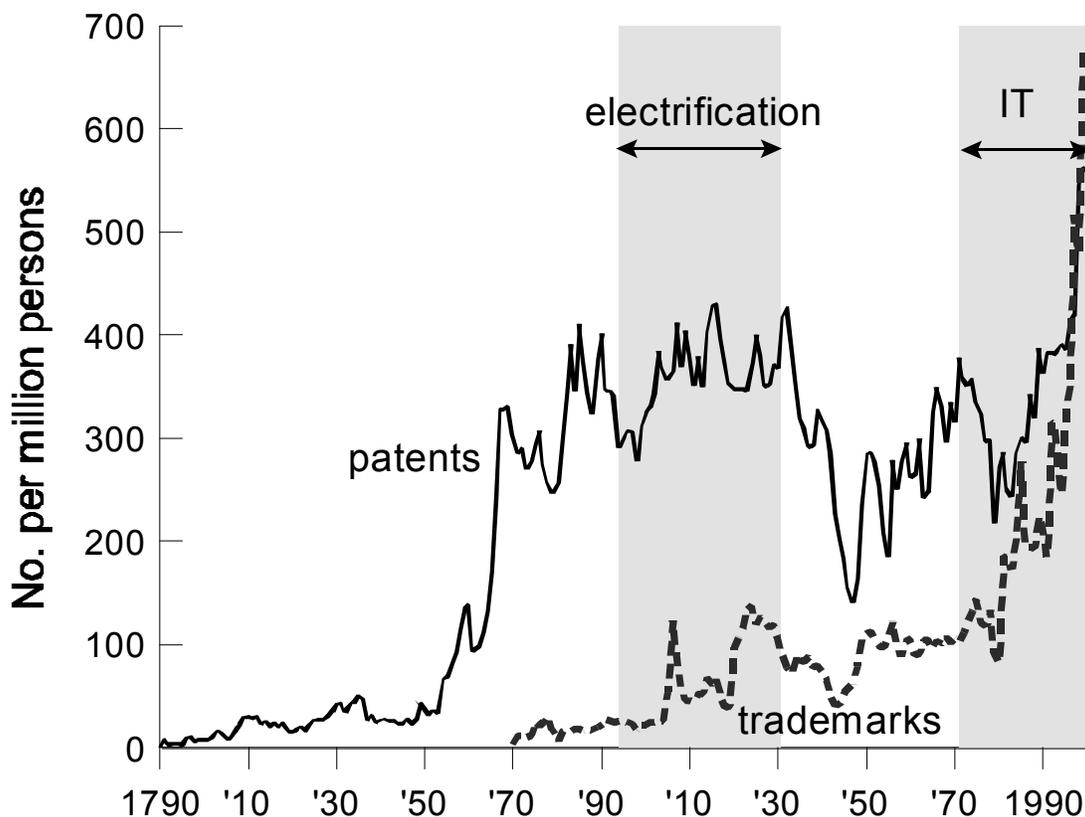


Figure 12: Patents issued on inventions and trademarks registered in the United States per million persons, 1790-2000.

Further support for this view comes from the behavior of trademarks per head, which we also plot in figure 12. Trademarks behave more or less the same as patents do, except for their higher trend. Trademarks are easier to obtain than patents and are not governed by legal developments concerning patents. But with trademarks we have a different concern: Do trademarks proxy for the number of products, or do they just measure duplicative activity and the amount of competition? The answer may depend on what market one looks at. In the market for bananas, for example, Wiggins and Raboy (1996) find that brand names are correlated with measures of quality that do explain price variation, suggesting, therefore, that brand names do signify product differentiation.

2.3.2 Investment in new firms vs. investment by incumbents

If new technologies are more easily embraced by new firms that do not bear the burden of costs sunk in old technologies and the rigid and firm-specific organization capital required to operate them, we should expect to see waves of new listings on

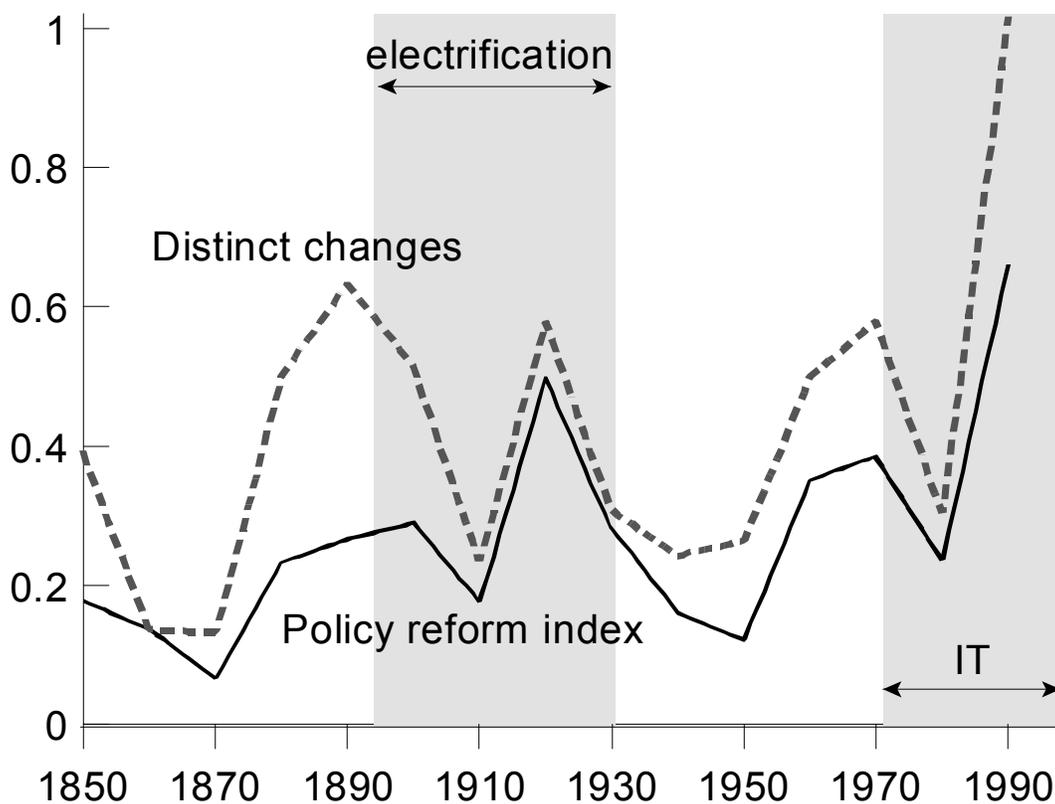


Figure 13: Indexes of worldwide changes in patent laws.

the stock exchange during GPT eras. Figure 14 shows the value of firms entering the New York Stock Exchange (NYSE), the American Stock Exchange (AMEX), and NASDAQ in each year from 1885 through 2001 as percentages of total stock market value.¹¹ As predicted by Trajtenberg and Helpman, IPOs surge between 1895 and 1929, and then after 1977, which again closely matches the dating of our two technological revolutions.

¹¹The data used to construct Fig. 14 and others in this chapter that use stock market valuations are from the University of Chicago's Center for Research in Securities Prices (CRSP) files for 1925-2001. NYSE firms are available in CRSP continuously, AMEX firms after 1961, and NASDAQ firms after 1971. We extended the CRSP stock files backward from their 1925 starting year by collecting year-end observations from 1885 to 1925 for all common stocks traded on the NYSE. Prices and par values are from the *The Commercial and Financial Chronicle*, which is also the source of firm-level data for the price indexes reported in the well-known study by Cowles et al. (1939). We obtained firm book capitalizations from *Bradstreet's*, *The New York Times*, and *The Annalist*. The resulting dataset, which includes 24,475 firms, though limited to annual observations, actually includes more common stocks than the CRSP files in 1925. As such, the dataset complements others that have begun to build a more complete view of securities prices in other markets for the pre-CRSP period [see, for example, Rousseau (1999) on Boston's 19th century equity market.

