OECD Economics Department Working Papers No. 261

Raising the Speed Limit: US Economic Growth in the Information Age

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https://dx.doi.org/10.1787/561481176503

OECD

Unclassified **ECO/WKP(2000)34**

Organisation de Coopération et de Développement Economiques
Organisation for Economic Co-operation and Development

OLIS : 31-Oct-2000
Dist. : 09-Nov-2000

English text only

ECONOMICS DEPARTMENT

ECO/WKP(2000)34
Unclassified

Cancels & replaces the same document:
distributed 20-Oct-2000

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ABSTRACT/RÉSUMÉ

This paper examines the underpinnings of the successful performance of the US economy in the late 1990s. Relative to the early 1990s, output growth has accelerated by nearly two percentage points. We attribute this to rapid capital accumulation, a surge in hours worked, and faster growth of total factor productivity. The acceleration of productivity growth, driven by information technology, is the most remarkable feature of the US growth resurgence. We consider the implications of these developments for the future growth of the US economy.

JEL classification: O3, O4
Keywords: Productivity, economic growth, capital stock

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Ce document examine les facteurs qui ont contribués aux très bonnes performances de l'économie américaine à la fin des années 90. Par rapport au début des années 90, le taux de croissance a augmenté de près de deux points de pourcentage. Nous attribuons ceci à la croissance accrue du capital, une augmentation importante des heures travaillées et une croissance plus rapide de la productivité multifactorielle. Cette accélération de la croissance de la productivité, poussée par les technologies de l'information, est l'aspect le plus remarquable de la remontée de la croissance américaine. Nous prenons en considération les implications de ces développements pour la croissance future de l'économie américaine.

Classification JEL : O3, O4
*Mots-clés :*productivité, croissance économique, stock du capital

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RAISING THE SPEED LIMIT: US ECONOMIC GROWTH IN THE INFORMATION AGE

Dale W. Jorgenson and Kevin J. Stiroh[1]

I. Introduction

1. The continued strength and vitality of the US economy continues to astonish economic forecasters.[2] A consensus is now emerging that something fundamental has changed with "new economy" proponents pointing to information technology as the causal factor behind the strong performance of the US economy. In this view, technology is profoundly altering the nature of business, leading to permanently higher productivity growth throughout the economy. Skeptics argue that the recent success reflects a series of favorable, but temporary, shocks. This argument is buttressed by the view that the US economy behaves rather differently than envisioned by new economy advocates.[3]

2. While productivity growth, capital accumulation, and the impact of technology were once reserved for academic debates, the recent success of the US economy has moved these topics into popular discussion. The purpose of this paper is to employ well-tested and familiar methods to analyze important new information made available by the recent benchmark revision of the US National Income and Product Accounts (NIPA). We document the case for raising the speed limit – for upward revision of intermediate-term projections of future growth to reflect the latest data and trends.

3. The late 1990s have been exceptional in comparison with the growth experience of the US economy over the past quarter century. While growth rates in the 1990s have not yet returned to those of the golden age of the US economy in the l960s, the data nonetheless clearly reveal a remarkable transformation of economic activity. Rapid declines in the prices of computers and semi-conductors are well known and carefully documented, and evidence is accumulating that similar declines are taking place in the prices of software and communications equipment. Unfortunately, the empirical record is seriously

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1 . Jorgenson: Department of Economics, Harvard University, djorgenson@harvard.edu., (617) 495-0833. Stiroh: Banking Studies Function, Federal Reserve Bank of New York, kevin.stiroh@ny.frb.org, (212) 720-6633. We are indebted to Mun Ho for his comments and assistance with the industry and labor data. We are also grateful to Bob Arnold of CBO for helpful comments and discussions of the CBO's results and methods and Bruce Grimm and Dave Wasshausen of BEA for details on the BEA investment data and prices. Our thanks are due to Erwin Diewert, Robert Gordon, Steve Oliner, Dan Sichel, as well as seminar participants at the Brookings Panel on Economic Activity, the Federal Reserve Bank of New York, and the Federal Reserve Board for helpful comments and advice. Dave Fiore provided excellent research assistance. The views expressed in this paper are those of the authors only and do not necessarily reflect the views of the Federal Reserve Bank of New York or the Federal Reserve System.

2 . Labor productivity growth for the business sector averaged 2.7% for 1995-99, the four fastest annual growth rates in the 1990s, except for a temporary jump of 4.3% in 1992 as the economy exited recession (BLS (2000)).

3 . Stiroh (1999) critiques alternative new economy views, Triplett (1999) examines data issues in the new economy debate, and Gordon (1999b) provides an often-cited rebuttal of the new economy thesis.

incomplete, so much remains to be done before definitive quantitative assessments can be made about the complete role of these high-tech assets.

4. Despite the limitations of the available data, the mechanisms underlying the structural transformation of the US economy are readily apparent. As an illustration, consider the increasing role that computer hardware plays as a source of economic growth.[4] For the period 1959 to 1973, computer inputs contributed less than one-tenth of one percent to U.S. economic growth. Since 1973, however, the price of computers has fallen at historically unprecedented rates and firms and households have followed a basic principle of economics – they have substituted towards relatively cheaper inputs. Since 1995 the price decline for computers has accelerated, reaching nearly 28% per year from 1995 to 1998. In response, investment in computers has exploded and the growth contribution of computers increased more than five-fold to 0.46 percentage points per year in the late 1990s.[5] Software and communications equipment, two other information technology assets, contributed an additional 0.29 percentage points per year for 1995-98. Preliminary estimates through 1999 reveal further increases in these contributions for all three high-tech assets.

5. Next, consider the acceleration of average labor productivity (ALP) growth in the 1990s. After a 20-year slowdown dating from the early 1970s, ALP grew 2.4% per year for 1995-98, more than a percentage point faster than during 1990-95.[6] A detailed decomposition shows that capital deepening, the direct consequence of price-induced substitution and rapid investment, added 0.49 percentage points to ALP growth. Faster total factor productivity (TFP) growth contributed an additional 0.63 percentage points, largely reflecting technical change in the production of computers and the resulting acceleration in the price decline of computers. Slowing labor quality growth retarded ALP growth by 0.12 percentage points, relative to the early 1990s, a result of exhaustion of the pool of available workers.

6. Focusing more specifically on TFP growth, this was an anemic 0.34% per year for 1973-95, but accelerated to 0.99% for 1995-98. After more than twenty years of sluggish TFP growth, four of the last five years have seen growth rates near 1%. It could be argued this represents a new paradigm. According to this view, the diffusion of information technology improves business practices, generates spillovers, and raises productivity throughout the economy. If this trend is sustainable, it could revive the optimistic expectations of the 1960s and overcome the pessimism of The Age of Diminished Expectations, the title of Krugman’s (1990) influential book.

7. A closer look at the data, however, shows that gains in TFP growth can be traced in substantial part to information technology industries, which produce computers, semi-conductors, and other high-tech gear. The evidence is equally clear that computer-using industries like finance, insurance, and real estate (FIRE) and services have continued to lag in productivity growth. Reconciliation of massive high-tech

4 . Our work on computers builds on the path-breaking research of Oliner and Sichel (1994, 2000) and Sichel (1997, 1999), and our own earlier results, reported in Jorgenson and Stiroh (1995, 1999, 2000) and Stiroh (1998a). Other valuable work on computers includes Haimowitz (1998), Kiley (1999), and Whelan (1999). Gordon (1999a) provides valuable historical perspective on the sources of U.S. economic growth and Brynjolfsson and Yang (1996) review the micro evidence on computers and productivity.

5 . See Baily and Gordon (1988), Stiroh (1998a), Jorgenson and Stiroh (1999) and Department of Commerce (1999) for earlier discussions of relative price changes and input substitution in the high-tech areas.

6 . BLS (2000) estimates for the business sector show a similar increase from 1.6% for 1990-95 to 2.6% for 1995-98. See CEA (2000, pg. 35) for a comparison of productivity growth at various points in the economic expansions of the 1960s, 1980s, and 1990s.

investment and relatively slow productivity growth in service industries remains an important task for proponents of the new economy position.[7]

8. What does this imply for the future? The sustainability of growth in labor productivity is the key issue for future growth projections. For some purposes, the distinctions among capital accumulation and growth in labor quality and TFP may not matter, so long as ALP growth can be expected to continue. It is sustainable labor productivity gains, after all, that ultimately drive long-run growth and raise living standards.

