The Boom and Bust in Information Technology Investment*

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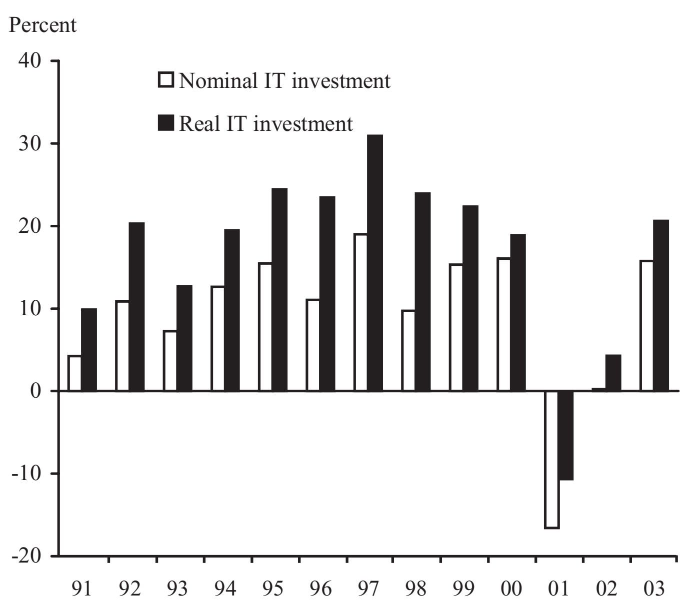
The growth rate of business investment in information technology boomed in the 1990s and 2000 before plunging in 2001. This boom and bust raises some natural questions: what were the reasons for the accentuated swings in growth rates, and, more importantly, what do those reasons portend for the future of IT investment? Much of the increase in IT investment in the late 1990s appears to be attributable to falling prices of IT goods, which in turn is largely attributable to technological change. However, IT investment was much higher in 1999 and 2000 than a model would predict. Another reason for the high growth rates in IT investment was that expectations were too high, especially in two sectors of the economy, telecommunications services and the dot-com sector. Looking ahead, technological change in the IT area will likely continue to move quickly, in large part because large amounts of research and development are being devoted to finding further technological breakthroughs.

1. Introduction

The last recession may well be remembered as a high-tech recession. The growth rate of investment by businesses in computers, communications equipment, and software (referred to as IT investment in this paper) boomed in the 1990s and 2000 before plunging in 2001. As shown in Figure 1, growth in real IT investment was especially strong between 1995 and 2000, averaging 24 percent per year and adding an annual average of over 3/4 percentage point to GDP growth (not shown).[1] However, in 2001, IT investment contracted sharply, with real IT investment falling nearly 11 percent and nominal investment plunging almost 17 percent.[2] In 2002, with a recovery in IT investment late in the year, real and nominal IT investment were up modestly. IT investment picked up further in 2003, with real investment posting a respectable 21 percent increase.[3]

The boom and bust in IT investment raises some natural questions: what were the reasons for the accentuated swings in growth rates, and, more importantly, what do those reasons portend for the future of IT investment? For example, were the very high growth rates in IT investment followed by a contraction the result of a surge in technological change in the late 1990s, or overly optimistic

Figure 1
Annual Percent Change in IT Investment



Source: Bureau of Economic Analysis. Percent changes based on year-end values.

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1. All percent changes are reported on an end-of-year basis unless otherwise noted.

2. When it comes to IT investment, the distinction between nominal and real investment can be quite important; for a discussion of the relationship between nominal and real investment and prices, see Box 1.

3. For a fuller and very readable discussion of the importance of IT to the economy, see Department of Commerce (2003).

Box 1
The Relationship between Prices and Nominal and Real Investment

Large differences in the growth rates for nominal investment and real investment can arise because the prices for high tech goods fall much more quickly than overall prices. As an example, say that nominal investment in (that is, actual dollars spent on) computers falls 10 percent in a year. However, as has been well documented and extensively studied, the prices of computers tend to fall sharply, averaging over 20 percent per year. In our example, suppose that prices fall 20 percent. Then, although nominal investment falls 10 percent, real investment grows by 12.5 percent.[1] Therefore, there can sometimes be confusion over what constitutes a rebound in investment.

1. The real growth rate in percent between two time periods (t and $t+1$) is $100 \times [(N_{t+1}/P_{t+1})/(N_t/P_t) - 1]$, where N denotes nominal investment and P is the price index.

expectations on the returns to IT investment, or changes in the service lives of IT goods, or some other factors?

To get at the answers to these questions, I present results from a model of IT investment to identify those portions of investment that are "explained" by economic fundamentals and those portions that are "unexplained." I then discuss and examine the reasons for the explained and unexplained portions. In a nutshell, the model suggests that most, but not all, of the very high rate of IT investment growth from 1994 through 1999 can be explained. The driving force behind the high rates predicted by the model is the cost of IT goods; these costs fall much more quickly than costs for other investment goods, hence the demand for IT goods rises. However, the gap between actual and predicted IT investment (the unexplained portion) grows in 1999 and 2000. Additionally, IT investment falls more quickly than the model predicts in 2001 and stays below the model's predictions for 2002 and into 2003 (that is, the unexplained portion turns negative and remains negative).

In trying to understand what can "explain" the unexplained portions, one hypothesis that I examine is that overly exuberant expectations about IT investment led businesses to overinvest in IT systematically. At first glance, the sharp contraction in IT investment following several years of exceptionally high growth lends credence to this hypothesis. However, the exceptional productivity performance in the economy that coincided with the boom in IT investment throws this hypothesis into doubt. With that said, there were indeed pockets in the economy that, ex post, overinvested in IT; two such pockets were the telecommunications services and dot-com sectors. Capital spending by telecom service providers, which are large consumers of IT products, surged in 2000 and subsequently fell sharply in 2001 and 2002. In fact, estimates show that the large swing in nominal IT investment between 2000 and 2001 was greatly exacerbated by the telecom service industry, and that the telecom service industry placed a significant drag on nominal IT investment in 2002. Data for the dot-com industry are harder to come by. However, by several measures, it appears that the rise and fall of the dot-com industry plays a nontrivial role in understanding the "unexplained" portion of IT investment.

Another hypothesis for why the model of investment would have underpredicted then overpredicted IT investment is that service lives of IT equipment were shortened in the late 1990s (boosting investment) and subsequently lengthened in this decade (damping investment). One reason why service lives were shortened in the late 1990s was because concerns surrounding the effects of the century date change (known as Y2K) forced firms to replace some of their IT capital earlier than they had expected. However, based on survey data, I find that the Y2K problem played a minor role, at best, in the swings in IT investment. A second reason for shortened service lives is that advances in personal computer (PC) software increased the obsolescence of PCs; thus, many firms upgraded their PC stock in the late 1990s, earlier than they had anticipated. So far this decade, so the story goes, the rate of obsolescence has apparently been reduced, lengthening the service lives of PCs and damping IT investment. Quantifying this story is extremely difficult, but there is much circumstantial evidence suggesting that this may indeed have happened.

The stories just discussed help explain why IT investment was so high in 1999 and 2000 and why it fell so quickly in 2001. However, the most salient feature of the model of IT investment is just how much growth in IT investment it predicted. The growth in predicted IT investment stems largely from the fall in prices of IT goods, which results largely from technological progress. I find that prices for several IT goods fell very quickly during the late 1990s, and that these drops in prices appear to coincide with an acceleration in technological progress. Prices in the late 1990s probably fell even faster than the official data indicate, especially for communications gear and software. There is also some evidence that technological progress eased up some at the beginning of this decade but continues to gain at a rapid pace. Looking forward, it appears that the pace of technological change for IT products should continue for a while, reflecting the large amounts that companies are spending on R&D and the expectations about what products can be developed.

In this paper, Section 2 presents the stylized facts about investment in IT goods. Section 3 discusses a model of IT investment, highlighting those factors that are important behind investment and a rough framework to think about IT investment. To address some possible reasons for the errors in the investment model, I present a discussion of the role of overly optimistic expectations in Section 4 and the role of shortened IT service lives in Section 5. To explain one of the more important determinants of IT investment, I describe what has happened to prices and technological change for computers, communications equipment, and software in Section 6. Section 7 concludes with some information about what may be in store for technological change in the IT field.