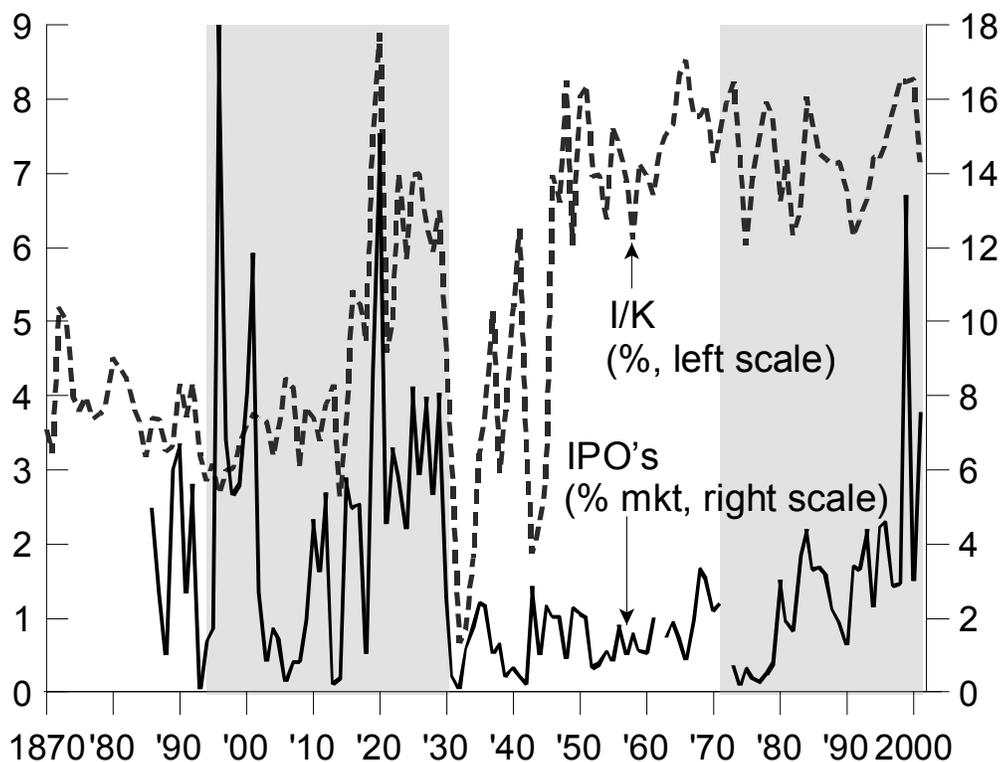


Figure 14: Annual IPOs as a percent of stock market value, and investment as a percent of the net capital stock, 1870-2001.

The dashed line in Figure 14 is private investment since 1870 as a percent of the net stock of private capital for the U.S. economy as a whole, and as such is the aggregate analog of the solid line that covers only the stock market.¹² The solid line in Figure 15 shows the ratio of the solid and dashed lines in Figure 14. In both figures it is clear that, during Electrification, investment by stock market entrants accounted for a larger portion of stock market value than overall new investment in

¹²To build the investment rate series, we start with gross private domestic investment in current dollars from the Bureau of Economic Analysis (2002, Table 1, pp. 123-4) for 1929-2001 and then ratio splice the gross capital formation series in current dollars, excluding military expenditures, from Kuznets (1961b, Tables T-8 and T-8a) for 1870-1929. We construct the net capital stock using the private fixed assets tables of the Bureau of Economic Analysis (2002) for 1925-2001. Then, using the estimates of the net stock of non-military capital from Kuznets (1961a, Table 3, pp. 64-5) in 1869, 1879, 1889, 1909, 1919, and 1929 as benchmarks, we use the percent changes in a synthetic series for the capital stock formed by starting with the 1869 Kuznets (1961a) estimate of \$27 billion and adding net capital formation in each year through 1929 from Kuznets (1961b) to create an annual series that runs through the benchmark points. Finally, we ratio-splice the resulting series for 1870-1925 to the later BEA series. The investment rate that appears in Figure 14 is the ratio of our final investment to the capital stock series, expressed as a percentage.

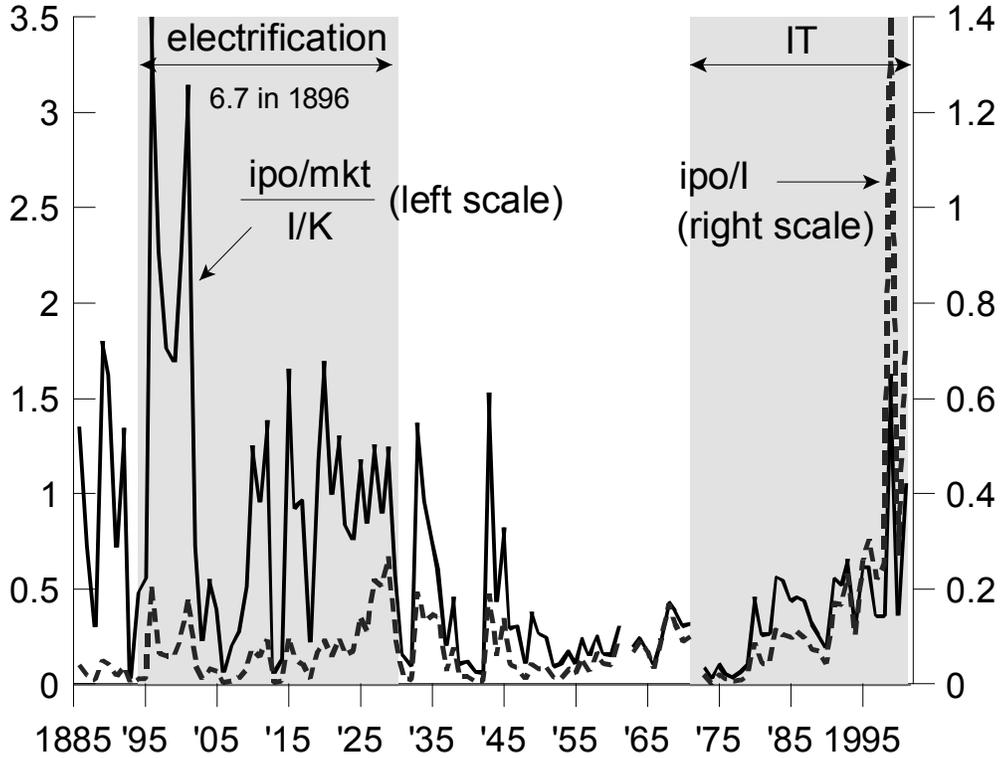


Figure 15: Ratio of IPOs as a percent of the stock market to investment as a percent of the net capital stock, 1885-2001.

the U.S. economy contributed to the aggregate capital stock. This is consistent with the adoption of electricity favoring the unencumbered entrant over the incumbent, who may have incurred large adjustment costs in using the new technology. We say this because aggregate investment, while indeed including new firms, has an even larger component attributable to incumbents. Moreover, the ratio of IPO to aggregate investment activity was highest in the early years of Electrification, which is when these adjustment costs would have been greatest. Although the ratio given by the solid line in Figure 15 has so far stayed below unity for most of the IT-era, it has been rising rapidly in recent years. This could be because IT adoption involved very large adjustment costs for both incumbents and entrants in the early years until the price of equipment and software fell enough to promote adoption among new firms.

The solid line in Figure 15 shows a downward trend mainly because the stock market gained importance as a model of financing in the early part of the 20th century. IPOs are normalized by the stock market which was small early on, and has since become larger. The dotted line in Figure 15 shows the ratio of the unnormalized series of IPOs and aggregate investment. This has a positive trend for

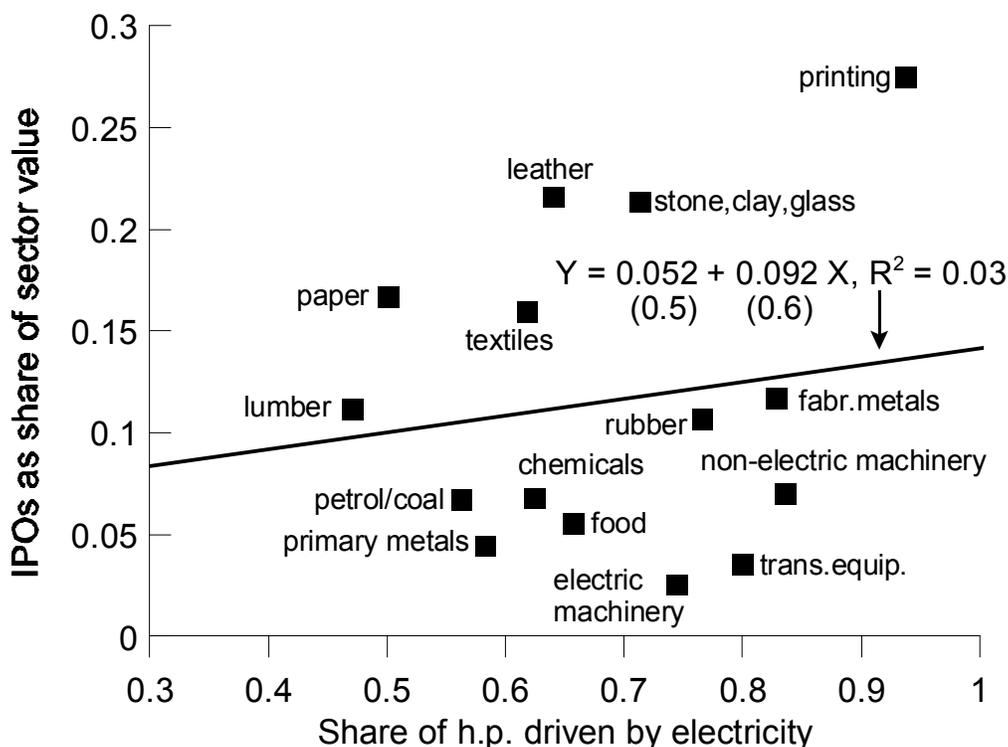


Figure 16: IPOs as shares of sector value 1890-1930 vs. shares of electricity-driven horsepower in 1929.

the same reason that the previous figure showed a negative one: IPOs were not that important early on because the stock market was small. After 1970, IPOs capture a much larger share of the investment by new entrants than they did before the first World War, for example, and even a larger fraction than in the 1920s. When we consider both lines together, we do get the impression that new firms invest more during the GPT eras than at other times.