9. In this respect, the recent experience provides grounds for caution, since much depends on productivity gains in high-tech industries. Ongoing technological gains in these industries have been a direct source of improvement in TFP growth, as well as an indirect source of more rapid capital deepening. Sustainability of growth, therefore, hinges critically on the pace of technological progress in these industries. As measured by relative price changes, progress has accelerated recently, as computer prices fell 28% per year for 1995-98 compared to 15% in 1990-95. There is no guarantee, of course, of continued productivity gains and price declines of this magnitude. Nonetheless, as long as high-tech industries maintain the ability to innovate and improve their productivity at rates comparable to their long-term averages, relative prices will fall and the virtuous circle of an investment-led expansion will continue.[8]

10. Finally, we argue that rewards from new technology accrue to the direct participants; first, to the innovating industries producing high-tech assets and, second, to the industries that restructure to implement the latest information technology. There is no evidence of spillovers from production of information technology to the industries that use this technology. Indeed, many of the industries that use information technology most intensively, like FIRE and services, show high rates of substitution of information technology for other inputs and relatively low rates of productivity growth. In part, this may reflect problems in measuring the output from these industries, but the empirical record provides little support for the “new economy” picture of spillovers cascading from information technology producers onto users of this technology.[9]

11. The paper is organized as follows. Section II describes our methodology for quantifying the sources of U.S. economic growth. We present results for the period 1959-1998, and focus on the “new economy” era of the late 1990s. Section III explores the implications of the recent experience for future growth, comparing our results to recent estimates produced by the Congressional Budget Office, the Council of Economic Advisors, and the Office of Management and Budget. Section IV moves beyond the aggregate data and quantifies the productivity growth at the industry level. Using methodology introduced by Domar (1961), we consider the impact of information technology on aggregate productivity. Section V concludes.

II. The recent US growth experience

12. The US economy has undergone a remarkable transformation in recent years with growth in output, labor productivity, and total factor productivity all accelerating since the mid-1990s. This growth

7 . See Gullickson and Harper (1999), Jorgenson and Stiroh (2000), and Section IV, below, for industry-level analysis.

8 . There is no consensus, however, that technical progress in computer and semi-conductor production is slowing. According to Fisher (2000), chip processing speed continues to increase rapidly. Moreover, the product cycle is accelerating as new processors are brought to market more quickly.

9 . See Dean (1999) and Gullickson and Harper (1999) for the BLS perspective on measurement error; Triplett and Bosworth (2000) provide an overview of measuring output in the service industries.

resurgence has led to a widening debate about sources of economic growth and changes in the structure of the economy. "New economy" proponents trace the changes to developments in information technology, especially the rapid commercialization of the Internet, that are fundamentally changing economic activity. "Old economy" advocates focus on lackluster performance during the first half of the 1990s, the increase in labor force participation and rapid decline in unemployment since 1993, and the recent investment boom.

13. Our objective is to quantify the sources of the recent surge in U.S. economic growth, using new information made available by the benchmark revision of the US National Income and Product Accounts (NIPA) released in October 1999, BEA (1999). We then consider the implications of our results for intermediate-term projections of U.S. economic growth. We give special attention to the rapid escalation in growth rates in the official projections, such as those by the Congressional Budget Office (CBO) and the Council of Economic Advisers (CEA). The CBO projections are particularly suitable for our purposes, since they are widely disseminated, well documented, and represent "best practice." We do not focus on the issue of inflation and do not comment on potential implications for monetary policy.

a) Sources of economic growth

14. Our methodology is based on the production possibility frontier introduced by Jorgenson (1966) and employed by Jorgenson and Griliches (1967). This captures substitutions among outputs of investment and consumption goods, as well inputs of capital and labor. We identify *information technology* (IT) with investments in computers, software, and communications equipment, as well as consumption of computer and software as outputs. The service flows from these assets are also inputs. The aggregate production function employed by Solow (1957, 1960) and, more recently by Greenwood, Hercowitz, and Krusell (1997), is an alternative to our model. In this approach a single output is expressed as a function of capital and labor inputs. This implicitly assumes, however, that investments in information technology are perfect substitutes for other outputs, so that relative prices do not change.

15. Our methodology is essential in order to capture two important facts about which there is general agreement. The first is that prices of computers have declined drastically relative to the prices of other investment goods. The second is that this rate of decline has recently accelerated. In addition, estimates of investment in software, now available in the NIPA, are comparable to investment in hardware. The new data show that the price of software has fallen relative to the prices of other investment goods, but more slowly than price of hardware. We examine the estimates of software investment in some detail in order to assess the role of software in recent economic growth. Finally, we consider investment in communications equipment, which shares many of the technological features of computer hardware.

i) Production possibility frontier

16. Aggregate output Y_t consists of investment goods I_t and consumption goods C_t. These outputs are produced from aggregate input X_t, consisting of capital services K_t and labor services L_t. We represent productivity as a "Hicks-neutral" augmentation A_t of aggregate input:[10]

$$(1) \qquad Y(I_t, C_t) = A_t \cdot X(K_t, L_t).$$

10 . It would be a straightforward change to make technology labor-augmenting or "Harrod-neutral," so that the production possibility frontier could be written: $Y(I, C) = X(K, AL)$. Also, there is no need to assume that inputs and outputs are separable, but this simplifies our notation.

The outputs of investment and consumption goods and the inputs of capital and labor services are themselves aggregates, each with many sub-components.

17. Under the assumptions of competitive product and factor markets, and constant returns to scale, growth accounting gives the share-weighted growth of outputs as the sum of the share-weighted growth of inputs and growth in *total factor productivity* (TFP):

$$\bar{w}_{I,t}\Delta \ln I_t + \bar{w}_{C,t}\Delta \ln C_t = \bar{v}_{K,t}\Delta \ln K_t + \bar{v}_{L,t}\Delta \ln L_t + \Delta \ln A_t \quad (2)$$,

where $\bar{w}_{I,t}$ is investment's average share of nominal output, $\bar{w}_{C,t}$ is consumption's average share of nominal output, $\bar{v}_{K,t}$ is capital's average share of nominal income, $\bar{v}_{K,t}$ is labor's average share of nominal income, $\bar{w}_{I,t} + \bar{w}_{C,t} = \bar{v}_{K,t} + \bar{v}_{L,t} = 1$, and Δ refers to a first difference. Note that we reserve the term *total factor productivity* for the augmentation factor in Equation (1).

18. Equation (2) enables us to identify the contributions of outputs as well as inputs to economic growth. For example, we can quantify the contributions of different investments, such as computers, software, and communications equipment, to the growth of output by decomposing the growth of investment among its sub-components. Similarly, we can quantify the contributions of different types of consumption, such as services from computers and software, by decomposing the growth of consumption. As shown in Jorgenson and Stiroh (1999), both computer investment and consumption of IT have made important contributions to U.S. economic growth in the 1990s. We also consider the output contributions of software and communications equipment as distinct high-tech assets. Similarly, we decompose the contribution of capital input to isolate the impact of computers, software, and communications equipment on input growth.

19. Rearranging Equation (2) enables us to present our results in terms of growth in *average labor productivity* (ALP), defined as $y_t = Y_t / H_t$, where Y_t is output, defined as an aggregate of consumption and investment goods, and $k_t = K_t / H_t$ is the ratio of capital services to hours worked H_t:

$$\Delta \ln y_t = \bar{v}_{K,t}\Delta \ln k_t + \bar{v}_{L,t}\left(\Delta \ln L_t - \Delta \ln H_t\right) + \Delta \ln A_t \quad (3)$$.