2. Basic Facts of the Boom and Bust

Investment in IT has become an increasingly important component of the economy and played a disproportionately large role in the past economic downturn. In 1990, nominal investment in IT goods totaled just $131.5 billion, a bit less than one-third of private nonresidential equipment and software (E&S) investment. By 2000, IT investment had surged to $401.6 billion, close to a 44 percent share of E&S spending. Nominal IT investment still accounted for close to 43 percent of E&S investment in 2003, two years after the IT bubble burst.

These IT investments contributed significantly to GDP growth during the late 1990s and contributed greatly to the swings in GDP growth during the past economic downturn. For instance, IT investment contributed about 3/4 percentage point to real GDP growth in 1998, 1999, and again in 2000. However, in 2001, the drop in IT investment subtracted 0.4 percentage point from GDP growth. After having a minor effect in 2002, IT investment once again provided a substantive boost to GDP in 2003 by contributing 0.7 percentage point to growth.

Table 1 presents a fuller description of what happened to IT investment in the late 1990s and so far this decade. The table summarizes the changes in nominal investment, prices, and real investment for three IT categories: software, computers, and communications equipment. The table also presents statistics on nonresidential investment outside of IT (non-IT). There are several stories to take away from the table. The most striking is that nominal and real investment grew very sharply during the late 1990s and into 2000 for all IT categories. Between 1995 and 2000, growth in IT investment in real terms averaged nearly 24 percent per year, five times greater than investment in other types of equipment. In nominal terms,

Table 1
Changes in Nominal Investment, Real Investment, and Prices for IT

	Average annual percent change			Percent change from preceding year				
	1990–1995	1995–2000	2000–2003	1999	2000	2001	2002	2003
Nominal investment								
IT	10.0	14.2	–1.2	15.3	16.0	–16.6	0.2	15.5
Software	9.5	18.5	0.8	24.1	12.2	–9.6	2.5	10.6
Computers	13.5	7.1	1.4	6.6	9.2	–23.4	8.4	25.4
Communications equipment	7.2	15.5	–6.4	11.0	28.6	–21.1	–9.8	15.2
Non-IT	6.8	4.9	–1.4	3.6	0.2	–7.8	0.3	3.6
Prices								
IT	–6.2	–7.8	–4.8	–5.7	–2.4	–6.6	–3.9	–4.0
Software	–2.7	–0.5	–0.9	2.3	3.5	–0.4	–0.7	–1.7
Computers	–14.8	–21.0	–14.3	–18.3	–11.1	–20.6	–11.8	–10.1
Communications equipment	–1.4	–3.4	–2.7	–4.7	–3.2	–3.9	–2.4	–1.8
Non-IT	1.9	0.4	1.3	–0.1	0.5	0.6	0.6	2.8
Real Investment								
IT	17.2	23.8	3.9	22.3	18.9	–10.7	4.3	20.3
Software	12.6	19.1	1.8	21.3	8.4	–9.3	3.2	12.6
Computers	33.2	35.6	18.3	30.5	22.9	–3.5	22.9	39.6
Communications equipment	8.7	19.6	–3.8	16.6	32.9	–17.9	–7.6	17.4
Non-IT	4.8	4.4	–2.7	3.7	–0.3	–8.3	–0.3	0.8

Source: Bureau of Economic Analysis. All figures computed using year-end values.

growth in IT investment in the late 1990s was nearly three times as great as in other equipment.

The gaps between the growth rates in real and nominal IT investment reflect the estimated changes in prices for IT equipment and software based on price deflators compiled by the Bureau of Labor Statistics (BLS) and the Bureau of Economic Analysis (BEA). These agencies face a difficult task in deriving accurate price indexes for IT products because IT products are constantly changing. There has been much research into measuring prices for computers (the component of IT that shows the fastest price declines), but much less progress has been made in measuring quality-adjusted prices for software and communications equipment. As I discuss in Section 6, it is very likely that prices for these two components actually fell much faster than the official data indicate, implying that the growth in real investment was even higher than reported in the table.

Another notable feature in Table 1 is the sharp reversal of fortune that befell IT investment and other investment to a lesser extent in 2001. To paraphrase, the higher the rise, the harder the fall. Nominal IT investment dropped almost 17 percent in 2001, a whopping 33 percentage point reversal, reflecting declines in all three IT categories, but especially for computers and communications equipment. Real investment in IT declined 10.7 percent in 2001, representing an equally stunning swing in growth rates. The slide in IT investment began to reverse slowly in 2002 and had recovered substantially by the end of 2003.

Although business demand for IT goods declined sharply during the recession, the declines should not be overstated since the level of investment remained high. For instance, nominal investment in 2002 was at the same level as it was in 1999, and real investment was 30 percent higher, indicating that businesses continued to add to their stock of IT hardware and software, at least in real terms.

3. A Model of IT Investment

The data in the previous section show IT investment went through a period of phenomenal growth followed by a sudden contraction. This brings to mind the question, how much of this pattern was based on economic fundamentals and how much was based on other factors? Another way to pose the question is to ask, how much of the boom and bust in IT investment can be "explained" by traditional models of IT investment and how much is "unexplained"?

One model of IT investment, as described in Kiley (2001), is part of the larger macroeconomic model, known as FRB/US, that is maintained at the Board of Governors of the Federal Reserve System. At its heart, the FRB/US model asks what profit-maximizing amount of IT capital firms in the U.S. economy should have, what it refers to as the "optimal" IT capital stock. The optimal IT capital stock for the economy depends on a number of factors, including a concept referred to as the "user cost of capital." The user cost of capital is akin to the wage rate for labor in that it attempts to capture how much it costs a firm to use a piece of capital over a period of time, just as the wage rate attempts to capture how much a firm has to pay for a worker. Box 2 provides more details. Although the exact construction of the user cost of capital can be a little convoluted, it stands to reason that if, for instance, the user cost of IT declines, then firms would buy more IT and substitute away from other factors of production, such as labor or other types of capital.

Figure 2 shows indexes of the user cost for IT goods and for other investment goods since 1990.[4] The user cost of IT goods has fallen over time, averaging about 6 percent per year in the early 1990s and over 7 percent in the late 1990s. In contrast, the user cost of non-IT goods increased an average of little more than 1 percent per year from 1990 to 2003. Over the 1990s, the primary factor driving down the user cost of IT was the decline in the price of IT capital goods, at least as measured by the BLS and BEA. The decline in the prices for IT goods was stunning, and, like other normal goods, these falling prices pushed up the quantity of IT capital demanded by busi-

Box 2
The User Cost of Capital

The user cost of capital is made up of two types of costs. The first is the cost of the acquisition of the capital good, and this equals the prevailing interest rate, i, multiplied by the purchase price of the capital good, p_t.

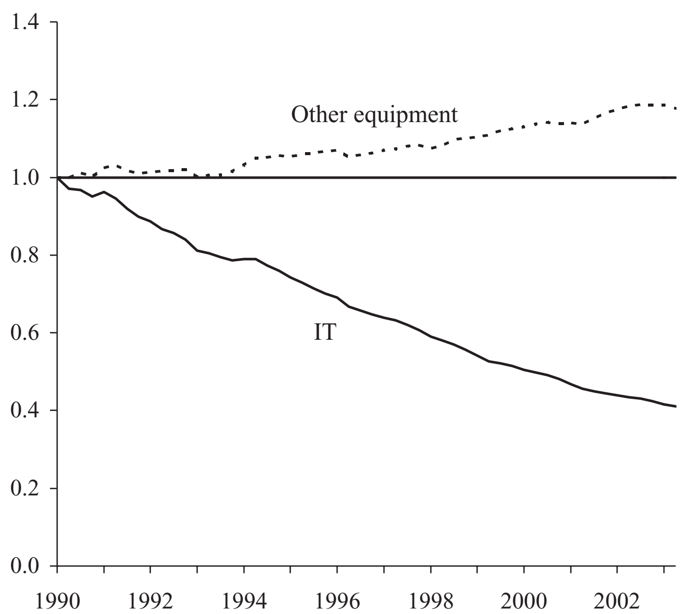
The second type of cost is what happens to the value of the capital good over the period it is used. This type of cost includes the change in prices, π, and depreciation, δ. Depreciation is the idea that the value of the good declines over time simply because it ages. The change in prices, π, enters into the user cost because the worth of a good depends on the market for that good. Say, for example, a company buys a computer for $1,000. If computer prices fall 20 percent in the next year, that computer will have lost $200 in value because of price changes alone.