Does the distribution of entries across sectors shed light on the role of technological factors in the entry waves? Perhaps so. Figure 16 is a scatterplot of the share of IPOs in the market capitalization of 15 manufacturing sectors between 1890 and 1930 vs. their respective shares of horsepower driven by electricity in 1929.¹³ In other words, we ask whether sectors with more IPOs ended up embracing the new technology more vigorously than sectors with less entry. The regression line plotted in Fig. 16

¹³We compute the IPO shares by sector by summing year-end IPO values by sector for 1890 through 1930, converting each year's total into real terms using the implicit price deflator for gross domestic product, and then summing across years. We do the same for all listed firms by sector, and use the quotient of sector IPO values and total sector values to compute the shares shown in Fig. 16.

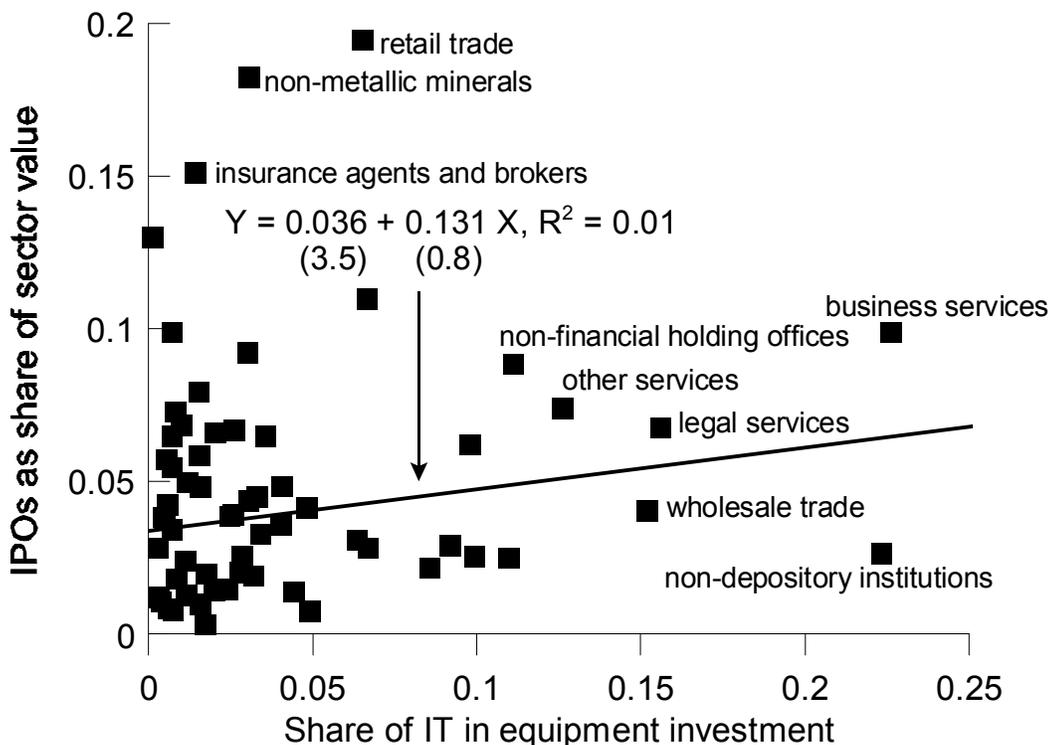


Figure 17: IPOs as shares of sector value 1971-2001 vs. shares of IT in equipment investment in 2000.

indicates that this relationship is indeed positive, though with only 15 observations the slope coefficient is not statistically significant at conventional levels.

In Figure 17, we consider IPOs over the 1971-2001 IT-epoch against shares of computers and peripherals in equipment investment in 2000, we once again obtain a sectoral scatter with a positive slope, though like Electrification, the slope coefficient is not statistically significant.

3 Other symptoms of GPT

So far we have provided some measures of the three qualities of a GPT – its pervasiveness, its rate of improvement, and its innovation-spawning tendency. Now we turn to less direct measures, as are suggested by various theoretical models that deal with GPTs and that predict the following symptoms:

1. *Productivity should slow down.*—The new technology may not be user friendly at first, and output may fall for a while as the economy adjusts.

2. *The skill premium should rise.*—If the GPT is at first user unfriendly, skilled people will be in greater demand when a new technology arrives, and their earnings should rise compared to those of the unskilled.
3. *Entry, exit and mergers should rise.*—These are alternative modes of reallocation of assets.
4. *Stock prices should initially fall.*—The value of old capital should fall; how fast it does so depends on the way that the market learns of the GPT’s arrival.
5. *Young and small firms should do better.*—The ideas and products associated with the GPT will often be brought in by new firms. The market share and market value of young firms should rise relative to old firms
6. *Interest rates and the trade deficit.*—The rise in desired consumption relative to output should cause interest rates to rise or the trade balance to worsen.

These are not propositions but hypotheses that one can find in much of the work on GPTs. Now we give evidence on each one in turn. Each gets its own subsection.

3.1 Productivity slowdown

Even in routine activities, learning seems to cause delays of several years before plant productivity peaks [Bahk and Gort (1993)]. It is far from settled whether IT is the reason for the productivity slowdown – Bessen (2002) finds that IT did cause a big part of the slowdown, whereas Comin (2002) argues the opposite. It also is not yet definitely known from the work of Caballero and Hammour (1994) and others whether recessions at business-cycle frequencies are episodes of heightened reallocation. At any rate, the theoretical models of Atkeson and Kehoe (1993), Hornstein and Krusell (1996), Jovanovic and Nyarko (1996), Greenwood and Yorukoglu (1997) and Jovanovic and Rousseau (2002a) emphasize various adjustment costs and learning delays that may cause output to fall at first when a GPT arrives. David (1991) argues that the speed with which a new technology diffuses depends on the pool of investment opportunities that are available when it arrives, and remarks that the quality of this pool in the late 1960s was low because the large backlog of the post-war period had just and finally been eliminated. He also points out that there can often be “slippage” between the technology frontier and implementation due to high input costs and the slow introduction of complementary products.

Figure 1 shows that productivity does not rise quickly in the early phases of the two GPTs, though there is some evidence of greater productivity between 1918 and 1929. This could be taken as further evidence that IT did not do as much as did electricity to raise the productivity on existing processes and products. Productivity was high in the early years of Electrification but fell rapidly as the technology matured. It

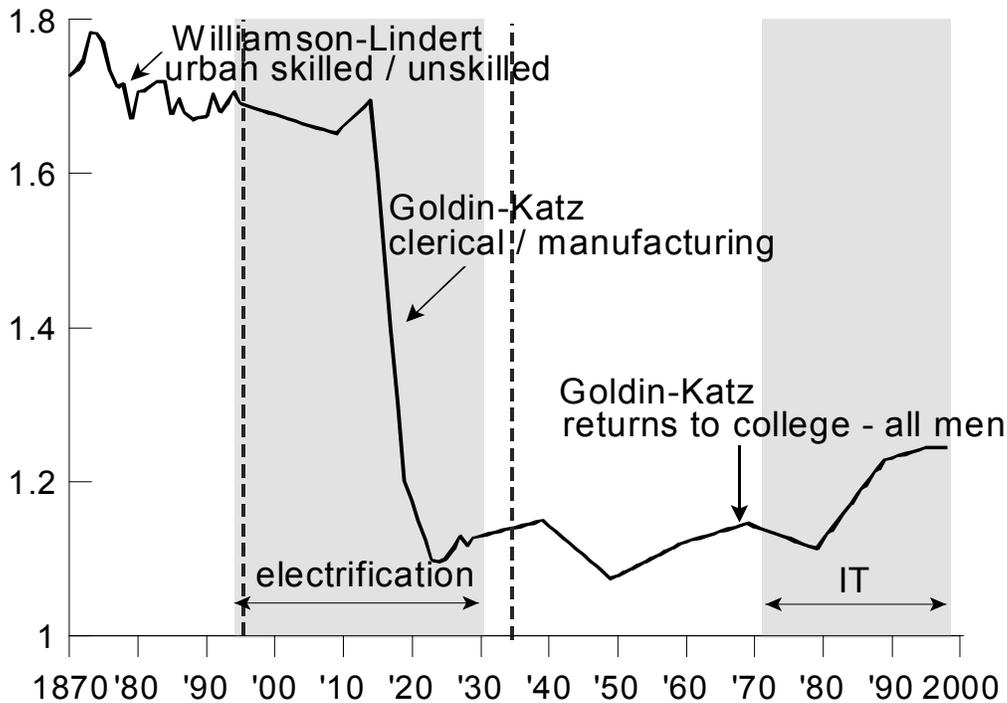


Figure 18: The skill premium.

stayed low through the Depression and 1940s, and then rose rapidly before the IT-age arrived. This pattern is consistent with David’s model of exhausted investment opportunities. And while it is interesting to consider the productivity slowdown after 1971, it is also important to recognize that productivity is considerably higher today than it was before IT’s arrival.