20. This gives the familiar allocation of ALP growth among three factors. The first is *capital deepening*, the growth in capital services per hour. Capital deepening makes workers more productive by providing more capital for each hour of work and raises the growth of ALP in proportion to the share of capital. The second term is the improvement in *labor quality*, defined as the difference between growth rates of labor input and hours worked. Reflecting the rising proportion of hours supplied by workers with higher marginal products, labor quality improvement raises ALP growth in proportion to labor's share. The third factor is TFP growth, which increases ALP growth on a point-for-point basis.

ii) Computers, software, and communications equipment

21. We now consider the impact of investment in computers, software, and communications equipment on economic growth. For this purpose we must carefully distinguish the *use* of information technology and the *production* of information technology.[11] For example, computers themselves are an

11 . Baily and Gordon (1988), Griliches (1992), Stiroh (1998a), Jorgenson and Stiroh (1999), Whelan (1999), and Oliner and Sichel (2000) discuss the impact of investment in computers from these two perspectives.

output from one industry (the computer-producing industry, Commercial and Industrial Machinery), and computing services are inputs into other industries (computer-using industries like Trade, FIRE, and Services).

22. Massive increases in computing power, like those experienced by the US economy, therefore reflect two effects on growth. First, as the production of computers improves and becomes more efficient, more computing power is being produced from the same inputs. This raises overall productivity in the computer-producing industry and contributes to TFP growth for the economy as a whole. Labor productivity also grows at both the industry and aggregate levels.[12]

23. Second, the rapid accumulation of computers leads to input growth of computing power in computer-using industries. Since labor is working with more and better computer equipment, this investment increases labor productivity. If the contributions to output are captured by the effect of capital deepening, aggregate TFP growth is unaffected. As Baily and Gordon (1988) remark, "there is no shift in the user firm's production function (pg. 378)," and thus no gain in TFP. Increasing deployment of computers increases TFP only if there are spillovers from the production of computers to production in the computer-using industries, or if there are measurement problems associated with the new inputs.

24. We conclude that rapid growth in computing power affects aggregate output through both TFP growth and capital deepening. Progress in the technology of computer production contributes to growth in TFP and ALP at the aggregate level. The accumulation of computing power in computer-using industries reflects the substitution of computers for other inputs and leads to growth in ALP. In the absence of spillovers this growth does not contribute to growth in TFP.

25. The remainder of this section provides empirical estimates of the variables in Equations (1) through (3). We then employ Equations (2) and (3) to quantify the sources of growth of output and ALP for 1959-1998 and various sub-periods.

b) Output

26. Our output data are based on the most recent benchmark revision of NIPA.[13] Real output Y_t is measured in chained 1996 dollars, and $P_{Y,t}$ is the corresponding implicit deflator. Our output concept is similar, but not identical, to one used in the Bureau of Labor Statistics (BLS) productivity program. Like BLS, we exclude the government sector, but unlike BLS we include imputations for the service flow from consumers' durables and owner-occupied housing. These imputations are necessary to preserve comparability between durables and housing and also enable us to capture the important impact of information technology on households.

27. Our estimate of current dollar, private output in 1998 is \$8,013B, including imputations of \$740B that primarily reflect services of consumers' durables.[14] Real output growth was 3.63% for the full period,

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12. Triplett (1996) points out that much of decline of computer prices reflects falling semi-conductor prices. If all inputs are correctly measured for quality change, therefore, much of the TFP gains in computer production are rightly pushed back to TFP gains in semi-conductor production since semi-conductors are a major intermediate input in the production of computers. See Flamm (1993) for early estimates on semi-conductor prices. We address this further in Section IV.

13. See Appendix A for details on our source data and methodology for output estimates.

14. Current dollar NIPA GDP in 1998 was \$8,759.9B. Our estimate of \$8,013B differs due to total imputations (\$740B), exclusion of general government and government enterprise sectors (\$972B and \$128B, respectively, and exclusion of certain retail taxes (\$376B).

compared to 3.36% for the official GDP series. This difference reflects both our imputations and our exclusion of the government sectors in the NIPA data. Appendix Table A-1 presents the current dollar value and corresponding price index of total output and the IT assets – investment in computers I_c, investment in software I_s, investment in communications equipment I_m, consumption of computers and software C_c, and the imputed service flow from consumers' computers and software, D_c.

28. The most striking feature of these data is the enormous price decline for computer investment, 18% per year from 1960 to 1995 (Chart 1). Since 1995 this decline has accelerated to 27.6% per year. By contrast the relative price of software has been flat for much of the period and only began to fall in the late 1980s. The price of communications equipment behaves similarly to the software price, while consumption of computers and software shows declines similar to computer investment. The top panel of Table 1 summarizes the growth rates of prices and quantities for major output categories for 1990-95 and for 1995-98.

29. In terms of current dollar output, investment in software is the largest IT asset, followed by investment in computers and communications equipment (Chart 2). While business investments in computers, software, and communications equipment are by far the largest categories, households have spent more than $20B per year on computers and software since 1995, generating a service flow of comparable magnitude.

c) Capital stock and capital services

30. This section describes our capital estimates for the US economy from 1959 to 1998.[15] We begin with investment data from the Bureau of Economic Analysis, estimate capital stocks using the perpetual inventory method, and aggregate capital stocks using rental prices as weights. This approach, originated by Jorgenson and Griliches (1967), is based on the identification of rental prices with marginal products of different types of capital. Our estimates of these prices incorporate differences in asset prices, service lives and depreciation rates, and the tax treatment of capital incomes.[16]

31. We refer to the difference between growth in capital services and capital stock as the growth in *capital quality* $q_{K,t}$; this represents substitution towards assets with higher marginal products.[17] For example, the shift toward IT increases the quality of capital, since computers, software, and communications equipment have relatively high marginal products. Capital stock estimates, like those originally employed by Solow (1957), fail to account for this increase in quality.

32. We employ a broad definition of capital, including tangible assets such as equipment and structures, as well as consumers' durables, land, and inventories. We estimate a service flow from the installed stock of consumers' durables, which enters our measures of both output and input. It is essential to include this service flow, since a steadily rising proportion is associated with investments in IT by the household sector. In order to capture the impact of information technology on U.S. economic growth,

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15 . See Appendix B for details on theory, source data, and methodology for capital estimates.

16 . Jorgenson (1996) provides a recent discussion of our model of capital as a factor of production. BLS (1983) describes the version of this model employed in the official productivity statistics. Hulten (2000) provides a review of the specific features of this methodology for measuring capital input and the link to economic theory.

17 . More precisely, growth in capital quality is defined as the difference between the growth in capital services and the growth in the average of the current and lagged stock. Appendix B provides details. We use a geometric depreciation rate for all reproducible assets, so that our estimates are not identical to the wealth estimates published by BEA (1998b).

investments by business and household sectors as well as the services of the resulting capital stocks must be included.

33. Our estimate of capital stock is $26T in 1997, substantially larger than the $17.3T in fixed private capital estimated by BEA (1998b). This difference reflects our inclusion of consumer's durables, inventories, and land. Our estimates of capital stock for comparable categories of assets are quite similar to those of BEA. Our estimate of fixed private capital in 1997, for example, is $16.8T, almost the same as that of BEA. Similarly, our estimate of the stock of consumers' durables is $2.9T, while BEA's estimate is $2.5T. The remaining discrepancies reflect our inclusion of land and inventories. Appendix Table B-1 list the component assets and 1998 investment and stock values; Table B-2 presents the value of capital stock from 1959 to 1998, as well as price indices for total capital and IT assets.

34. The stocks of IT business assets (computers, software, and communications investment equipment), as well as consumers' purchases of computers and software, have grown dramatically in recent years, but remain relatively small. In 1998, combined IT assets accounted for only 3.4% of tangible capital, and 4.6% of reproducible, private assets.

35. We now move to estimates of capital services flows, where capital stocks of individual assets are aggregated using rental prices as weights. Appendix Table B-3 presents the current dollar service flows and corresponding price indexes for 1959-98, and the second panel of Table 1 summarizes the growth rates for prices and quantities of inputs for 1990-95 and 1995-98.

36. There is a clear acceleration of growth of aggregate capital services from 2.8% per year for 1990-95 to 4.8% for 1995-98. This is largely due to rapid growth in services from IT equipment and software, and reverses the trend toward slower capital growth through 1995. While information technology assets are only 11.2% of the total, the service shares of these assets are much greater than the corresponding asset shares. In 1998 capital services are only 12.4% of capital stocks for tangible assets as a whole, but services are 40.0% of stocks for information technology. This reflects the rapid price declines and high depreciation rates that enter into the rental prices for information technology.