Putting all of these components together (excluding the effects of taxes for simplicity), the user cost of capital can be written as

$$(1)\quad UC_t = p_t(i_t + \delta - \pi_t).$$

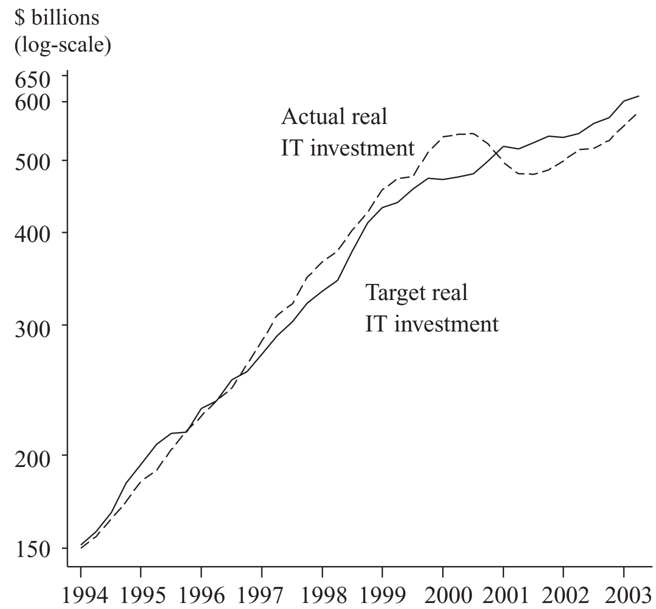
4. The user costs shown here do not make any adjustments for taxes.

FIGURE 2
INDEXES OF USER COSTS FOR IT AND OTHER EQUIPMENT
(1990:Q1=1)



Source: Federal Reserve Board of Governors.

FIGURE 3
ACTUAL AND TARGET REAL IT INVESTMENT
(1996 $ BILLIONS)



Source: Federal Reserve Board of Governors.

nesses. In fact, the declining user cost for IT is the primary driver of the strong IT investment during the 1990s, according to FRB/US.

Using the user cost of capital, FRB/US estimates how much IT investment would be necessary to reach the optimal capital stock. This is referred to as the "target level" of investment. Figure 3 shows actual real IT investment and the target level of real investment predicted by FRB/US since 1994.[5,6] The figure shows that the target level of investment and actual investment track each other fairly well from 1994 to 1998, though FRB/US tends to systematically underestimate IT investment a bit. For instance, over the 1994 to 1998 period, the average target IT investment growth is 24.4 percent per year, compared to 25.2 percent for actual IT investment. The underestimation of the model is about $26 billion (in 1996 dollars) as of 1998. That is, IT investment was about 6 percent greater in 1998 than would be expected based on the model.

The model does not do quite as well predicting the rapid growth of IT investment in 1999 nor the slump during the recession and the degree of rebound. For instance, the model predicted that real investment would increase 14.7 percent in 1999, when in fact it increased 20.5 percent. Also, in 2001, the model predicted a 7.9 percent increase, but investment actually fell 7.8 percent.[7] In 2002, actual investment remained below predicted investment. In the first half of 2003, some shortfall in actual investment still was evident, but it was quite small.

The results in Figure 3 appear to take a good deal of the mystery out of the boom in IT investment by businesses. A concern is that the results in Figure 3 are based on an estimated model. However, the results of the model should not be taken as truth for several reasons. For example, the outputs of the model are only as good as the inputs, and, as I discuss later in this paper, it is extremely difficult to measure the components of IT properly. Additionally, there are the problems associated with any estimated model, such as parameters that may vary over

5. The FRB/US estimates are based on data from before the benchmark revision in December 2003. It is too early to tell if the new data will produce a better or worse fit. However, the percentage decrease in real IT investment in 2001 before the benchmark revision was 7.2 percent, and after the benchmark revision the drop was 2.7 percent.

6. Figure 3 is drawn with a logarithmic vertical scale instead of a traditional linear vertical scale. A straight line on a graph with a logarithmic vertical scale indicates that a series is changing at a constant rate. In contrast, when graphed with a traditional linear vertical scale, that same series that increases at a positive constant rate would become steeper over time. The distinction between linear and logarithmic scales can be especially important for a variety of series in the IT industry that are characterized by high growth rates, such as Moore's law, the speed of microprocessors, the prices of IT goods, and so on.

7. These gaps are large relative to how FRB/US performs for other types of equipment investment.

time or missing factors in the equations. Therefore, it is still interesting to ask whether there is any other evidence of overinvestment in IT during the 1990s.

Another more indirect way to examine the IT investment trend is to assume that firms are making the correct decisions in terms of how much they are investing in IT, and then examine what has happened to productivity. The logic behind this approach is that, if there were a great deal of overinvestment in IT—that is, if a lot of IT goods were purchased that ended up not being very useful—then productivity would not be as high as expected. This is not a conclusive test, as there are many factors that affect productivity, but, as discussed in Box 3, it appears to be increasingly difficult to tell a story that there was too much investment in IT given what has happened to productivity growth and given the multitude of stories that cite the importance of IT. With that said, however, there were several sectors that obviously overspent on IT (and on other equipment, for that matter), and they are described in the next section.

4. Ebullience

Perhaps the story that is first and foremost in many people's minds to explain the excessive IT investment in 1999 and 2000 is that expectations about the rate of return on IT investment were too high. In the late 1990s, the dot-com industry was growing and there was a sense that the way business was conducted around the world was changing, creating a "new economy." Businesses believed that they had to invest heavily in IT if they wanted to be part of this new economy. Using the language from the model section, businesses thought that there was an outward shift on the returns to IT investment, increasing the desired capital stock and, therefore, increasing investment in IT goods. In 2000 and 2001, expectations began to sour (lowering the expected rate of return on IT goods) and the reverse happened: firms cut investment in IT goods.

Although this story has a tremendous amount of intuitive appeal, the question is, to what extent did changes in

Box 3

The Relationship between Productivity Growth and IT Investment

Labor productivity grew at an average rate of 1.4 percent between 1973 and 1995. Since 1995 through the end of 2003, labor productivity growth perked up to 3.1 percent, with especially strong gains of over 4 percent since the end of 2000.

Why did productivity growth pick up in the late 1990s and so far this decade? To answer that question, many studies have decomposed labor productivity growth into several sources.[1] These sources include improvements in the quality of labor, increases in the amount of capital, and improved efficiencies in producing with a given amount of capital and labor. This last form of productivity improvement is often called total factor productivity, or TFP. Although different studies use different decompositions, most come to the conclusion that a good deal of the pickup in labor productivity growth comes from a pickup in TFP.[2]

If firms made many unwise capital investments, including IT investments, all else equal, then TFP would be adversely affected. Yet, TFP has gone up during and after the strong surge in IT spending. Now, there are many reasons why TFP may have gone up, and TFP is something that is not well understood (in fact, TFP is sometimes referred to as a measure of our ignorance). However, the collected stories about the improving productivity performance of the U.S. economy resonate an IT theme, either directly or indirectly. For instance, Jorgenson, Ho, and Stiroh (2002) find that industries that were intense users of IT accounted for a disproportionate share of productivity growth. Similar results are produced independently by the Department of Commerce (2003). For instance, the finance and retail industries posted above average gains in productivity growth and they are also sectors that are also relatively IT-intensive.

Digging beneath the surface a bit, the McKinsey Global Institute has come out with several studies (McKinsey 2001, 2002) that examine productivity growth and ask, sometimes specifically, what role IT played. A theme of the McKinsey studies is that IT was one reason, but not the only reason, for the surge in productivity growth. Other reasons McKinsey cites include increases in competition (in the case of the development of microprocessors) and changes in the regulatory environment (in the case of cellular phones). Another theme in the McKinsey studies is that investment in IT does not in itself yield marked productivity improvements. Instead, organizations must make complementary changes in the way they do business to reap the full rewards that IT potentially offers. In a related vein, Basu, et al. (2003) argue that IT is a general purpose technology, that is, a technology that is widely used in a number of different applications. As such, it takes time for firms and industries to learn how to use IT, so the improvements we are seeing more recently in TFP are the fruits of investments made several years ago.