3.2 The skill premium

As Nelson and Phelps (1966) and Griliches (1969) argued, and Bartel and Lichtenberg (1987) and Krusell et al. (2000) have confirmed, new technology should raise the relative earnings of the skilled. Figure 18 presents a series for the earnings of skilled relative to unskilled labor. We construct the series by combining Williamson’s and Lindert’s (1980, p. 307) estimates of the wage ratio for urban skilled and unskilled workers for 1870-1894 with estimates from Goldin and Katz (1999) of the ratio of clerical to manufacturing production wages for 1895-1938 and the returns to 16 versus 12 years of schooling for men for 1939-1995.¹⁴ Despite the need to merge data from

¹⁴Combining several very different series into a continuous “skill premium” is necessary due to sectoral shifts in the skilled and unskilled labor forces that render some measures of skill more applicable to certain periods than others. For example, a college education appears to have become

disparate sources to form a continuous series, a U-shape still emerges, with the skill premium high in the early stages of Electrification (i.e., 1890 to 1918), and then rising rapidly during the post-1978 part of the IT epoch. We suspect that the fall in the skill premium from 1918-1924 would be less deep, and thus the overall U-shape of Figure 18 more apparent, had it not been for the rapid rise of the public higher-education system after the end of the first World War [see Goldin and Katz (1998, p. 10)].

3.3 Entry, exit, and mergers should rise

Gort (1969) argued that technological change will generate merger waves. Evidence since then has shown that mergers and takeovers play a reallocative role. Lichtenberg and Siegel (1987), McGuckin and Ngyen (1995) and Schoar (2000) find that the productivity of a target firm rises following a takeover. The trade-off between exits and acquisitions margins is studied by Jovanovic and Rousseau (2002b,c). This last pair of papers shows that firms will tend to place themselves on the merger market rather than disassemble and sell their assets at times when the value of organization capital is high. Further, reallocation of assets among firms either by merger, consolidation, or purchases of unbundled used capital are more likely to occur than purchases of new capital when firms need to make large adjustments to their capital stocks because of the fixed costs associated with entering the merger market. We believe that both of these conditions are likely to hold during times of sweeping technological change.

The U-shaped top line of Figure 19 is our estimate of the total amount of capital that has been reallocated on the U.S. stock market over the past 112 years. Its components are the stock market capitalization of entering and exiting firms divided by two, and the value of merger targets.¹⁵ Entries and exits divided by two, given

a more important determinant of income in the postwar period than it was in earlier years. Since the Goldin and Katz observations are generally decadal, we interpolate between them to obtain an annual series for 1895 to 1995. The vertical dotted lines in Figure 18 mark the points where we need to change data sources.

¹⁵We identify targets for 1926-2001 using the CRSP stock files and various supplementary sources. CRSP itself identifies more than 8,000 firms that exited the database by merger between 1926 and 2001, but links less than half of them to acquirers. Our examination of the 2000 Edition of Financial Information Inc.'s *Directory of Obsolete Securities* and every issue of Predicasts Inc.'s *F&S Index of Corporate Change* between 1969 and 1989 uncovered the acquirers for 3,646 of these unlinked mergers, 1803 of which turned out to be CRSP firms. We also recorded all mergers from 1895 to 1930 in the manufacturing and mining sectors from the original worksheets underlying Nelson (1959) and collected information on mergers from 1885 to 1894 from the financial news section of weekly issues of the *Commercial and Financial Chronicle*. For 1890-1930, we use worksheets for the manufacturing and mining sectors that underlie Nelson (1959). The resulting target series includes the market values of exchange-listed firms in the year prior to their acquisition, and reflects 9,030 mergers. Stock market capitalizations are from our extension of CRSP backward to 1885 (see footnote 11). Before assigning a firm that no longer carries a price in our database as an "exit," we check the list of hostile takeovers from Schwert (2000) for 1975-1996 and individual issues of the *Wall Street Journal* from 1997-2001 to ensure that we record firms taken private under a hostile tender offers as mergers.

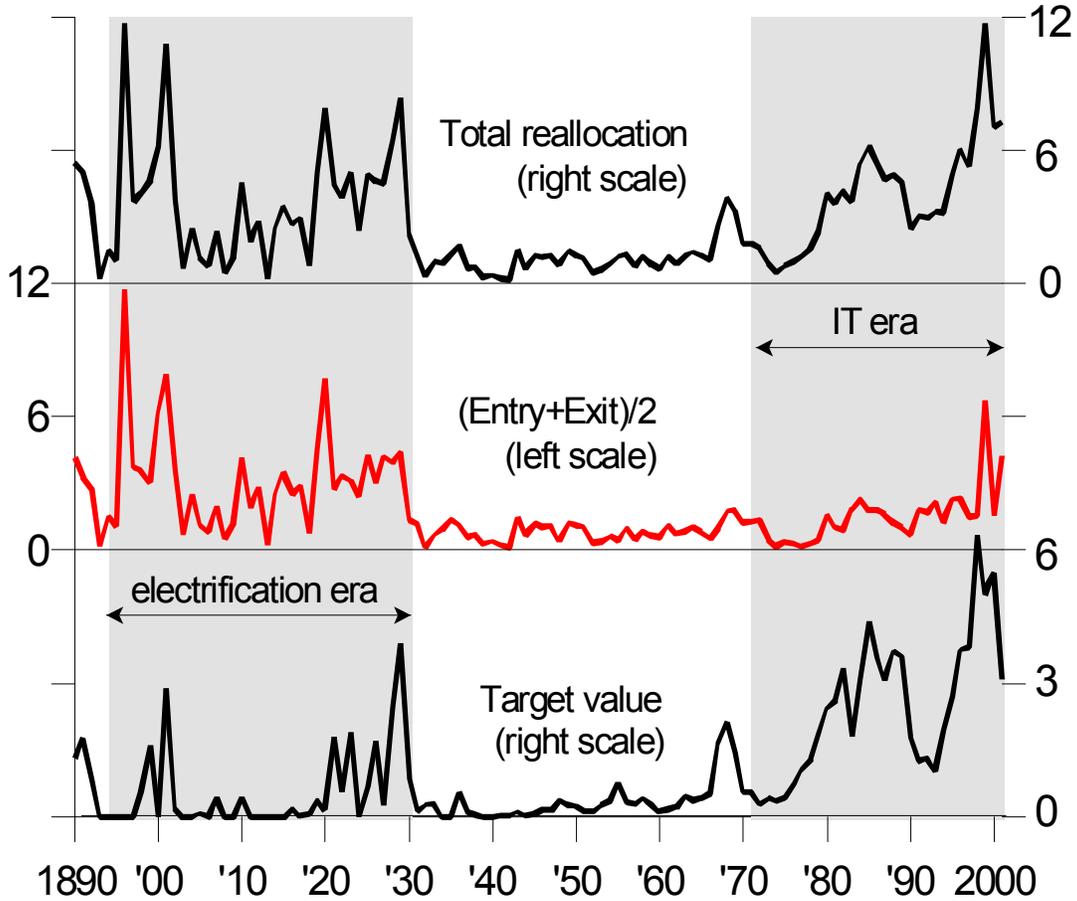


Figure 19: Reallocated capital and components as percentages of stock market value, 1890-2001.

by the center line, is a rough measure of how much capital exits from the stock market and comes back in under different ownership, or at least under a different name. The lower line is the stock-market value of merger targets. Regardless of whether reallocation occurs through mergers or through entry and exit, it is much more prevalent during the periods that we associate with Electrification and IT.

3.4 Stock prices should fall

The value of old capital should fall suddenly if the arrival of the GPT is a surprise, as in Greenwood and Jovanovic (1999) Hobijn and Jovanovic (2001), Jovanovic and Rousseau (2002a) and Laitner and Stolyarov (2002), or more gradually as in Trajtenberg and Helpman (1998). Figure 20 shows that the stock market declined in 1973-74. No such sudden drop is visible for stock prices in the early 1890's. Why not? Maybe