37. Chart 3 highlights the rapid increase in the importance of IT assets, reflecting the accelerating pace of relative price declines. In the 1990s, the service price for computer hardware fell 14.2% per year, compared to an increase of 2.2% for non-information technology capital. As a direct consequence of this relative price change, computer services grew 24.1%, compared to only 3.6% for the services of non-IT capital in the 1990s. The current dollar share of services from computer hardware reached nearly 3.5% of all capital services in 1998.[18]

38. The rapid accumulation of software, however, appears to have different origins. The price of software investment has declined much more slowly, -1.7% per year for software versus -19.5% for computer hardware for 1990 to 1998. These differences in investment prices lead to a much slower decline in service prices for software and computers, -1.6% versus -14.2%. Nonetheless, firms have been accumulating software quite rapidly, with real capital services growing 13.3% per year in the 1990s. While lower than the 24.1% growth in computers, software growth is much more rapid than growth in other forms of tangible capital. Complementarity between software and computers is one possible explanation.

18 . Tevlin and Whelan (1999) provide empirical support for this explanation, reporting that computer investment is particularly sensitive to the cost of capital, so that the rapid drop in service prices can be expected to lead to large investment response.

Firms respond to the decline in relative computer prices by accumulating computers and investing in complementary inputs like software to put the computers into operation.[19]

39. A competing explanation is that the official price indexes used to deflate software investment omit a large part of true quality improvements. This would lead to a substantial overstatement of price inflation and a corresponding understatement of real investment, capital services, and economic growth. According to Moulton, Parker, and Seskin (1999) and Parker and Grimm (2000), only prices for prepackaged software are calculated from constant-quality price deflators based on hedonic methods. Prices for business own-account software are based on input-cost indexes, which implicitly assume no change in the productivity of computer programmers. Custom software prices are a weighted average of prepackaged software and own-account software, with an arbitrary 75% weight for business own-account software prices. Thus, the price deflators for nearly two-thirds of software investment are estimated under the maintained assumption of no gain in productivity.[20] If the quality of own-account and custom software is improving at a pace even remotely close to packaged software, this implies a large understatement in investment in software.

40. Although the price decline for communications equipment during the 1990s is comparable to that of software, as officially measured in the NIPA, investment has grown at a rate that is more in line with prices. However, there are also possible measurement biases in the pricing of communications equipment. The technology of switching equipment, for example, is similar to that of computers; investment in this category is deflated by a constant-quality price index developed by BEA. Conventional price deflators are employed for transmission gear, such as fiber-optic cables, which also appear to be declining rapidly in price. This could lead to an underestimate of the rate of growth in communications equipment investment, capital stock, and capital services, as well as an overestimate of the rate of inflation.[21] We return to this issue at the end of Section II.

d) Measuring labor services

41. This section describes our estimates of labor input for the US economy from 1959 to 1998. We begin with individual data from the Census of Population for 1970, 1980, and 1990, as well as the annual Current Population Surveys. We estimate constant quality indexes for labor input and its price to account for heterogeneity of the workforce across sex, employment class, age, and education levels. This follows the approach of Jorgenson, Gollop and Fraumeni (1987), whose estimates have been revised and updated by Ho and Jorgenson (1999).[22]

42. The distinction between labor input and labor hours is analogous to the distinction between capital services and capital stock. Growth in labor input reflects the increase in labor hours, as well as changes in the composition of hours worked as firms substitute among heterogeneous types of labor. We define the growth in labor quality as the difference between the growth in labor input and hours worked.

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19 . An econometric model of the responsiveness of different types of capital services to own- and cross-price effects could be used to test for complementarity, but this is beyond the scope of the paper.

20 . According to Parker and Grimm (2000), total software investment of $123.4B includes $35.7B in prepackaged software, $42.3B in custom software, and $45.4B in own-account software in 1998. Applying the weighting conventions employed by BEA, this implies $46.3B=$35.7B+0.25*$42.3B, or 38% of the total software investment, is deflated with explicit quality adjustments.

21 . Grimm (1997) presents hedonic estimates for digital telephone switches and reports average price declines of more than 10% per year from 1985 to 1996.

22 . Appendix C provides details on the source data and methodology.

Labor quality reflects the substitution of workers with high marginal products for those with low marginal products, while the growth in hours employed by Solow (1957) and others does not capture this substitution. Appendix Table C-1 presents our estimates of labor input, hours worked, and labor quality.

43. Our estimates show the value of labor expenditures to be $4,546B in 1998, roughly 57% of the value of output. This value share accurately reflects the NIPA measure of output and our imputations for capital services. If we exclude these imputations, labor's share rises to 62%, in line with conventional estimates. As shown in Table 1, the growth of the index of labor input L_t appropriate for our model of production in Equation (1) accelerated to 2.8% for 1995-98, from 2.0% for 1990-95. This is primarily due to the growth of hours worked, which rose from 1.4% for 1990-95 to 2.4% for 1995-98, as labor force participation increased and unemployment rates plummeted.[23]

44. The growth of labor quality decelerated in the late 1990s, from 0.65% for 1990-95 to 0.43% for 1995-98. This slowdown captures well-known underlying demographic trends in the composition of the work force, as well as exhaustion of the pool of available workers as unemployment rates have steadily declined. Projections of future economic growth that omit labor quality, like those of CBO, implicitly incorporate changes in labor quality into measured TFP growth. This reduces the reliability of projections of future economic growth. Fortunately, this is easily remedied by extrapolating demographic changes in the work force in order to reflect foreseeable changes in composition by characteristics of workers such as age, sex, and educational attainment.

e) Quantifying the sources of growth

45. Table 2 presents results of our growth accounting decomposition based on Equation (2) for the period 1959 to 1998 and various sub-periods, as well as preliminary estimates through 1999. As in Jorgenson and Stiroh (1999), we decompose economic growth by both output and input categories in order to quantify the contribution of information technology (IT) to investment and consumption outputs, as well as capital and consumers' durable inputs. We extend our previous treatment of the outputs and inputs of computers by identifying software and communications equipment as distinct IT assets.

46. To quantify the sources of IT-related growth more explicitly, we employ the extended production possibility frontier:

$$(4) \qquad Y(Y_n, C_c, I_c, I_s, I_m, D_c) = A \cdot X(K_n, K_c, K_s, K_m, D_n, D_c, L)$$

where outputs include computer and software consumption C_c, computer investment I_c, software investment I_s, telecommunications investment I_m, the services of consumers' computers and software D_c, and other outputs Y_n, Inputs include the capital services of computers K_c, software K_s, telecommunications equipment K_m, and other capital assets K_n, services of consumers' computers and software D_c and other durables D_n, and labor input L.[24] As in Equation (1), total factor productivity is denoted by A and represents the ability to produce more output from the same inputs. Time subscripts have been dropped for convenience.

47. The corresponding extended growth accounting equation is:

23 . By comparison, BLS (2000) reports growth in business hours of 1.2% for 1990-95 and 2.3% for 1995-98. The slight discrepancies reflect our methods for estimating hours worked by the self-employed, as well as minor differences in the scope of our output measure

24 . Note we have broken broadly defined capital into tangible capital services, K, and consumers' durable services, D.

$$(5)\quad \begin{aligned} &\overline{w}_{Yn}\Delta\ln Y_n + \overline{w}_{Cc}\Delta\ln C_c + \overline{w}_{Ic}\Delta\ln I_c + \overline{w}_{Is}\Delta\ln I_s + \overline{w}_{\mathrm{Im}}\Delta\ln I_m + \overline{w}_{Dc}\Delta\ln D_c = \\ &\overline{v}_{Kn}\Delta\ln K_n + \overline{v}_{Kc}\Delta\ln K_c + \overline{v}_{Ks}\Delta\ln K_s + \overline{v}_{Km}\Delta\ln K_m + \overline{v}_{Dn}\Delta\ln D_n + \overline{v}_{Dc}\Delta\ln D_c + \overline{v}_L\Delta\ln L + \Delta\ln A \end{aligned}$$

where $\overline{w}$ and $\overline{v}$ denote average shares in nominal income for the subscripted variable $\overline{w}_{Yn} + \overline{w}_{Cc} + \overline{w}_{Ic} + \overline{w}_{Is} + \overline{w}_{\mathrm{Im}} + \overline{w}_{Dc} = \overline{v}_{Kn} + \overline{v}_{Kc} + \overline{v}_{Ks} + \overline{v}_{Km} + \overline{v}_{Dn} + \overline{v}_{Dc} + \overline{v}_L = 1$, and we refer to a share-weighted growth rate as the *contribution* of an input or output.

i) Output growth

48. We first consider the sources of output growth for the entire period 1959 to 1998. Capital services make the largest growth contribution of 1.8 percentage point (1.3 percentage points from business capital and 0.5 from consumers' durable assets), labor services contribute 1.2 percentage points, and TFP growth is responsible for only 0.6 percentage points. Input growth is the source of nearly 80 percent of U.S. growth over the past 40 years, while TFP has accounted for approximately one-fifth. Chart 4 highlights this result by showing the relatively small growth contribution of the TFP residual in each sub-period.