1. Several of the more commonly cited studies include Oliner and Sichel (2002), Gordon (2003), Jorgenson, Ho, and Stiroh (2002), and the Council of Economic Advisors (2003).

2. It should be noted that most of the pickup in TFP is outside of the IT-producing industries.

expectations affect the swing in IT goods? It is dangerous to point to examples and then make generalizations, because regardless of the type of investment good we could examine—computers, airplanes, aluminum smelters—one can always find examples of investments that turned out not to be wise. The more appropriate question to ask is, what happened on average or, if there were particular pockets of excessive enthusiasm, how large were those pockets and what effects could they have had on the aggregate figures for IT investment? What follows, then, is a closer examination of two industries that epitomized overinvestment in IT.

4.1. Dot-com Overinvestment

There were expectations that new firms that relied heavily on the Internet, and firms that provided services to other businesses that relied heavily on the Internet, would be wildly profitable, a claim that only a few firms would be able to make several years later. Ebay is one such dot-com company that has survived, while Pets.com and Furniture.com are examples of dot-com companies that failed. Unfortunately, there are no accurate statistics on the dot-com industry, especially when it comes to IT capital spending. However, there are several ways to obtain some back-of-the-envelope calculations to see how potentially important these companies may have been to the swings in IT investment. One method is to examine patterns of venture capital (VC) spending and another is to examine employment in industries that have properties similar to dot-coms. Both methods come to a similar conclusion: the dot-com bubble and its bursting could have accounted for a small portion of the excessive run-up in IT investment and a somewhat larger portion of the decline.

The first method of measuring the potential magnitude of dot-coms on the investment swings is to examine VC spending. According to the MoneyTree survey,[8] VC spending (excluding health care and biotechnology) surged in 2000 to nearly $98 billion, a staggering increase from nearly $18 billion just two years earlier. The question is, how much of this money was spent on IT? According to data from Informationweek,[9] companies tend to spend very little of their revenue on IT. For instance, even telecom firms (which are IT-intensive) are estimated to spend only about 4 percent of their revenue on IT, and about one-third of that spending is on salaries. If we assume that companies that received VC funding spent 5 percent of their funding on IT equipment and software (about double the rate of telecom companies), then VC spending accounted for $2.4 billion of the $53.8 billion increase (4.5 percent) in IT spending between 1999 and 2000. However, between 2000 and 2002, the drop in VC spending would have accounted for a $4.1 billion drop in IT spending, about 7.5 percent of the $55 billion decline.

Another approach to looking at the effect dot-coms had on IT investment is to examine employment in industries that are dot-com-like. Four industries that likely encompassed many of the dot-coms are wholesale electronic markets and agents and brokers; electronic shopping and mail-order services; Internet service providers and web search portals; and data processing, hosting, and related services. Between 1995 and the end of 2000, employment in these industries accounted for 2.3 percent of all net nonfarm jobs created in the U.S. (365,000 compared to 16.1 million created elsewhere in the nonfarm sector). In terms of the downturn though, these industries accounted for about 5 percent of the decline in total nonfarm employment.

In terms of the role that these industries played in the swings of IT investment, we need to make an assumption about how IT-intensive they are relative to the rest of the economy. For example, let's suppose these industries invest three times more in IT per employee than other industries do.[10] Under this assumption, these industries would have accounted for about 6.5 percent of the increase in IT spending from 1995 to 2000 and 13.1 percent of the drop from 2000 to 2002.

4.2. Telecommunications Service Industry Overinvestment

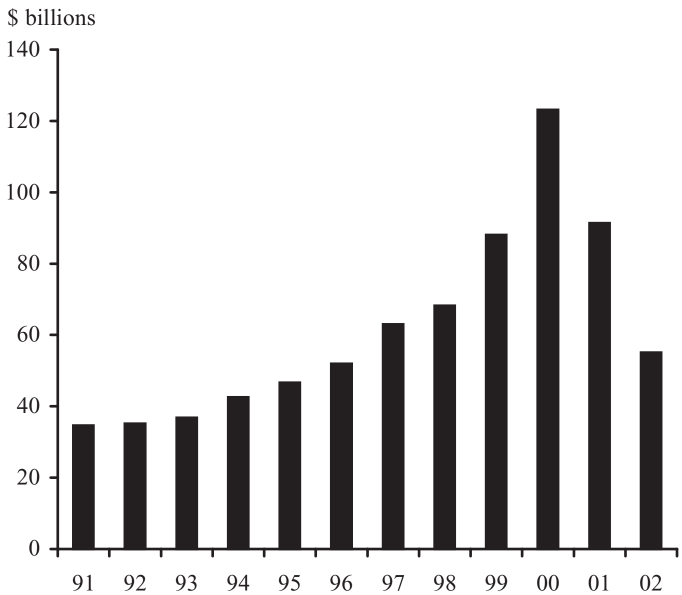
More than any other sector, the telecom service industry was the poster child of overinvestment. Spurred on by the Telecommunications Act of 1996 and ebullient expectations for future demand, the telecom service sector went on a capital expenditure binge. As shown in Figure 4, capital investment by publicly traded telecom service companies rose sharply in the late 1990s, starting at $47 billion in 1995 and peaking at $121 billion in 2000. Since then, however, the telecom service industry landscape is littered with the wrecks of overly optimistic expectations, as witnessed by the bankruptcies by WorldCom, Global Crossing, and numerous smaller

8. The MoneyTree Survey is a collaboration among PricewaterhouseCoopers, Thomson Venture Economics, and the National Venture Capital Association.

9. See www.Informationweek.com.

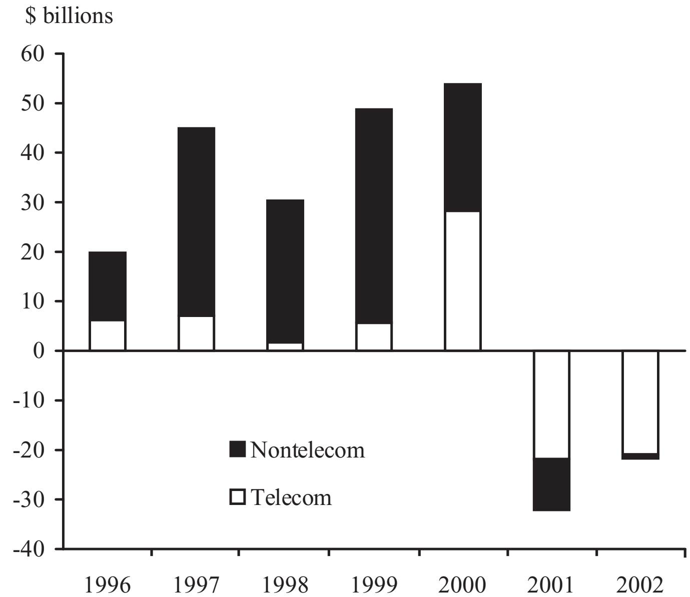
10. Based on the 1998 Annual Capital Expenditure Survey (ACES), this assumption would make dot-coms about two times more IT-intensive than the financial services industries.

FIGURE 4
CAPITAL SPENDING BY PUBLICLY TRADED TELECOMMUNICATIONS SERVICE PROVIDERS



Source: Compustat and author's calculations.

FIGURE 5
CHANGES IN ESTIMATED NOMINAL IT SPENDING BY TELECOM AND NONTELECOM COMPANIES ($ BILLIONS)



Note: All figures are year-over-year changes
Source: Author's calculations based on data from Compustat, the Annual Capital Expenditures Survey (multiple years), and the 1997 Capital Flows Tables (from BEA).

firms. By 2002, investment had fallen by over half to $49 billion.[11,12] These large swings in investment by this single industry likely helps explain a portion of the swing in IT investment, since telecom service providers are big spenders on IT equipment.

Working on the assumption that capital spending by telecom service providers fell by 20 percent in 2001 and using information from the U.S. Census Bureau's 1998 Annual Capital Expenditures Survey and the BEA's 1997 Capital Flows Table, Figure 5 shows the changes in estimated annual IT spending by telecom and nontelecom firms.[13] In 2000, telecom companies went on a spending binge, accounting for a majority of the increase in IT investment in the country. Almost as pronounced as the 2000 increase is the 2001 decrease. I estimate that IT spending by telecom companies dropped by $22 billion, more than two-thirds of the total decrease in IT spending. In 2002, I estimate that a further drop in telecom spending accounted for nearly all of the decline in total IT spending.[14] The Appendix provides a more detailed look at the causes of the boom and bust in capital investment by the telecom service industry.