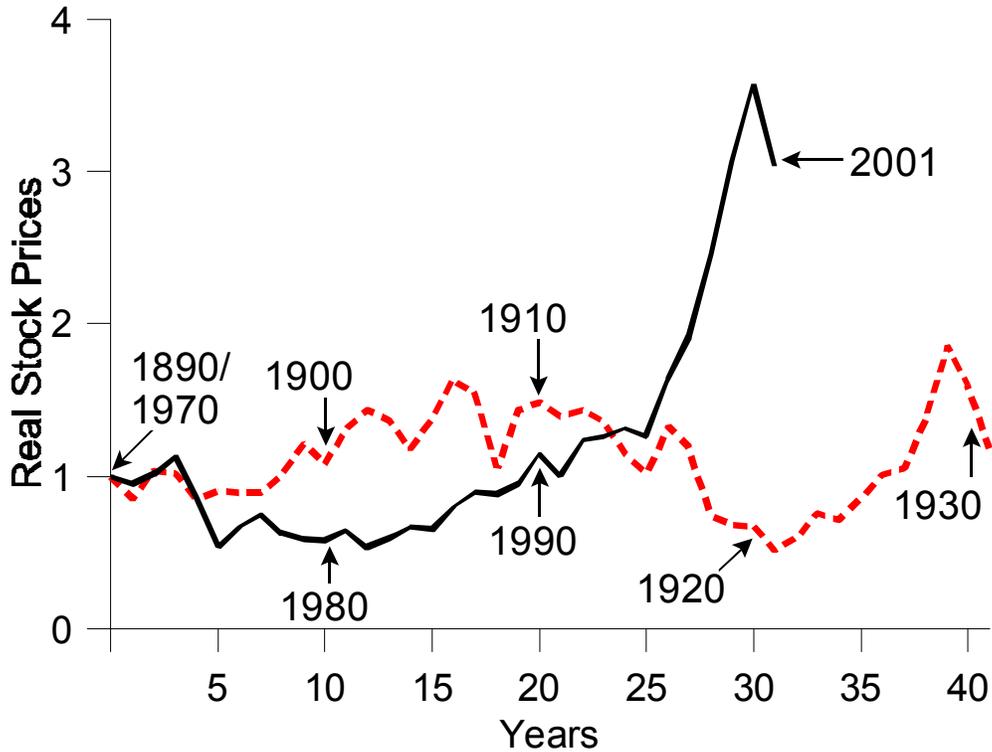


Figure 20: The real Cowles/S&P stock price index across the transition periods.

because the market was thin and unrepresentative in those days, with railway stocks absorbing a large chunk of market capitalization. More likely, the realization that the new technology would work well was more gradual and was not prompted by any single event like the completion of the Niagara Falls dam in 1894.¹⁶

In other words, that it does not happen for the first period could be that the events of the early 1890's were foreseen, as would be the case in Helpman and Trajtenberg (1998a) where stock prices are predicted to fall earlier and more gradually. It also could be, as Boldrin and Levine (2001) would claim, that old capital is essential in the production of new capital and that its value may not fall in quite the way that it would when capital can be produced from consumption goods alone as is the case in many growth models, including that of Jovanovic and Rousseau (2002a).

If stock-price declines were caused by the threat of IT to incumbents, this should relate especially to those sectors that later invested heavily in IT. Hobijn and Jovanovic (2001, p. 1218) confirm this using regression analysis.

¹⁶We obtain the composite stock price index from Wilson and Jones (2002), and deflate using the CPI.

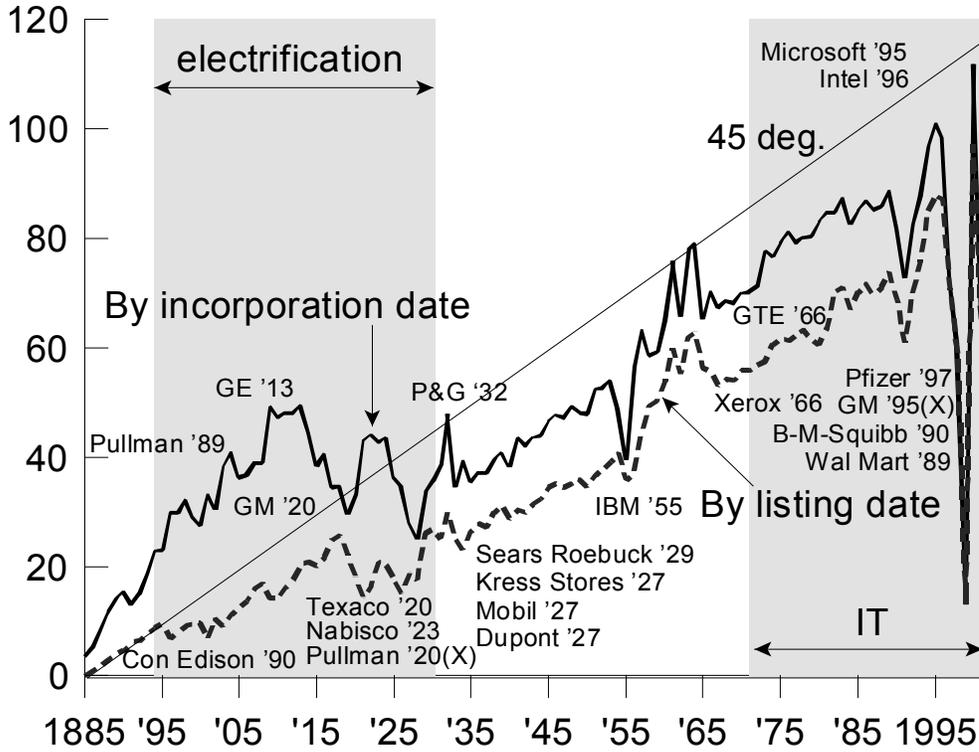


Figure 21: Average age (in years) of the largest firms whose market values sum to 5 percent of GDP.

3.5 Young firms should do better

The evidence on this hypothesis is mixed, but positive overall.

3.5.1 The age of the leadership

As a GPT takes hold, we should not only expect to see firms coming to market more quickly, but the market leaders getting younger as well. In other words, every stage in the lifetime of the firm should be shorter. This stands in contrast to Hopenhayn (1982), in which the age distribution of an industry's leadership is invariant when an industry is in a long-run stochastic equilibrium. 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.

Figures 21 and 22 show that, overall, the age of the leaders is anything *but* flat. It sometimes rises faster than the 45⁰ line, indicating that the age of the leaders is

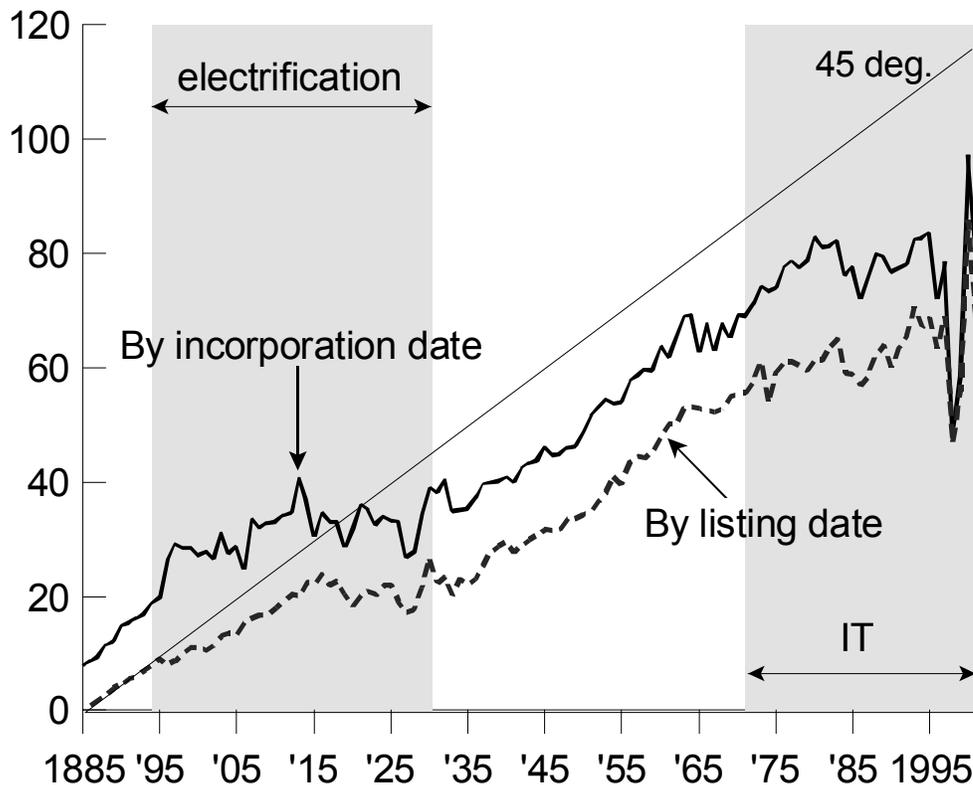


Figure 22: Average age (in years) of the largest firms whose market values sum to 10 percent of GDP.

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 22.