49. More than three-quarters of the contribution of broadly defined capital reflects the accumulation of capital stock, while increased labor hours account for slightly less than three-quarters of labor's contribution. The quality of both capital and labor have made important contributions, 0.45 percentage points and 0.32 percentage points per year, respectively. Accounting for substitution among heterogeneous capital and labor inputs is therefore an important part of quantifying the sources of economic growth.

50. A look at the US economy before and after 1973 reveals some familiar features of the historical record. After strong output and TFP growth in the 1960s and early 1970s, the US economy slowed markedly through 1990, with output growth falling from 4.3% to 3.1% and TFP growth falling almost two-thirds of a percentage point from 1.0% to 0.3%. Growth in capital inputs also slowed, falling from 5.0% for 1959-73 to 3.8% for 1973-90, which contributed to sluggish ALP growth, 2.9% for 1959-73 to 1.4% for 1973-90.

51. We now focus on the period 1995-98 and highlight recent changes.[25] Relative to the early 1990s, output growth has increased by nearly two percentage points. The contribution of capital jumped by 1.0 percentage point, the contribution of labor rose by 0.4 percentage points, and TFP growth accelerated by 0.6 percentage point. ALP growth rose 1.0 percentage point. The rising contributions of capital and labor encompass several well-known trends in the late 1990s. Growth in hours worked accelerated as labor markets tightened, unemployment fell to a 30-year low, and labor force participation rates increased.[26] The contribution of capital reflects the investment boom of the late 1990s as businesses poured resources into plant and equipment, especially computers, software, and communications equipment.

52. The acceleration in TFP growth is perhaps the most remarkable feature of the data. After averaging only 0.34% per year from 1973 to 1995, the acceleration of TFP to 0.99% suggests massive

25 . Table 2 also presents preliminary results for the more recent period 1995-99, where the 1999 numbers are based on the estimation procedure described in Appendix E, rather than the detailed model described above. The results for 1995-98 and 1995-99 are quite similar; we focus our discussion on the period 1995-98.

26 . See Katz and Krueger (1999) for explanations for the strong performance of the US labor market, including demographic shifts toward a more mature labor force, a rise in the prison age population, improved efficiency in labor markets, and the "weak backbone hypothesis" of worker restraint.

improvements in technology and increases in the efficiency of production. While the resurgence in TFP growth in the 1990s has yet to surpass periods of the 1960s and early 1970s, more rapid TFP growth is critical for sustained growth at higher rates.

53. Charts 5 and 6 highlight the rising contributions of information technology (IT) outputs to U.S. economic growth. Chart 5 shows the breakdown between IT and non-IT outputs for various sub-periods from 1959 to 1998, while Chart 6 decomposes the contribution of IT outputs into its components. Although the role of IT has steadily increased, Chart 5 shows that the recent investment and consumption surge nearly doubled the output contribution of IT for 1995-98 relative to 1990-95. Chart 6 shows that computer investment is the largest single IT contributor in the late 1990s, and that consumption of computers and software is becoming increasingly important as a source of output growth.

54. Charts 7 and 8 present a similar decomposition of the role of IT as an input into production, where the contribution is rising even more dramatically. Chart 7 shows that the capital and consumers' durable contribution from IT increased rapidly in the late 1990s, and now accounts for more two-fifths of the total growth contribution from broadly defined capital. Chart 8 shows that computer hardware is also the single largest IT contributor on the input side, which reflects the growing share and rapid growth rates of the late 1990s.

55. The contribution of computers, software, and communications equipment presents a different picture from Jorgenson and Stiroh (1999) for both data and methodological reasons. First, the BEA benchmark revision has classified software as an investment good. While software is growing more slowly than computers, the substantial nominal share of software services has raised the contribution of information technology. Second, we have added communications equipment, also a slower growing component of capital services, with similar effects. Third, we now incorporate asset-specific revaluation terms in all rental price estimates. Since the acquisition prices of computers are steadily falling, asset-specific revaluation terms have raised the estimated service price and increased the share of computer services. Finally, we have modified our timing convention and now assume that capital services from individual assets are proportional to the average of the current and lagged stock. For assets with relatively short service lives like IT, this is a more reasonable assumption than in our earlier work, which assumed that it took a full year for new investment to become productive.[27]

56. This large increase in the growth contribution of computers and software is consistent with recent estimates by Oliner and Sichel (2000), although their estimate of contribution is somewhat larger. They report that computer hardware and software contributed 0.93 percentage points to growth for 1996-99, while communications contributed another 0.15. The discrepancy primarily reflects our broader output concept, which lowers the input share of these high-tech assets, and also minor differences in tax parameters and stock estimates. Whelan (1999) also reports a larger growth contribution of 0.82 percentage points from computer hardware for 1996-98. The discrepancy also reflects our broader output concept. In addition, Whelan (1999) introduces a new methodology to account for retirement and support costs that generates a considerably larger capital stock and raises the input share and the growth contribution from computer capital.

57. Despite differences in methodology and data sources among studies, a consensus is building that computers are having a substantial impact on economic growth.[28] What is driving the increase in the contributions of computers, software, and communications equipment? As we argued in Jorgenson and

27 . We are indebted to Dan Sichel for very helpful discussions of this timing convention.

28 . Oliner and Sichel (2000) provide a detailed comparison of the results across several studies of computers and economic growth.

Stiroh (1999), price changes lead to substitution toward capital services with lower relative prices. Firms and consumers are responding to relative price changes.

58. Table 1 shows the acquisition price of computer investment fell nearly 28% per year, the price of software fell 2.2%, and the price of communications equipment fell 1.7% during the period 1995-98, while other output prices rose 2.0%. In response to these price changes, firms accumulated computers, software, and communications equipment more rapidly than other forms of capital. Investment other than information technology actually declined as a proportion of private domestic product. The story of household substitution toward computers and software is similar. These substitutions suggest that gains of the computer revolution accrue to firms and households that are adept at restructuring activities to respond to these relative price changes.

ii) Average labor productivity growth

59. To provide a different perspective on the sources of economic growth we can focus on ALP growth. By simple arithmetic, output growth equals the sum of hours growth and growth in labor productivity.[29] Table 3 shows the output breakdown between growth in hours and ALP for the same periods as in Table 2. For the period 1959-1998, ALP growth was the predominant determinant of output growth, increasing just over 2% per year for 1959-98, while hours increased about 1.6% per year. We then examine the changing importance of the factors determining ALP growth. As shown in Equation (3), ALP growth depends on a capital deepening effect, a labor quality effect, and a TFP effect.

60. Chart 9 shows the importance of each factor, revealing the well-known productivity slowdown of the 1970s and 1980s, and highlighting the acceleration of labor productivity growth in the late 1990s. The slowdown through 1990 reflects less capital deepening, declining labor quality growth, and decelerating growth in TFP. The growth of ALP slipped further during the early 1990s with the serious slump in capital deepening only partly offset by a revival in the growth of labor quality and an up-tick in TFP growth. Slow growth in hours combined with slow ALP growth during 1990-95 to produce a further slide in the growth of output. This stands out from previous cyclical recoveries during the postwar period, when output growth accelerated during the recovery, powered by more rapid hours and ALP growth.