11. The data for publicly traded companies are very close to the figures reported in ACES for communications service firms. For instance, government data show that telecom companies ramped up capital spending by 206 percent between 1994 and 2000, slightly above the 189 percent increase for the publicly traded companies. U.S. Census Bureau data are usually about 90 percent of the publicly traded company data, again likely reflecting that some firms in our sample do make capital investments outside of the U.S. The one anomaly between the two series occurs in 2001, the last year government data are available, when the government data show only a 7 percent drop in capital spending, whereas publicly traded companies register a 25 percent drop. Given what happened in the industry, the numerous reports of companies slashing capital spending, various financial indicators of the industry, what happened to revenues of companies that make communications gear, and the number of bankruptcies, the true drop in investment spending could be much larger than the figures reported by the Census Bureau.

12. Based on results from the first half of 2003, it is likely that capital spending for these companies increased in 2003 to over $55 billion.

13. According to the 1998 ACES, the communications industry spent 72 percent of its capital expenditures on information processing equipment. Additionally, the 1997 Capital Flows Table suggests that, of capital equipment spending by communications firms, 62 percent is doled out on communications equipment, 9 percent on computers, and 12 percent on software.

14. The decompositions presented in Figure 5 are based on several assumptions, so they should not be taken literally. Nonetheless, the results that telecom service firms would have accounted for a disproportionate share in the 2000/2001 swing in IT investment is robust to a wide range of alternative assumptions.

5. Changes in IT Service Lives

Most investment models assume depreciation is constant over time, that is, that capital goods are discarded according to a fixed schedule. These assumptions about fixed retirement schedules are made because there is a lack of information otherwise.[15] For IT goods, there were three events in the 1990s and 2000 that would have caused firms to shorten the service lives of their IT goods unexpectedly and then boost their IT investment. The first was the famous Y2K problem, which implied that some software and hardware would not function or would function improperly after December 31, 1999. As a result, firms had to replace some hardware and software sooner than they had expected. Second, unexpectedly large advances in software requirements during the second half of the 1990s induced firms to upgrade their computer hardware more quickly. Finally, a more nuanced argument has been put forth by Whelan (2000) that says that service lives are shortened when prices fall rapidly; during the late 1990s, computer prices fell extremely rapidly and arguably more rapidly than firms expected.[16] The three stories have a certain amount of credibility. What is unfortunate, though, is that it is difficult to quantify the importance of the two latter stories.

5.1. Preparations for Y2K

According to the Department of Commerce (1999), it is estimated that about $100 billion was spent on “fixing” the Y2K problem from 1995–2001.[17] Money was spent on fixing and testing software, replacing embedded chips that had the Y2K problem hard-wired, and replacing computers and software earlier than they would have been otherwise. Based on data in the Department of Commerce report, it is unlikely that fixing the Y2K problem had an appreciable effect on the time series pattern of aggregate IT spending.[18] For instance, in 1998, the year in which Y2K-related expenditures peaked, these expenses accounted for only an estimated $4.8 billion in software (compared to a total $140 billion that private businesses spent on software in that year) and $3.2 billion in hardware (compared to a total $165 billion that private businesses spent on IT hardware).[19]

5.2. Changes in PC Hardware Requirements

Perhaps more important in understanding the swings in IT investment than Y2K are the more general relationships between hardware and software, especially for PCs. During the 1990s, sales of PCs outstripped sales of midrange and mainframe computers, and PCs became a more important component of the IT capital stock. Also during this decade, there were tremendous changes in the technology of PCs and in their software. Windows-based operating systems and software became the norm, as did the ability to browse the Internet. In the face of these software changes, the replacement cycle of PCs may have changed. Some research suggests that the mean service life of personal computers shortened during the late 1990s (McKinsey 2001), which provided a boost to investment. During the more recent downturn, there were claims that the average service lives of PCs were lengthened, damping investment. However, just how long PCs (or other IT goods for that matter) are used before they are retired is not known; in most investment models and in calculations that estimate the contribution of IT capital to productivity growth, the replacement cycle is considered to be constant.[20]

The story is that during the late 1990s there was a surge in the hardware requirements needed for running various software programs. Since the recommended configurations for many computer operating systems are very similar to the recommended configuration for the latest version of Microsoft Office, I use that software package’s configurations to measure changes in business requirements for computing. The increases for minimum required hardware during the mid- to late 1990s are stark: between 1994 and 2000, RAM requirements increased at a 67 percent annual rate (from 2 megabytes to 64 megabytes), while hard disk requirement increased at a 90 percent annual rate (from 8 megabytes to 650 megabytes). Therefore, firms may have replaced their PCs more frequently during the late 1990s and less since then.

5.3. Faster Falling Prices, Faster Replacement

The other story of how service lives may vary over time is provided by Whelan (2000) who suggests that the faster the

15. Just how little is known about service lives is discussed in Doms, et al. (2003).

16. Another form of increased depreciation that may have been important during the 1990s was the depreciation of midrange and mainframe computers induced by the widening acceptance of the personal computer.

17. The Department of Commerce analysis uses estimates from the Federal Reserve and from IDC.

18. According to IDC, about 16.5 percent of these Y2K expenditures were on software and 10.9 percent were on hardware.

19. Another way the Y2K problem may have affected IT investment is that investment in the latter part of 1999 could have been postponed until 2000, until after the effects of Y2K were established. The magnitude of this swing is hard to quantify and is not likely to be large.

20. In calculating depreciation rates for capital stocks, there are several components, including the loss of value as a good ages and when a good is retired. For computers, it is the latter that is the most important, as shown by Doms et al. (2003).

Box 4
The Relationship between Technological Change and Prices

Although measuring the changes in the technology of goods (such as chip speed and horsepower) is interesting in its own right, perhaps a more important question to ask is, how much is our welfare improved by those technological changes? For instance, if Intel comes out with a new microprocessor that is twice as fast as the previous generation, or if General Motors comes out with a car that has twice the horsepower of last year's model, does that mean that we are twice as well-off? Probably not, especially if the faster computers and faster cars are more expensive than the older models.

One way to measure how much our society values technological change is by examining prices. Price indexes are supposed to answer the question of how much money we need today to be as well-off as we were, say, last year. For the economy as a whole, prices tend to increase, so we tend to need more money today than we did last year to maintain a given level of satisfaction. In contrast, prices for high-tech goods tend to fall, implying that not as much money is needed today to spend on IT goods to get the same level of performance that we got last year. In practice though, official price indexes for many high-tech goods likely understate price declines, that is, they understate how much better-off we are because of new and better products.

There are many other factors beyond technological change that affect prices as well, especially in the short-run, such as changes in profit margins, costs of supplies, and production efficiency. However, technological change appears to be the dominant force in the downward price trends for a wide variety of high-tech goods.

pace of price declines, the faster machines will be replaced. As I noted in Section 2, computer prices fell exceptionally quickly in the late 1990s. The thinking behind Whelan's research is that firms incur expenses in maintaining computers, an idea that has a lot of appeal based on estimates of support costs relative to the cost of computer hardware. Facing these costs, when new computer prices drop significantly, firms will be more inclined to buy a newer machine rather than incur the costs of maintaining an older one. The Whelan story reinforces the story that service lives may have decreased in the late 1990s (when computer prices fell the quickest) but have since increased.[21]

6. Technological Change and Prices

One of the driving factors in IT investment has been the rapid drop in the user cost of capital for IT goods, which is driven mainly by the drops in prices for IT goods. Going one step further, the drops in prices for IT are largely driven by technological change, as discussed in Box 4. Given the importance of prices and technological change, this section goes into more detail about what happened to prices and technology for the three components of IT investment.