Figure 21 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 21 (estimated with constant and

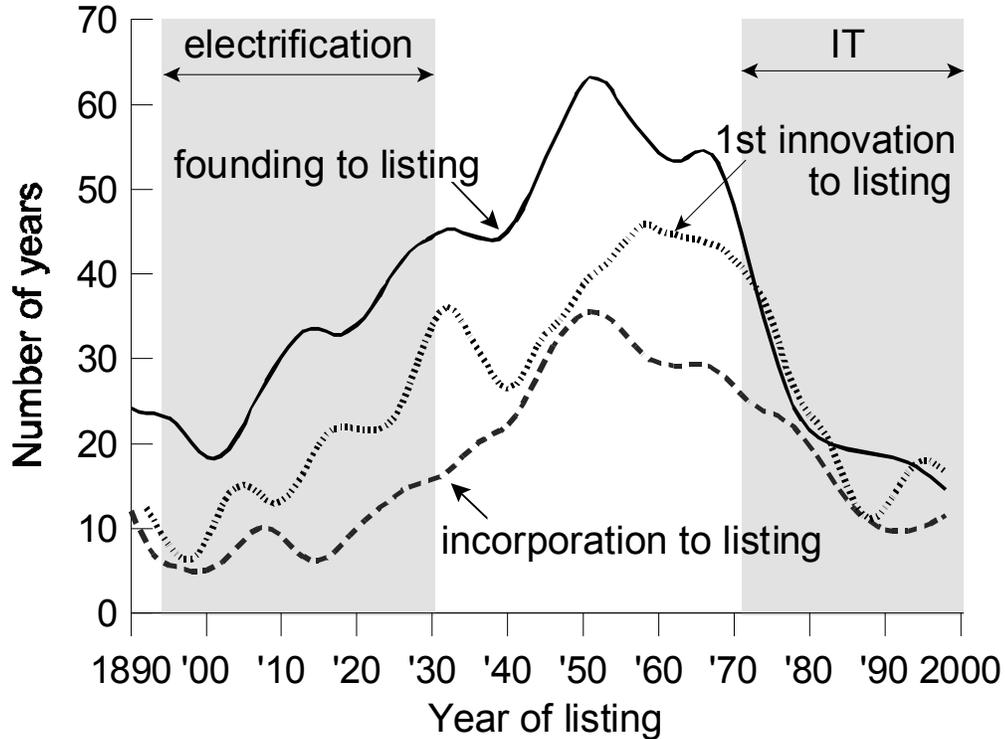


Figure 23: Waiting times to exchange listing.

time trend) are 0.62 for years since incorporation and 0.67 for years since exchange listing.

3.5.2 The age of firms at their IPO

According to its third “innovation-spawning” characteristic, when a GPT arrives it gives rise to new projects that are unusually profitable. When such projects arrive, firms will be more impatient to implement them. When it is the new firms that come upon such projects (rather than the incumbents), they will feel the pressure to list sooner. The argument is developed and tested in Jovanovic and Rousseau (2001b). We argue there that the Electricity-era and the IT-era firms came in younger because the technologies that they brought in were too productive to be kept out of the market for very long.

Figure 23 shows HP-filtered average waiting times from founding, first product or process innovation, and incorporation to exchange listing based upon individual company histories and our extended CRSP database.¹⁷ The vertical distance between

¹⁷Listing years after 1925 are those for which firms enter CRSP. For 1885-1924, they are years in which prices first appear in the NYSE listings of *The Annalist*, *Bradstreet's*, *The Commercial*

the solid and dotted lines shows that firms often have their first innovation soon after founding, but that it then takes years, even decades, to list on a stock exchange. We interpret this delay as a period during which the firm and possibly its lenders learn about what the firm’s optimal investment should be. But when the technology is highly innovative, the incentive to wait is reduced, and the firm lists earlier, which is what the evidence shows.

When firms gather less information before investing, the investments that they undertake will be riskier. One may conjecture that if new entrants waited less before investing, then incumbents also undertook projects earlier than they would normally. In all these cases, the resulting investments would be riskier than if more time were allowed to plan them. Moreover, the newness of the GPT would add further risk. On all these grounds, we expect higher interest rate differentials on the average investment.

Figure 24, which portrays the spread between interest rates on riskier and safe investments since 1885, shows that this has been for the most part the case.¹⁸ It is important to note that we formed the series in Figure 24 by ratio-splicing three different spreads together, and that the “safe” asset after 1920 is the short-term treasury bill while for earlier years it is a long-term government bond, yet the fluctuations in this series should still reflect fluctuations in risk perceptions reasonably well, at least to the extent that term premia rather than riskiness are the main factors that lead to yield differentials among the various government securities.

During the Electrification era, spreads rose between 1894 and 1907, which is when uncertainty about the usefulness and possibilities for adoption of the new technology were greatest. Spreads fell after that as the future of electricity became more clear. In the IT-era, spreads have an upward trend from 1970 through the 1990s, and only seem to have fallen recently. This may well reflect the lag in the widespread adoption of the IT technology. The rise of the spread in 1930 and its very slow decline in the subsequent 15 years through 1945 probably has to do with the macroeconomic instability induced by the events prior and during the Great Depression, and then

and Financial Chronicle, or *The New York Times*. The 6,238 incorporation dates used to construct Figure 23 are from *Moody’s Industrial Manual* (1920, 1928, 1955, 1980), Standard and Poor’s *Stock Market Encyclopedia* (1981, 1988, 2000), and various editions of Standard and Poor’s *Stock Reports*. The 3,827 foundings are from Dun and Bradstreet’s *Million Dollar Directory* (2000), Moody’s, Etna M. Kelley (1954), and individual company websites. The 482 first innovations were obtained by reading company histories in *Hoover’s Online* (2000) and company websites. We linearly interpolate the series between missing points before applying the HP-filter to the time series in the figure.

¹⁸In Figure 24, we use the spread between the interest rates on Baa rated corporate bonds (from Moody’s Investors Service) and three-month T-bills [from the FRED database for 1934-2001 and the Board of Governors (1976) for 1920-34] for the period from 1920 to the present. For 1900-20, we ratio splice the spread between the interest rate on prime commercial paper with 60-90 days until maturity [Homer and Sylla (1991, table 49, p. 358)] and the redemption yields on the U.S. government consol 2s of 1930 [Homer and Sylla (1991, table 46, p. 343)] onto the Baa - T-bill spread. Finally, for 1885-99, we splice the spread between the commercial paper rate [Homer and Sylla (1991, table 44, p. 320)] and the redemption yields on U.S. government refunding 4s of 1907 [Homer and Sylla (1991, table 43, p. 316)] onto the previous result.

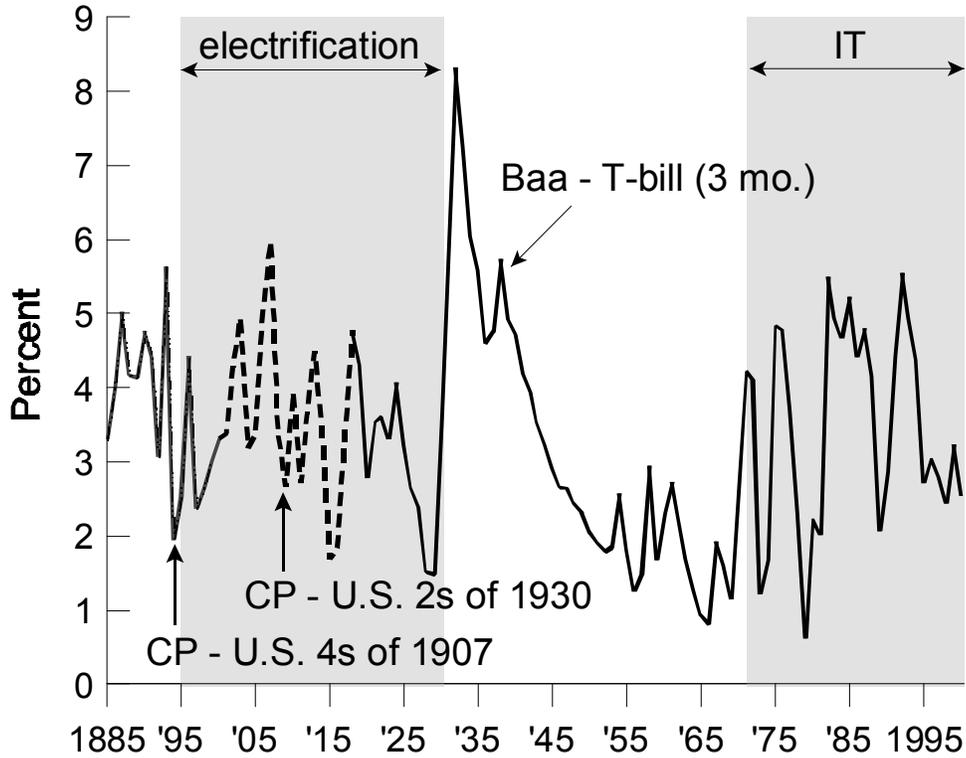


Figure 24: Nominal interest rate spreads between riskier and safer bonds, 1885-2000.

the heavy borrowing by the U.S. government to to finance the second World War, which lowered rates on T-bills.

3.5.3 The stock market performance of young vs. old after entry

Young firms are smaller. If “creative destruction” does indeed mean that old firms give way to young firms, then we should see signs of it in Figure 25, which depicts the relative appreciation of *total* market value of small versus large firms since 1885.¹⁹ 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 era 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.

¹⁹Being a total value index, this differs from the relative stock price index that is plotted in Figure 8 of Hobijn and Jovanovic (2001). For the post-1925 period for which they overlap, the qualitative behavior of the two series is essentially the same.