61. For the most recent period of 1995-98, strong output growth reflects growth in labor hours and ALP almost equally. Comparing 1990-95 to 1995-98, output growth accelerated by nearly 2 percentage points due to a 1 percentage point increase in hours worked, and a 1.0 percentage point increase in ALP growth.[30] Chart 9 shows the acceleration in ALP growth is due to capital deepening from the investment boom, as well as faster TFP growth. Capital deepening contributed 0.49 percentage points to the acceleration in ALP growth, while acceleration in TFP growth added 0.63 percentage points. Growth in labor quality slowed somewhat as growth in hours accelerated. This reflects the falling unemployment rate and tightening of labor markets as more workers with relatively low marginal products were drawn into the workforce. Oliner and Sichel (2000) also show a decline in the growth contribution of labor quality in the late 1990s, from 0.44 for 1991-95 to 0.31 for 1996-99.

62. Our decomposition also throws some light on the hypothesis advanced by Gordon (1999b), who argues the vast majority of recent ALP gains are due to the production of IT, particularly computers, rather than the use of IT. As we have already pointed out, more efficient IT-production generates aggregate TFP growth as more computing power is produced from the same inputs, while IT-use affects ALP growth via

29 . See Krugman (1997) and Blinder (1997) for a discussion of the usefulness of this relationship.

30 . BLS (2000) shows similar trends for the business sector with hours growth increasing from 1.2% for 1990-95 to 2.3% for 1995-98, while ALP increased from 1.58% to 2.63%.

capital deepening. In recent years, acceleration of TFP growth is a slightly more important factor in the acceleration of ALP growth than capital deepening. Efficiency gains in computer production are important part of aggregate TFP growth, as Gordon's results on ALP suggest. We return to this issue in Section III.

iii) Total factor productivity growth

63. Finally, we consider the remarkable performance of U.S. TFP growth in recent years. After maintaining an average rate of 0.33% for the period 1973-90, TFP growth rose to 0.36% for 1990-95 and then vaulted to 0.99% per year for 1995-98. This jump is a major source of growth in output and ALP for the US economy (Charts 4 and 9). While TFP growth for the 1990s has yet to attain the peaks of some periods in the golden age of the 1960s and early 1970s, the recent acceleration suggests that the US economy may be recuperating form the anemic productivity growth of the past two decades. Of course, caution is warranted until more historical experience is available.

64. As early as Domar (1961), economists have utilized a multi-industry model of the economy to trace aggregate productivity growth to its sources at the level of individual industries. Jorgenson, Gollop, and Fraumeni (1987) and Jorgenson (1990) have employed this model to identify the industry-level sources of growth. More recently, Gullickson and Harper (1999) and Jorgenson and Stiroh (2000) have used the model for similar purposes. We postpone more detailed consideration of the sources of TFP growth until we have examined the implications of the recent growth resurgence for intermediate-term projections.

f) Alternative growth accounting estimates

65. Tables 1 through 3 and Charts 1 through 9 report our primary results using the official data published in the NIPA. As we have already noted, however, there is reason to believe that the rates of inflation in official price indices for certain high-tech assets, notably software and telecommunications equipment, may be overstated. Moulton, Parker, and Seskin (1999) and Parker and Grimm (2000), for example, report that only the pre-packaged portion of software investment is deflated with a constant-quality deflator. Own-account software is deflated with an input cost index and custom software is deflated with a weighted average of the prepackaged and own-account deflator. Similarly, BEA reports that in the communications equipment category, only telephone switching equipment is deflated with a constant-quality, hedonic deflator.

66. This subsection incorporates alternative price series for software and communications equipment and examines the impact on the estimates of U.S. economic growth and its sources. Table 4 presents growth accounting results under three different scenarios. The Base Case repeats the estimates from Table 2, which are based on official NIPA price data. Two additional cases, Moderate Price Decline and Rapid Price Decline, incorporate price series for software and communications equipment that show faster price declines and correspondingly more rapid real investment growth.[31]

67. The Moderate Price Decline case assumes that prepackaged software prices are appropriate for all types of private software investment, including custom and business own-account software. Since the index for prepackaged software is based on explicit quality adjustments, it falls much faster than the prices

31 . The notion that official price deflators for investment goods omit substantial quality improvements is hardly novel. The magisterial work of Gordon (1990) successfully quantified the overstatements of rates of inflation for the prices of a wide array of investment goods, covering all producers' durable equipment in the NIPA.

of custom and own-account software, -10.1% vs. 0.4% and 4.1% respectively, for the full period 1959-98 according to Parker and Grimm (2000). For communications equipment, the data are more limited and we assume prices fell 10.7% per year throughout the entire period. This estimate is the average annual "smoothed" decline for digital switching equipment for 1985-96 reported by Grimm (1997). While this series may not be appropriate for all types of communications equipment, it exploits the best available information.

68. The Rapid Price Decline case assumes that software prices fell 16% per year for 1959-98, the rate of quality-adjusted price decline reported by Brynjolfsson and Kemerer (1996) for microcomputer spreadsheets for 1987-92. This is a slightly faster decline than the –15% for 1986-91 estimated by Gandal (1994), and considerably faster than the 3% annual decline for word processors, spreadsheets, and databases for 1987-93 reported by Oliner and Sichel (1994). For communications equipment, we used estimates from the most recent period from Grimm (1997), who reports a decline of 17.9% per year for 1992-96.

69. While this exercise necessarily involves some arbitrary choices, the estimates incorporate the limited data now available and provide a valuable perspective on the crucial importance of accounting for quality change in the prices of investment goods. Comparisons among the three cases are useful in suggesting the range of uncertainty currently confronting analysts of U.S. economic growth.

70. Before discussing the empirical results, it is worthwhile to emphasize that more rapid price decline for information technology has two direct effects on the sources of growth, and one indirect effect. The alternative investment deflators raise real output growth by reallocating nominal growth away from prices and towards quantities. This also increases the growth rate of capital stock, since there are larger investment quantities in each year. More rapid price declines also give greater weight to capital services from information technology.

71. The counter-balancing effects of increased output and increased input growth lead to an indirect effect on measured TFP growth. Depending on the relative shares of high-tech assets in investment and capital services, the TFP residual will increase if the output effect dominates or decrease if the effect on capital services dominates.[32] Following Solow (1957, 1960), Greenwood, Hercowitz, and Krusell (1997) omit the output effect and attribute the input effect to "investment-specific" (embodied) technical change. This must be carefully distinguished from the effects of industry-level productivity growth on TFP growth, discussed in Section IV.

72. Table 4 reports growth accounting results from these three scenarios – Base Case, Moderate Price Decline, and Rapid Price Decline. The results are not surprising – the more rapid the price decline for software and communications, the faster the rate of growth of output and capital services. Relative to the Base Case, output growth increases by 0.16 percentage points per year for 1995-98 in the Moderate Price Decline case and by 0.34 percentage points in the Rapid Price Decline case. Capital input growth shows slightly larger increases across the three cases. Clearly, constant-quality price indexes for information technology are essential for further progress in understanding the growth impact of high-tech investment.

73. The acceleration in output and input growth reflects the increased contributions from IT, as well as the effect on the TFP residual. In particular, the output contribution from software for 1995-98 increases from 0.21 percentage points in the Base Case to 0.29 percentage points under Moderate Price Decline to 0.40 percentage points with Rapid Price Decline. Similarly, the capital services contribution for software increase from 0.19 to 0.29 to 0.45 percentage points. The contribution of communications equipment

32 . This point was originally made by Jorgenson (1966); Hulten (2000) provides a recent review.

shows similar changes. Residual TFP growth falls slightly during the 1990s, as the input effect outweighs the output effect, due to the large capital services shares of IT.