In particular, one reason for going through this exercise is to try to understand better why prices for IT goods fell very quickly in the late 1990s, more quickly than they had earlier in the 1990s.[22] Did these rapid price declines in the late 1990s coincide with an increased pace of technological change, or did prices appear to fall for other reasons? Also, what has happened to the pace of technological change since then? The answer to the first question appears to be that the pace of technological change did pick up in the late 1990s, at least for certain types of IT products, helping to propel prices downward very quickly. The answer to the second question is less clear. Official prices for IT goods show some deceleration, and there are some areas where technological change may have slowed. However, the deceleration in IT prices is somewhat puzzling given that demand slowed (which usually puts downward pressure on prices) and prices for several types of semiconductors (important components of IT goods) continued to fall very quickly.

6.1. Computers

Given the importance of the prices of IT goods in understanding investment, it is not surprising that there has been some effort exerted in measuring prices for IT goods, much of it devoted to measuring prices for computers. According to the BEA, prices for computers and peripheral equipment fell at unusually high rates in the late 1990s, dropping an average of 21.0 percent per year

21. One way to think about the Whelan story through the user cost of capital framework presented in Box 2 is that the depreciation term is a function of the change-in-price term.

22. This quickening in the fall of prices likely had little effect on the predictions of the FRB/US model though, since IT investment responds slowly to price changes. Kiley (2001) performs a simulation where he holds prices of IT goods fixed at their 1995 level. This simulation shows that it takes several years for the change in the price path of IT goods to manifest itself in significantly lower IT investment.

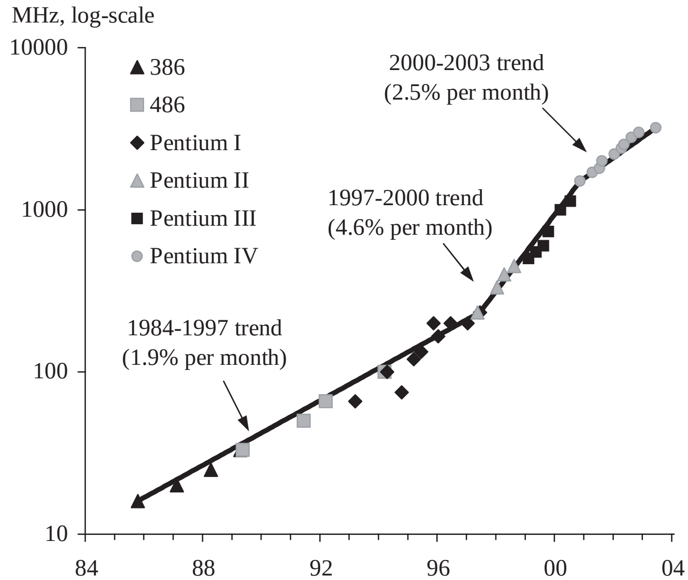
between 1995 and 2000 compared to 14.8 percent for the previous five years. Since 2000, computer prices have fallen at a more modest pace of 14.3 percent.

One approach to understanding computer prices is to examine the prices for the components that make up computers. Two of the more important components are rigid hard drives and semiconductors. Aizcorbe, Flamm, and Khurshid (2002) (hereafter referred to as AFK) conclude that much of the acceleration in the decline of computer prices in the late 1990s can be explained by what happened to the prices of semiconductors.[23] For instance, AFK show that prices for chips that are used in computers fell an average of 13.3 percent between 1992 and 1995, and fell an average of 47.3 percent between 1995 and 1999, reflecting sharp drops in the prices of microprocessors (MPUs) and memory chips.[24] Unfortunately, the data used in the AFK study stop in 1999.

There has been some research exploring why the declines in the prices for semiconductors picked up steam in the latter part of the 1990s. One explanation is that technological change accelerated in the late 1990s, which helped speed up price declines. To address this hypothesis, the International Technology Roadmap for Semiconductors (ITRS) (various issues during the 1990s and 2000s) has noted that the shrinking of the size of features on MPUs and dynamic random access memory (DRAM) chips did accelerate in the second half of the 1990s.[25] To use the terminology of the ITRS, the "technology node cycle," a rough measure for the length of time between the shrinking of features by 50 percent, shifted from three years to two years in the late 1990s and remained at two years through 2003.[26] The smaller the size of the features, the more chips can be etched onto a wafer, the greater the number of transistors per chip, and also the faster those chips are able to run.

As an example of the rate of technological change in this area, Figure 7 shows the evolution of Intel microprocessors by speed (as measured by megahertz) for different chip families. The speed of the chip is not equal to its processing power, especially when you compare the speeds of the chip across two processor families.[27] However, at least by this imperfect measure, it does appear that there was some pickup in the pace of technological change in the late 1990s. Between 1984 and mid-1997, the average speed increased at an average pace of 1.9 percent per month. From 1997 to December 2000, the pace more than doubled to 4.6 percent. Since then, the pace has fallen back to about 2.5 percent per month. Another dimension of microprocessors is the number of transistors. By this measure, between 1985 and 1997, the number of transistors per chip increased by about 32 percent per year. From 1997 to early 2004, the pace had picked up to almost 60 percent.[28]

FIGURE 7
PROCESSOR SPEED BY INTEL PROCESSOR FAMILY AND DATE OF INTRODUCTION (MEGAHERTZ)



Source: Intel.

23. McKinsey (2001) reaches a similar conclusion. McKinsey found that there was an acceleration in productivity in producing PC units, but that this acceleration had a fairly small effect on the acceleration of price declines of computers.

24. McKinsey (2001) claims that the change in the rate of price decline for MPUs is the main reason for the acceleration in price declines for semiconductors. However, AFK use a different, and likely better, measure for memory prices and that is why there is a difference in their conclusions.

25. In terms of technological innovations, these two classes of chips are often at the frontier. Two specific measures that are tracked and receive a fair amount of attention are gate length (for MPUs) and metal half pitch (for DRAMs and MPUs).

26. It is also interesting to note that this acceleration was somewhat unexpected. Throughout the 1990s, the ITRS projections for the pace of technological change consistently proved to be too conservative.

27. There are many ways to measure the processing power of chips. However, finding a consistent method over time is difficult, as new tests have been developed. Additionally, there are other dimensions to a chip's performance than its clock speed. For example, in the past several years, Intel has introduced a number of chips that contain features such as wireless networking and power saving. See "Why Speed Isn't Everything," *The Economist,* March 11, 2004.

28. Another reason why microprocessor prices fell especially quickly during the late 1990s is because profit margins may have shrunk. Aizcorbe, Oliner, and Sichel (2003) found that price-cost margins for Intel did indeed fall, and that the reductions accounted for about one-quarter of the acceleration in price declines. Yet another reason why MPU prices fell so quickly is that increased competition might have prompted firms to develop and release new products faster than they otherwise would have, a story touted by McKinsey (2001). Throughout the 1990s, the time it took Intel's primary rival, AMD, to produce a chip comparable to Intel's leading-edge chip steadily shrank. In response, the story goes, Intel made more frequent releases, increasing the share of chips being sold that were close to the leading edge.

Another major component of computers are rigid disk drives, an area where there has been tremendous technological change, but that, for some reason, does not get the attention that is bestowed upon semiconductors. In terms of technological change, according to Grochowski and Halem (2003) the areal density (how much information can be placed on a given area, such as megabytes per square inch) of drives doubled about every three years before 1991. Between 1991 and 1997, the areal density doubled about every two years, and since 1997 the areal density has been doubling every year. Unfortunately, what has been happening to prices during the 1990s and this decade is less than clear. According to the BLS, prices for computer storage follow a different pattern; prices for computer storage devices fell at 16–18 percent rates between 1995 and 1997, but prices fell only 9 percent on average from 1999 to 2000. However, according to Grochowski and Halem (2003), the declines in prices as measured in price per megabyte did accelerate in the late 1990s for desktop, mobile, and server hard drives. They find that not only has density been increasing sharply, but seek and access times have also been steadily decreasing.[29]

6.2. Communications Equipment

The 1990s witnessed tremendous technological change in communications equipment; computer networks grew ever more powerful, cellular phone networks were built out and upgraded, and there were tremendous advances in fiber-optic technology. In contrast to computer prices, however, prices for communications equipment fell only a touch, according to official statistics. Independent research has found potentially more believable results for the prices of communications equipment; Doms (2003) finds that prices fell considerably faster than the official measures and that the decline in prices appeared to pick up steam in the late 1990s and into 2000.