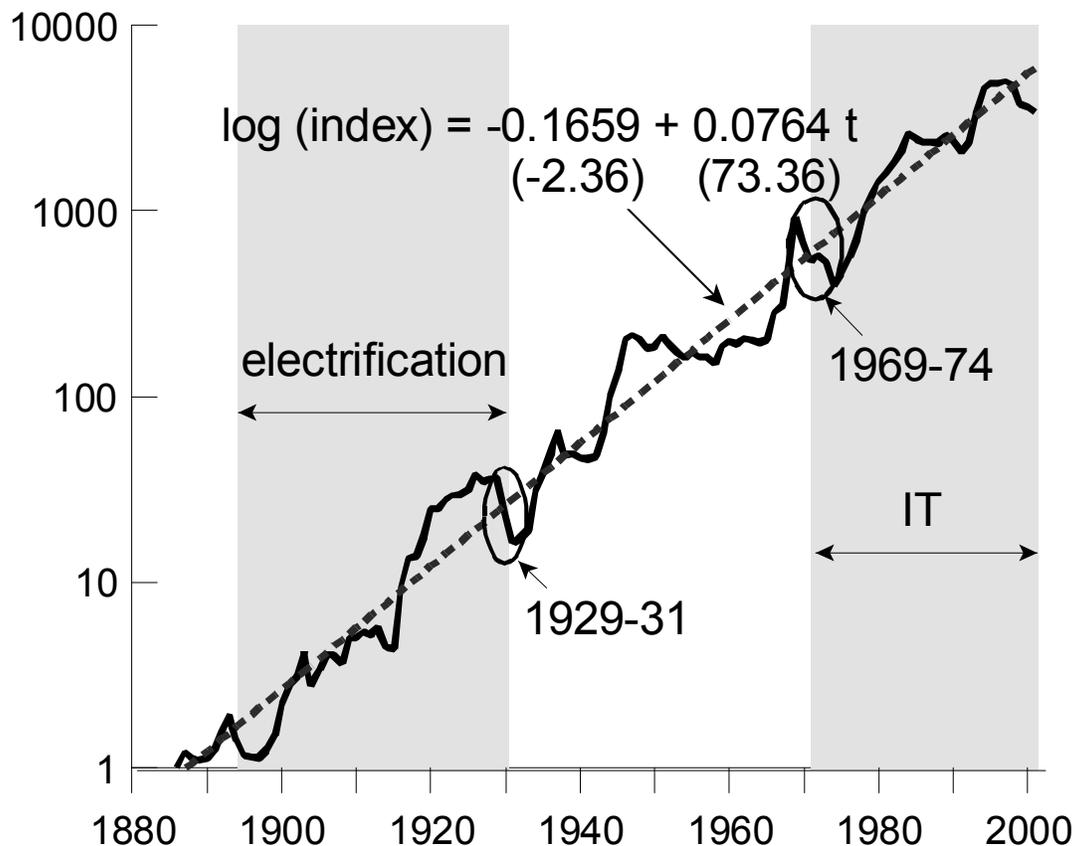


Figure 25: The relative capital appreciations of small vs. large firms.

The two periods that we wish to focus on are 1929-31 and the early 1970s. In both periods, the small-cap firms lost out relative to the large-cap firms. The first period comes at the end of the Electrification era and the relative decline of small cap firms is what one would have expected. But the early 1970's come at the beginning of a new GPT, and small-cap firms should have outperformed the large-cap firms during that time. Yet the opposite happened. It is only after 1974 that the small-cap firms start to perform better.

Regression evidence on age and stock-market performance.—If the GPT is brought in by young firms, then the capital loss imposed by the GPT's arrival should fall more heavily on old firms. To test this using data on individual firms, let

A_i = age since listing of firm i in 1970.

S_i = share (in firm i 's sector) of IT capital in the capital stock in 2001.

This measures firm's exposure to the impact of the new technology of the sector. For the measure of expected performance we take the change in a firm's stock price over intervals that start in 1971 and end in 1975, 1980, 1985, 1990, and 1995. These should

reflect the market’s expectation of how well the firm will handle the consequences of the GPT. We regressions take the form:

$$\ln \left(\frac{P_{i,1975}}{P_{i,1970}} \right) = c_0 + c_1 A_i + c_2 S_i - c_3 A_i S_i. :$$

We summarize the firm-level results in Table 4.

Table 4
Age and stock market performance

	Dependent variable: $\ln(P_{t+i}/P_t)$				
	1971-75	1971-80	1971-85	1971-90	1971-95
constant	-0.737 (-24.3)	-0.143 (-2.96)	0.152 (2.58)	-0.057 (-0.59)	0.577 (6.06)
A	0.007 (6.40)	-0.001 (-0.46)	-0.001 (-0.55)	0.003 (0.97)	-.002 (-0.51)
S	-3.497 (-7.60)	-2.266 (-3.37)	-1.035 (-1.20)	-0.602 (-0.46)	2.719 (1.88)
$A * S$	0.047 (2.22)	0.043 (1.14)	-0.016 (-0.39)	-0.122 (-2.09)	-0.106 (-1.76)
R^2	.089	.009	.003	.006	.012
N	2218	1814	1367	981	843

Note: The table presents coefficient estimates for the sub-periods included in column headings with T-statistics in parentheses. The R^2 and number of observations (N) for each regression appear in the final two rows.

The interaction between the firm’s age (A) and its exposure to (S) is negative and significant only when the period during which we measure price appreciation extends to 1990 and 1995. We would have expected this coefficient to be negative always since older firms in sectors in which IT would become important would be less able to adjust to the new technology than newer ones. Over the 1971-75, 1971-80, and 1971-85 periods, the interaction term comes in positive, but statistically significant only in the first subperiod. It thus seems that IT firms took a long time to realize gains in the market after the technology’s arrival. We do not have a lot of firms with continuous price data prior to 1900, but have enough observations to at least attempt the same regression for the Electrification era. In this case, we got

$$\ln \left(\frac{P_{i,1899}}{P_{i,1894}} \right) = 2.111 - 0.129 A_i - 2.307 S_i + 0.213 A_i S_i$$

(1.09) (-0.46) (-0.88) (0.55)

(T-stats in parenthesis) $R^2 = .015$, $N = 56$. In this very small sample, we do not see a direct effect of age on capital depreciation as the Electrification era got underway, and the interaction term is not statistically significant.

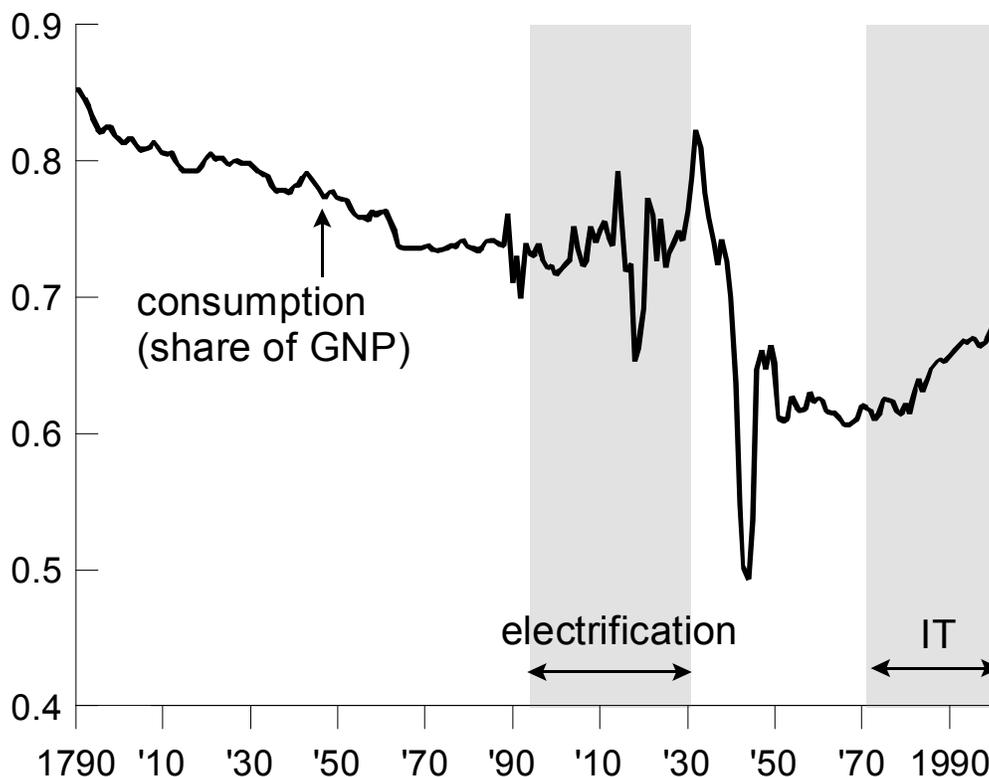


Figure 26: The ratio of consumption to income.

3.6 Interest rates and the trade deficit

First, if the productivity gains of the GDP are deferred, the consumption income ratio should rise. Second, the consumer becomes wealthier when the GPT arrives, interest rates should rise to choke off some of the increased consumption demand. Finally, some of the extra consumption comes from imports and so the trade deficit should rise. The evidence on these three point is mixed, but on balance favorable.