74. This exercise illustrates the sensitivity of the sources of growth to alternative price indexes for information technology. We do not propose to argue the two alternative cases are more nearly correct than the Base Case with the official prices from NIPA. Given the paucity of quality-adjusted price data on high-tech equipment, we simply do not know. Rather, we have tried to highlight the importance of correctly measuring prices and quantities to understand the dynamic forces driving U.S. economic growth. As high-tech assets continue to proliferate through the economy and other investment goods become increasingly dependent on electronic components, these measurement issues will become increasingly important. While the task that lies ahead of us will be onerous, the creation of quality-adjusted price indexes for all high-tech assets deserves top priority.

g) Decomposition of TFP estimates.

75. We next consider the role of high-tech industries as a source of continued TFP growth. As discussed above, increased output of high-tech investment goods has made important contributions to aggregate growth.[33] CEA (2000) allocates annual TFP growth of 0.39 percentage points to the computer production, while Oliner and Sichel (2000) allocate 0.47 percentage points to the production of computers and computer-related semi-conductor production for the period 1995-99.

76. We employ a methodology based on the price "dual" approach to measurement of productivity at the industry level. Anticipating our complete industry analysis Section IV, below, it is worthwhile to spell out the decomposition of TFP growth by industry. Using the Domar approach to aggregation, industry-level productivity growth is weighted by the ratio of the gross output of each industry to aggregate value-added to estimate the industry contribution to aggregate TFP growth. In the dual approach, the rate of productivity growth is measured as the decline in the price of output, plus a weighted average of the growth rates of input prices.

77. In the case of computer production, this expression is dominated by two terms; namely, the price of computers and the price of semi-conductors, a primary intermediate inputs into the computer-producing industry. If semi-conductor industry output is used only to produce computers, then its contribution to computer industry productivity growth, weighted by computer industry output, precisely cancels its independent contribution to aggregate TFP growth.[34] This independent contribution from the semi-conductor industry, based on the complete Domar weighting scheme, is the value of semi-conductor output divided by aggregate value added, multiplied by the rate of price decline in semi-conductors.

78. We report details of our TFP decomposition for 1990-95 and 1995-98 in Table 5 and summarize the IT vs. non-IT comparison in Chart 10. In our Base Case, using official NIPA data, we estimate the production of information technology accounts for 0.44 percentage points for 1995-98, compared to 0.25 percentage points for 1990-95. This reflects the accelerating relative price changes prices due to radical shortening of the product cycle for semi-conductors.[35]

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33 . CEA (2000), Gordon (1999a), Jorgenson and Stiroh (1999), Oliner and Sichel (2000), Stiroh (1998), and Whelan (1999) have provided estimates.

34 . This calculation shows that the simplified model of Oliner and Sichel (2000) is a special case of the complete Domar weighting scheme used in Section IV.

35 . Relative price changes in the Base Case are taken from the investment prices in Table 5. Output shares are estimated based on final demand sales available from the BEA website for computers and from Parker and

79. As we have already suggested, the estimates of price declines for high-tech investments in our Base Case calculations may be conservative; in fact, these estimates may be *very* conservative. Consider the Moderate Price Decline Case, which reflects only part of the data we would require for constant-quality estimates of the information technology price declines. This boosts the contribution of information technology to TFP growth to 0.64 percentage points, an increase of 0.20 percentage points for 1995-98. Proceeding to what may appear to be the outer limit of plausibility, but still consistent with the available evidence, we can consider the case of Rapid Price Decline. The contribution of information technology to TFP growth is now a robust 0.86 percentage points, accounting for all of TFP growth for 1995-98.

III. Setting the speed limit

80. We next consider the sustainability of recent U.S. growth trends over longer time horizons. Rapid output growth is highly desirable, of course, but cannot continue indefinitely if fueled by a falling unemployment rate and higher labor force participation. Output growth driven by continuing TFP improvements, on the other hand, is more likely to persist. The sustainability of growth has clear implications for government policies. Since economic growth affects tax revenues, potential government expenditures, and the long-term viability of programs like Social Security and Medicare, it is closely studied by government agencies. This section examines the impact of the recent success of the US economy on official growth forecasts.

a) A brief review of forecast methodologies

81. The importance of economic growth for the US government is evident in the considerable effort expended on projecting future growth. No fewer than five government agencies – the Congressional Budget Office (CBO), the Social Security Administration (SSA), the Office of Management and Budget (OMB), the Council of Economic Advisors (CEA), and the General Accounting Office (GAO) – report estimates of future growth for internal use or public discussion. This section briefly discusses the methodologies used by these agencies.[36]

82. All five agencies employ models that rest securely on neoclassical foundations. While the details and assumptions vary, all employ an aggregate production model similar to Equation (1), either explicitly or implicitly. In addition, they all incorporate demographic projections from the SSA as the basic building block for labor supply estimates. CBO (1995, 1997, 1999a, 1999b, 2000) and GAO (1995, 1996) employ an aggregate production function and describe the role of labor growth, capital accumulation, and technical progress explicitly. SSA (1992, 1996), OMB (1997, 2000), and CEA (2000) on the other hand, employ a simplified relationship where output growth equals the sum of growth in hours worked and labor productivity. Projections over longer time horizons are driven by aggregate supply with relatively little attention to business cycle fluctuations and aggregate demand effects.

83. Given the common framework and source data, it is not surprising that the projections are quite similar. Reporting on estimates released in 1997, Stiroh (1998b) finds that SSA and GAO projections of per capita GDP in 2025 were virtually identical, while CBO was about 9% higher due to economic feedback effects from the improving government budget situation. More recently, CBO (2000) projects

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Grimm (2000) for software. Investment in communications equipment is from the NIPA, and we estimate other final demand components for communications equipment using ratios relative to final demand for computers. This is an approximation necessitated by the lack of complete data of sales to final demand by detailed commodity.

36 . Stiroh (1998b) provides details and references to supporting documents.

real GDP growth of 2.8% and OMB (2000) projects 2.7% for 1999-2010, while CEA (2000) reports 2.8% for 1999-2007. Although the timing is slightly different – CBO projects faster growth than OMB earlier in the period and CEA reports projections only through 2007– the estimates are virtually identical. All three projections identify the recent investment boom as a contributor to rising labor productivity and capital deepening as a source of continuing economic growth. We now consider the CBO projections in greater detail.

b) CBO's growth projections

84. Of the five government agencies CBO utilizes a sophisticated and detailed long-run growth model of the US economy.[37] The core of this model is a two-factor production function for the non-farm business sector with CBO projections based on labor force growth, national savings and investment, and exogenous TFP growth. Production function parameters are calibrated to historical data, using a Cobb-Douglas model:

$$(6) \qquad Y = A \cdot H^{0.7} \cdot K^{0.3}$$

where Y is potential output, H is potential hours worked, K is capital input, and A is potential total factor productivity.[38]

85. CBO projects hours worked on the basis of demographic trends with separate estimates for different age and sex classifications. These estimates incorporate SSA estimates of population growth, as well as internal CBO projections of labor force participation and hours worked for the different categories. However, CBO does use this demographic detail to identify changes in labor quality. Capital input is measured as the service flow from four types of capital stocks – producers' durable equipment excluding computers, computers, nonresidential structures, and inventories. Stocks are estimated by the perpetual inventory method and weighted by rental prices, thereby incorporating some changes in capital quality. TFP growth is projected on the basis of recent historical trends, with labor quality growth implicitly included in CBO's estimate of TFP growth.

86. Turning to the most recent CBO projections, reported in CBO (2000), we focus on the non-farm business sector, which drives the GDP projections and is based on the most detailed growth model. Table 6 summarizes CBO's growth rate estimates for the 1980s and 1990s, and projections for 1999-2010. We also present estimates from BLS (2000) and our results.[39]

87. CBO projects potential GDP growth of 3.1% for 1999-2010, up slightly from 3.0% in the 1980s and 2.9% in the 1990s. CBO expects actual GDP growth to be somewhat slower at 2.8%, as the economy moves to a sustainable, long-run growth rate. Acceleration in potential GDP growth reflects faster capital accumulation and TFP growth, partly offset by slower growth in hours worked. Projected GDP growth is

37 . The five sectors – nonfarm business, farm, government, residential housing, and households and nonprofit institutions – follow the breakdown in Table 1.7 of the NIPA.

38 . See CBO (1995, 1997) for details on the underlying model and the adjustments for business cycle effects that lead to the potential series.