One reason for this acceleration in price declines was that prices for fiber-optic equipment started falling very quickly while the importance of fiber-optic equipment was increasing. Fiber-optic technology made several large advances in the 1990s, perhaps the most important of which was dense wave division multiplexing (DWDM). Before 1996, only a single light wave (also known as a channel) could be transmitted on a glass fiber. In 1996, a DWDM system could transmit eight channels simultaneously, with each channel carrying up to 2.5 gigabits per second (Gb/s), yielding a capacity of 20 Gb/s. By 2000, the capacity of DWDM systems increased twenty times; in 2000, there were DWDM systems that could transmit 160 channels simultaneously, producing a total capacity of 400 Gb/s. Therefore, between 1996 and 2000, the capacity of leading-edge DWDM systems increased at an annual rate of 115 percent. The pace of change has appeared to slow some since 2000; today there are systems that can carry 160 channels, each transmitting 10 Gb/s for a total capacity of 1.6 terabits per second, an average annual rate of increase of close to 60 percent.

Another area where technology improved rapidly during the 1990s was in local area network (LAN) equipment. Doms and Forman (2003) estimate that prices for LAN equipment fell at double digit rates during the latter half of the 1990s. Also, like computers, the prices of semiconductors that go into communications gear fell quickly. AFK estimate that prices for chips that are used in communications gear fell significantly faster during the late 1990s (23.7 percent) than during the early 1990s (3.4 percent). Unfortunately, the AFK study does not examine prices after 1999.

6.3. Software

Since 1990, software has consistently been the largest component of IT investment. Unfortunately, software has also been the least studied in terms of technological change and prices. This is especially unfortunate because there seems to be an incongruity in that software has gotten much better, but prices for software (as shown in Table 1) have not changed greatly. Although measurement problems exist for software prices used in national statistics, some independent information on software prices also has found that price changes have been fairly subdued compared to price changes for computers. For instance, Abel, Berndt, and White (2003) found that prices for Microsoft Office products fell an average of only about 5 percent per year between 1993 and 2001.

However, one must wonder if these results are consistent with the value that improvements in software have generated. A price index can show how much money is needed today to be as well-off as at some time in the past. During the 1990s, especially the latter half, there were monumental changes in PC software, though changes so far this

29. Not only is the cost per megabyte decreasing at rapid rates, but other factors that influence the total costs associated with hard disk drives have been falling as well, including power consumption and the physical volume of the drives. The trends of these series are described in Grochowski and Halem (2003).

decade seem to have slowed.[30] The primary PC operating system went through a series of changes, with Windows 95 (shipped in mass in 1996) ushering in a much better graphical user interface (GUI) than previous versions (Apple operating systems aside), and Windows 98 providing a more stable platform. PC programs that exploited the Windows GUI also garnered wider scale acceptance. Perhaps one of the most important technological revolutions in software was web browsers, which were first developed in the early 1990s but did not gain widespread acceptance until the latter half of the 1990s. Given these radical changes, how much money would have been required ten years ago to make us as well-off today in terms of software? According to the official data, the answer is that we would have needed only 8 percent more money in 1993 than we do today, which seems far off the mark.

Therefore, it could very well be the case that prices for software fell faster than the official data suggest, especially in the late 1990s when large advances in technology were made. However, the story of what has happened to innovation in PC software since the late 1990s is less clear. One anecdote reports that one-quarter of PCs still run Windows 98, an indication that there is at least one group of consumers that does not place much value on Microsoft's Windows XP offering in 2001; that is, the increment in technology between Windows 98 and Windows XP is not as great as the leaps from Windows 3.1 to Windows 95, and from Windows 95 to Windows 98. Looking ahead a little bit, Microsoft is not planning to update its operating system significantly until 2006. With all of that said, PC operating systems are just one small piece of the software pie, therefore caution should be used in extrapolating these observations too far.

7. Summary and Looking Ahead

The previous sections have laid out what happened to IT investment and what a fairly sophisticated model would have predicted for investment, followed by some cursory analysis of some common reasons given for the swings in investment. One of the primary reasons for going through these exercises is to provide some quantitative guidance as to what reasons seem the most likely, so that we may have a better idea of what lies ahead.

The most important message to take away from this analysis is that the main driver for real IT investment is prices; prices for IT goods have fallen considerably over time, in contrast to the tepid increases in prices for other investment goods. Prices for IT goods fell extremely fast in the late 1990s, pulled down by large drops in the prices of computers. Computer prices themselves reflect what happened to prices of their components, notably semiconductors and hard drives. The pace of decline in semiconductor prices picked up steam in the second half of the 1990s, reflecting very rapid rates of innovation in the semiconductor industry. The pace of innovation also picked up for hard drives. Elsewhere in the IT field, the pace of technological advances quickened in the area of communications equipment, especially for fiber-optic equipment and also, arguably, for computer software.

This paper also looked at some reasons that may have contributed to the large swings in IT investment around the turn of this century. For instance, the Y2K problem likely played only a minor role in the swings in IT investment. The dot-com boom and bust likely played a larger but still minor role. A sector that played a more significant role was the telecommunications sector, which was plagued by high expectations and a spectacular crash. The telecom crash placed a severe drag on IT investment in 2001 and again in 2002. Elsewhere in the economy, it is difficult to find excess ebullience in IT investment; in fact, the stellar productivity performance of the U.S. economy, especially in those sectors that invested heavily in IT goods, may suggest that firms, on average, did not overspend on IT.

Another reason for the large swings in IT investment could be that service lives of computers, especially personal computers, were shortened in the late 1990s in response to changes in the demands of software and also because of the rapid changes in the technology of computers themselves. So far this decade, service lives may have been extended once again, acting as a drag on IT investment. Although this story has some intuitive and anecdotal appeal, it is extremely difficult to quantify.

7.1. Looking Ahead

Technological change has been the driving force behind the high rates of investment in IT goods. Therefore, in looking at IT investment, it is important to think about what technological changes might lie ahead. One way to address this issue is to ask what factors generated the boom in innovation in the IT area and to ask to what extent those factors will be present in the future. Another method is to look at specific areas of technology and ask what innovations are likely to develop. Approaching the problem in both ways yields similar tentative conclusions: the future of innovation in IT looks fairly bright.

30. Unlike some semiconductors and communications gear, it is extremely difficult to measure technological changes in software. Measures of program size, say, in terms of lines of codes is not necessarily a good indicator, as large programs could simply be poorly written.

One reason for hope about future innovation in IT products is the amount of R&D that has been and is being spent. The latest official data from the National Science Foundation go through 2001. As seen in Table 2, R&D by companies in the IT industry grew sharply in the latter part of the 1990s and stood at record levels in 2001, totaling over $56 billion and making up almost one-third of all company-funded R&D. Based on reports, it appears that U.S. publicly traded companies did cut back on R&D some in 2002 (perhaps around 4 percent) and a bit further in 2003, but the level of R&D spending appears only to be a touch below the high levels posted in 2000.

Another hopeful sign is that the semiconductor industry expects to continue to make advances in the next several years, which in turn will help propel advances in computing and communication technologies. The ITRS, 2003 Edition, sponsored in part by the Semiconductor Industry Association, lays out what the industry expects in terms of advances and where major roadblocks may arise. The industry expects continued improvements throughout this decade, namely in the traditional areas of decreased feature size and increased performance. However, the pace of innovation may slow some. For certain chip features, the rate of decline in feature size may revert back to a three-year technology node cycle from a two-year cycle. Likewise, advances in storage technology are expected to continue at a very high rate well into the next decade, but perhaps not at the blistering pace that has been witnessed over the past several years (Grochowski and Halem 2003).

Another area of innovation that is receiving a tremendous amount of publicity is nanotechnology, an amorphous field that seems to include items such as very thin pieces of fiber-optic cable, small molecules that could be used in disease detection, new superconductors, solar cells, memory devices, and so on.[31] Although there has been a fair amount of attention given to nanotechnology, commercial products that use the technology are in short supply. Perhaps a word of caution is in order; carbon nanotubes once were touted as a potential replacement for steel and as an efficient conductor of electricity. However, since they were first developed in 1993, they have yet to be used in a widespread commercial application. The hype around nanotechnology resembles the hype around biotechnology over the past two decades; biotechnology has made some significant contributions to the health sciences, but it remains a small part of the economy and overall drug market.