3.6.1 The predicted rise in the consumption-income ratio during GPT eras

Private consumption rises gradually during each GPT era, and this is set against a long-run secular trend for private consumption that is negative. Figure 26 shows the ratio of consumption to gross national product (GNP) since 1790.²⁰ As our GPT

²⁰The series for consumption and GNP are from the Bureau of Economic Analysis (2002, table 1, pp. 123-24) for 1929-2001, Kendrick (1961, table A-IIb, cols. 4 and 11, pp. 296-97) for 1889-1929, and Berry (1988, table 9, pp. 25-26) for 1790-1889. The BEA figures are for personal consumption, but the Kendrick and Berry figures include the government sector as well. Since consumption in the

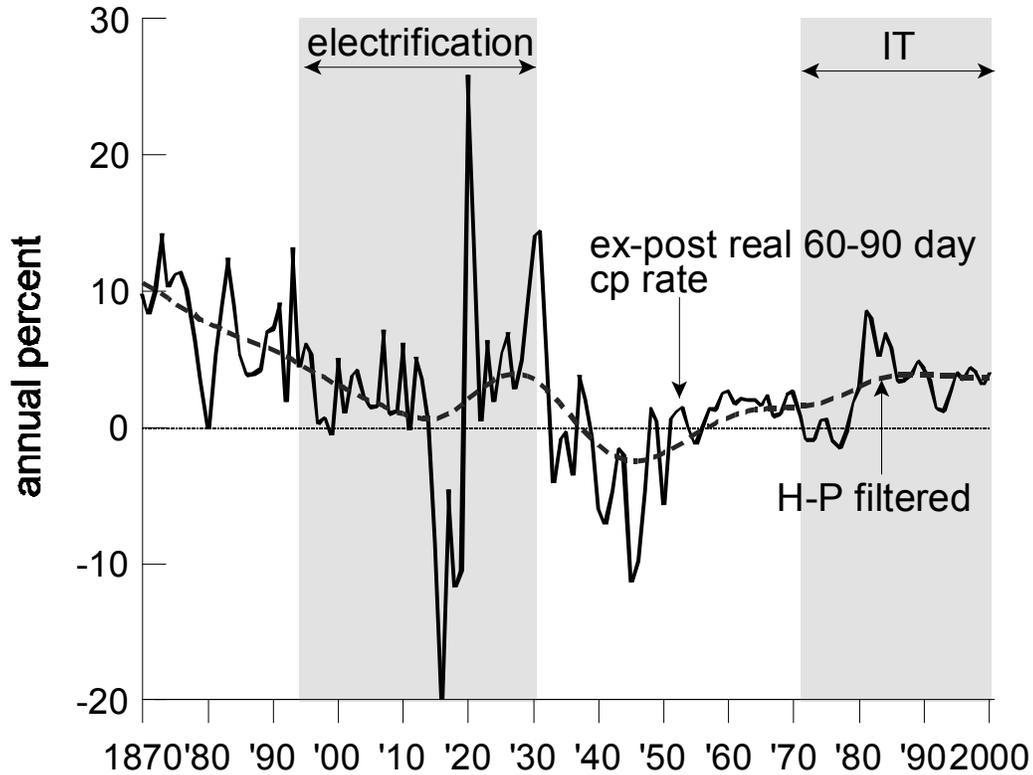


Figure 27: The ex-post real interest rate on commercial paper.

hypotheses would suggest, the arrival of Electricity in 1890 seems to mark the end of a long-term decline in the ratio that been underway for a century. And though the level of the series falls during the Great Depression and World War II, never to return to its pre-1930 levels, consumption takes another sharp upward turn near the start of the IT revolution, and has continued its rise to this day.

3.6.2 The predicted rise in interest rates

Figure 27 shows that ex-post real interest rates were about the same during the two GPT eras, and much lower in the middle 40 unshaded years of the 20th century.²¹

government sector was much smaller prior to the first World War, we suspect that the downward trend in the 19th century is a result of changing private consumption patterns rather than a reduction in the government sector's consumption.

²¹Commercial paper rates are annual averages from the FRED database for 1934-2001 and from Homer and Sylla (1991) for earlier years. We compute the ex-post return by subtracting inflation as computed by the growth of the implicit price deflator for GNP from the Bureau of Economic Analysis (2002) for 1929-2001 and Berry (1988) for earlier years.

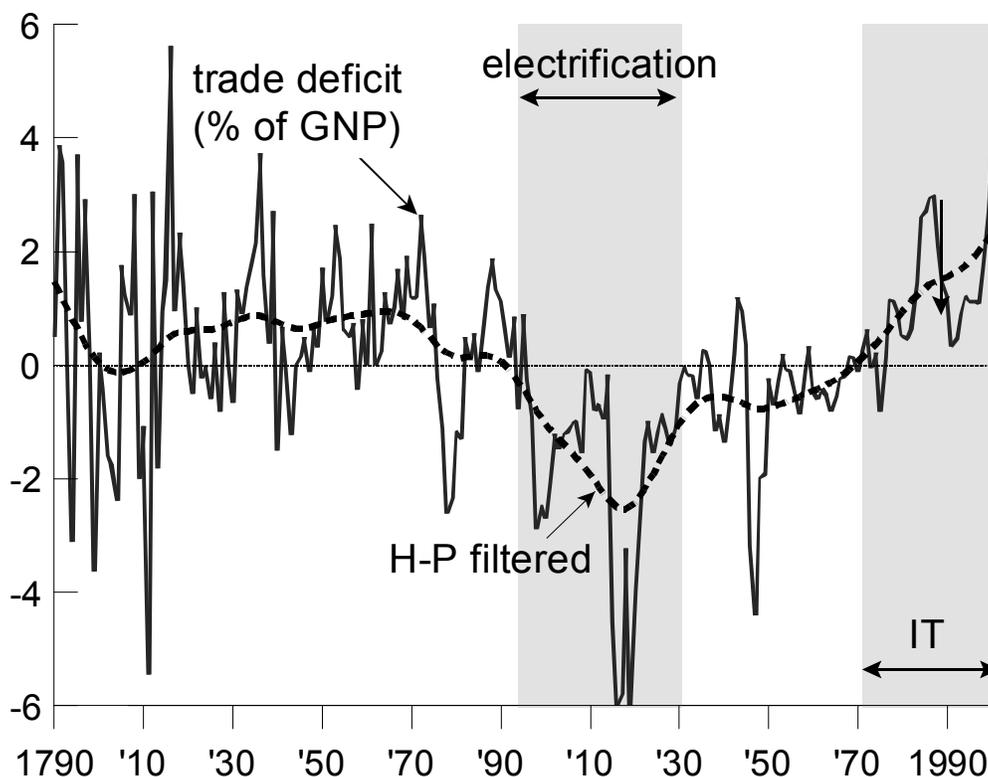


Figure 28: Trade deficit as a percent of GNP.

The dashed line is the H-P detrended series. The averages are

Era	Ex-post real interest rate
1870 – 1893	7.78
1894 – 1930	2.61
1931 – 1970	- 0.16
1971 – 2001	2.94

We note, however, that the ex-post rate is so high in the first era, before 1894. If the arrival of Electricity and its impact was foreseen prior to 1894, interest rates would have risen earlier, but this probably does not explain why it is so high then. More likely, the pre-1995 era reflects the lack of financial development: The stock market was small then, and the financial market not as deep. This may have given rise to an overall negative trend in interest rates over the 130-year period as a whole.

3.6.3 The predicted rise in the trade deficit

Alternatively, a trade deficit should open up, and right away if the economy is open. Figure 28, which plots the trade deficit as a percentage of GNP since 1790 along with

an H-P trend, shows this to be the case at the start of the IT revolution, though not in the early years of Electrification.²²

It is puzzling at first blush that the deficit did not appear during the IT era. If anything, it moves into surplus. Events in the rest of the world may explain a part of this. Europe needed to borrow heavily to finance its colonial wars and World War I, and the United States provided some of the loans. This may partly explain the surplus. The IT era is taking place while the world is largely at peace

4 Conclusion

Technological invention is uneven, and comes in bursts; that much has for a long time been clear to students of growth. Electricity and IT are, to most observers, the two most important GPTs to date, at least they seem so according to the three criteria that Bresnahan and Trajtenberg proposed. In this chapter we have analyzed how the U.S. economy reacted to the creation of these two GPTs. Having discussed in detail GPTs with reference to the Electricity and IT eras, we believe we have shown that the concept is a good way to organize how we think of technological change and its effects.

The Electricity and IT eras are similar, but they also different in important ways. Electrification was more broadly adopted, whereas IT seems to be technologically more revolutionary. The productivity slowdown is stronger in the IT era but the ongoing spread of IT and its continuing precipitous price decline are reasons for optimism about growth in the coming decades.

²²GNP and total imports and exports of goods and services are from the Bureau of Economic Analysis (2002, table 1, pp. 123-24) for 1929-2001. For 1790-1920, imports and exports are from Bureau of Census (1975), series U-8 and U-1, p. 864, respectively), and the GNP series are from Kendrick (1961) and Berry (1988).

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