Table 2
Company-Funded R&D Expenditures, 1997–2001
($ Billions)

	1997	1998	1999	2000	2001
IT equipment	25.0	26.4	21.3	29.4	34.9
Computers	7.7	8.3	4.1	5.2	5.2
Communications	2.8	8.4	5.8	11.1	15.2
Semiconductors	14.0	9.1	10.6	12.8	14.2
Other	0.5	0.6	0.8	0.3	0.3
IT services	10.2	12.0	14.9	17.5	21.7
Software	7.2	9.2	10.9	12.6	13.0
Computer design	3.0	2.9	4.0	4.9	8.7
Total IT R&D	35.2	38.4	36.2	46.9	56.5
Total R&D	133.6	145.0	160.2	180.4	181.6
IT share of total	26.4%	26.5%	22.6%	26.0%	31.2%

Sources: National Science Foundation and Department of Commerce (2003).

In terms of communications equipment, there are currently several struggles going on. One is related to extending the reach of long-haul networks to homes and businesses, the so-called "last mile" problem. Given the Gordian Knot that currently plagues the telecom regulatory environment, it is difficult to foresee when broadband services that exceed the current cable and DSL standards will become widespread. A second issue regarding the telecom industry is the evolution of wireless standards. There is far from universal agreement on what future networks will look like and when they will be deployed.

In summary, the future of IT investment looks bright, although perhaps not as bright as it did in the late 1990s. The most important force in IT investment has been the large drops in prices brought about by technological progress. There are several reasons to be optimistic about the future for technological progress in the IT area; firms continue to spend large sums on R&D, and rapid rates of innovation are expected to continue in several areas. No doubt there will be other areas as well where technological change will greatly reduce prices, and hence boost investment, for some time to come. Additionally, it appears that the economy is proving very adept at translating its IT investments into increased productivity.

31. See *The Economist*, "Beyond the Nanohype," March 13, 2003.

Appendix
Investment by the Telecom Service Industry

A number of factors contributed to the swings in investment in the telecom industry, including regulatory changes, new technology, and excess entry. As a first step in trying to understand what happened to the telecom service industry, each publicly traded company is placed into one of five categories: former Baby Bells (also known as incumbent local exchanges (ILECs)) competitive local exchanges (CLECs),[1] long-haul backbone providers (firms that specialized in deploying large-scale fiber-optic networks), long-distance companies (firms primarily in the long-distance voice and data business),[2] and wireless networks (cellular phone companies).[3]

Figure A.1 shows capital investment for each of these five categories between 1997 and 2002. An interesting note is that each of the five segments within the telecom service industry boosted capital spending between 1997 and 2000, only to be followed by sizable declines through 2002. The segment that has been the most consistent in its capital spending is the wireless networks; the nation is now criss-crossed with six nationwide wireless networks using three different technologies.

The two segments that epitomize overinvestment are the CLECs and the long-haul providers. Many CLECs entered the market after the 1996 Telecommunications Act, hoping to be able to lease equipment and facilities from the ILECs while providing services to businesses and consumers. The outlooks for this industry were hopeful, but for a variety of reasons many CLECs did not survive. From its peak in 2000, capital spending by CLECs fell by nearly 80 percent in 2002.

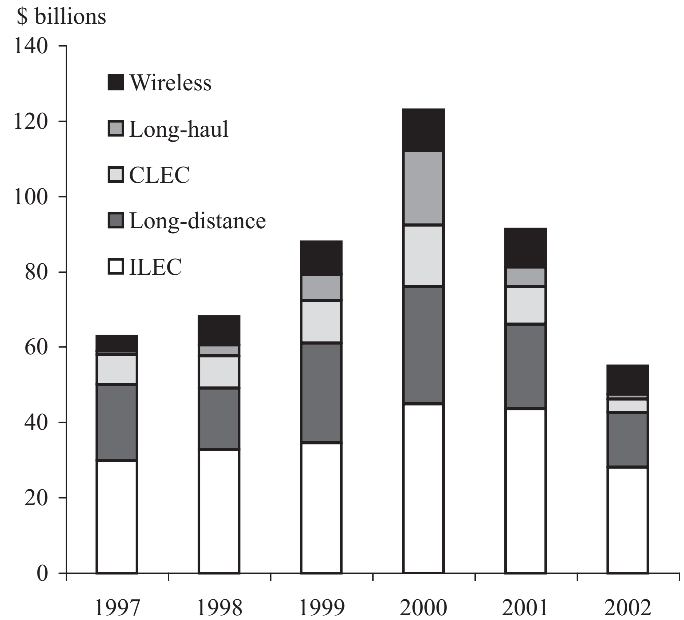
The segment that experienced the largest increase in capital spending in both percent and absolute terms was the long-haul industry, which also holds the distinction of having the largest decrease in both percent and absolute terms. The long-haul providers specialized primarily in deploying fiber-optic networks throughout the country and, in some cases, around the world. In the mid- to late 1990s and into 2000, there was significant entry into the market and massive increases in the amount of fiber that was laid in the ground. For instance, in 1990, there were four firms with nationwide fiber networks, but by 2000 there were ten.[4]

1. In this methodology, I use the CLEC category as a residual from the other four groups.

2. AT&T, MCI-Worldcom, and Sprint FON group are the three largest firms in the group.

3. Some firms straddle these groupings. For instance, Verizon is a traditional ILEC but also has the nation's largest wireless network. I classify each firm in the sample into the category where it received the most revenue.

FIGURE A.1
CAPITAL SPENDING BY TELECOMMUNICATIONS SERVICE PROVIDERS, BY TYPE OF PROVIDER



Additionally, in 1996 there were 143,000 route miles of fiber in the country, but by 2000 this had increased to 320,000.[5]

One reason for the massive increase in the capacity of the long-haul network was bullish expectations for future demand. For instance, a CEO of Level 3 Communications, a large long-haul firm, stated that Internet traffic would double every three to four months.[6] That didn't happen, and estimates are that demand (in terms of volume of data, not in terms of dollars spent) may be doubling every year, which is a significant increase but is substantially shy of expectations.[7,8] The high expectations were based in part on assumed rapid development and adoption of new technologies (such as deployment of high-speed cellular phone service) and widespread broadband access for homes and

4. A nationwide network is defined here as having more than 10,000 route miles of fiber.

5. This information came from KMI Research and from company reports.

6. Many people cited this statistic, although the original source is hard to verify. For a history of the use (misuse) of such statistics, see "Fallacies of the Tech Boom," *Wall Street Journal*, September 26, 2002.

7. Doubling every four months is the same as increasing by a factor of 8 per year, and doubling every three months is the same as increasing by a factor of 16 every year.

8. See Coffman and Odlyzko (2002) for an analysis of the estimates for Internet traffic.

businesses. However, the rollout of new technologies and the growth in broadband access has been slower than the industry anticipated.

Another reason why the industry overbuilt touches upon four areas of economics: network economics, patent races, large fixed costs, and technological change. In terms of network economics, a fiber network that reaches twenty points is more valuable than two separate networks that reach only ten points each—the whole is worth more than the sum of the pieces. Therefore, if a firm decides to build a fiber network, then it will build a large network. In terms of patent races, firms entered the market hoping to finish their networks before their competitors; the firm that completed its network first would, if expectations were correct, win the race. In this case, there can be too much duplication of effort. For example, Chicago and Minneapolis are each served by twenty long-haul firms, Kansas City by fifteen, and St. Louis by fourteen. In 1990, these cities each were served by about five carriers.

Another factor that contributed to the glut of fiber in the ground is that the marginal cost of fiber is small relative to the cost of laying a new fiber route; in other words, it would be much cheaper to lay additional strands of fiber today while trenches are open than to dig up the trenches again several years from now and lay some additional fiber lines. So, although the utilization rate is low, that does not imply that firms were irrational in the amount of fiber they installed. Finally, as discussed in Section 6.2, astronomical increases in the amount of information that could be transported over a piece of fiber in the late 1990s because of DWDM technology reduced the amount of fiber needed.

In summary then, the telecommunications sector contributed significantly to the boom and bust of IT investment (especially the bust) because of a wide array of factors, including extremely high expectations about future demand that were not met. Looking ahead, there is much confusion over what new technologies will become available and whether and when they will be deployed.

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