39 . Note the growth rates in Table 5 do not exactly match Table 2 due to differences in calculating growth rates. All growth rates in Table 5 follow CBO's convention of calculating discrete growth rates as $g = \left[(X_t / X_0)^{1/t} - 1\right] * 100$, while growth rates in Table 2 are calculated as $g = \left[\ln(X_t / X_0)/t\right] * 100$.

0.4% higher than earlier estimates (CBO (1999b)) due to an upward revision in capital growth (0.1%), slightly more rapid growth in hours (0.1%), and faster TFP growth, reflecting the benchmark revisions of NIPA and other technical changes (0.2%).[40]

88. CBO's estimates for the non-farm business sector show strong potential output growth of 3.5% for 1999-2010. While projected output growth is in line with experience of the 1990s and somewhat faster than the 1980s, there are significant differences in the underlying sources. Most important, CBO projects an increasing role for capital accumulation and TFP growth over the next decade, while hours growth slows. This implies that future output growth is driven by ALP growth, rather than growth in hours worked.

89. CBO projects potential non-farm business ALP growth for 1999-2010 to rise to 2.3%, powered by capital deepening (3.2%) and TFP growth (1.4%). This represents a marked jump in ALP growth, relative to 1.5% in the 1980s and 1.9% in the 1990s. In considering whether the recent acceleration in ALP growth represents a trend break, CBO "gives considerable weight to the possibility that the experience of the past few years represents such a break (CBO (2000), pg. 43)." This assumption appears plausible given recent events, and low unemployment and high labor force participation make growth in hours worked a less likely source of future growth. Falling investment prices for information technology make capital deepening economically attractive, while the recent acceleration in TFP growth gives further grounds for optimistic projections.

90. As the investment boom continues and firms substitute toward more information technology in production, CBO has steadily revised its projected growth rates of capital upward. It is worthwhile noting just how much the role of capital accumulation has grown in successive CBO projections, rising from a projected growth rate of 3.6% in January 1999 (CBO (1999a)) to 4.1% in July 1999 (CBO (1999b)) to 4.4% in January 2000 (CBO (2000)). This reflects the inclusion of relatively fast-growing software investment in the benchmark revision of NIPA, but also extrapolates recent investment patterns.

91. Similarly, CBO has raised its projected rate of TFP growth in successive estimates – from 1.0% in January 1999 to 1.1% in July 1999 to 1.4% in January 2000.[41] These upward revisions reflect methodological changes in how CBO accounts for the rapid price declines in investment, particularly computers, which added 0.2%. In addition, CBO adjustments for the benchmark revision of NIPA contributed another 0.1%.

92. Table 6 also reports our own estimates of growth for roughly comparable periods. While the time periods are not precisely identical, our results are similar to CBO's. We estimate slightly faster growth during the 1980s, due to rapidly growing CD services, but slightly lower rates of capital accumulation due to our broader measure of capital. Our growth of hours worked is higher, since we omit the cyclical adjustments made by CBO to develop their potential series.[42] Finally, our TFP growth rates are considerably lower, due to our labor quality adjustments and inclusion of consumers' durables. If we were to drop the labor quality adjustment, our estimate would rise to 1.0% per year from 1990 to 1998, compared to 1.2% for CBO for 1990-99. The remaining difference reflects the fact that we do not include the rapid TFP growth of 1999, but do include the services of consumers' durables, which involve no growth in TFP.

40 . See CBO (2000, pg. 25 and pg. 43) for details.

41 . Earlier upward revisions to TFP growth primarily reflect "technical adjustment…for methodological changes to various price indexes" and "increased TFP projections (CBO (1999b), pg. 3)."

42 . See CBO (1995) for details on the methodology for cyclical adjustments to derive the "potential" series.

c) Evaluating CBO's projections

93. Evaluating CBO's growth projections requires an assessment of their estimates of the growth of capital, labor, and TFP. It is important to emphasize that this is not intended as a criticism of CBO, but rather a description of "best practice" in the difficult area of growth projections. We also point out comparisons between our estimates and CBO's estimates are not exact due to our broader output concept and our focus on actual series, as opposed the potential series that are the focus of CBO.

94. We begin with CBO's projections of potential labor input. These data, based on the hours worked from BLS and SSA demographic projections, show a decline in hours growth from 1.5% in the 1990s to 1.2% for the period 1999-2010. This slowdown reflects familiar demographic changes associated with the aging of the US population. However, CBO does not explicitly estimate labor quality, so that labor composition changes are included in CBO's estimates of TFP growth and essentially held constant.

95. We estimate growth in labor quality of 0.57% per year for 1990-98, while our projections based on demographic trends yield a growth rate of only 0.32% for the 1998-2010 period. Assuming CBO's labor share of 0.70, this implies that a decline in the growth contribution from labor quality of about 0.18 percentage points per year over CBO's projection horizon. Since this labor quality effect is implicitly incorporated into CBO's TFP estimates, we conclude their TFP projections are overstated by this 0.18 percentage points decline in the labor quality contribution.

96. TFP growth is perhaps the most problematical issue in long-term projections. Based on the recent experience of the US economy, it appears reasonable to expect strong future productivity performance. As discussed above and shown in Table 2, TFP growth has increased markedly during the period 1995-98. However, extrapolation of this experience runs the risk of assuming that a temporary productivity spurt is a permanent change in trend.

97. Second, the recent acceleration of TFP growth is due in considerable part to the surge in productivity growth in industries producing IT. This makes the economy particularly vulnerable to slowing productivity growth in these industries. Computer prices have declined at extraordinary rates in recent years and it is far from obvious that this can continue. However, acceleration in the rate of decline reflects the change in the product cycle for semi-conductors, which has shifted from three years to two and may be permanent.

98. We conclude that CBO's projection of TFP growth is optimistic in assuming a continuation of recent productivity trends. However, we reduce this projection by only 0.18 percent per year to reflect the decline in labor quality growth, resulting in projected TFP growth of 1.22% per year. To obtain a projection of labor input growth we add labor quality growth of 0.32% per year to CBO's projection of growth in hours of 1.2% per year. Multiplying labor input growth of 1.52% per year by the CBO labor share of 0.7, we obtain a contribution of labor input of 1.06%.

99. CBO's projected annual growth of capital input of 4.4% is higher than in any other decade, and 0.8% higher than in the 1990s. This projection extrapolates recent increases in the relative importance of computers, software, and communications equipment. Continuing rapid capital accumulation is also predicated on the persistence of high rates of decline in asset prices, resulting from rapid productivity growth in the IT producing sectors. Any attenuation in this rate of decline would produce a double whammy – less TFP growth and reduced capital deepening.

100. Relative to historical trends, CBO's capital input growth projection of 4.4% seems out of line with the projected growth of potential output of 3.5%. During the 1980s capital growth exceeded output growth by 0.4%, according to their estimates, or 0.1% by our estimates. In the 1990s capital growth

exceeded output growth by only 0.2%, again according to their estimates, and 0.1% by our estimates. This difference jumps to 0.9% for the period of CBO's projections, 1999-2010.

101. Revising the growth of capital input downward to reflect the difference between the growth of output and the growth of capital input during the period 1995-98 of 0.2% would reduce the CBO's projected output growth to 3.34% per year. This is the sum of the projected growth of TFP of 1.22% per year, the contribution of labor input of 1.06% per year, and the contribution of capital input of 1.06% per year. This is a very modest reduction in output growth from CBO's projection of 3.5% per year and can be attributed to the omission of a projected decline in labor quality growth.

102. We conclude that CBO's projections are consistent with the evidence they present, as well as our own analysis of recent trends. We must emphasize, however, that any slowdown in technical progress in information technology could have a major impact on potential growth. Working through both output and input channels, the US economy has become highly dependent on information technology as the driving force in continued growth. Should productivity growth in these industries falter, the projections we have reviewed could be overly optimistic.

IV. Industry productivity

103. We have explored the sources of U.S. economic growth at the aggregate level and demonstrated that accelerated TFP growth is an important contributor to the recent growth resurgence. Aggregate TFP gains – the ability to produce more output from the same inputs – reflects the evolution of the production structure at the plant or firm level in response to technological changes, managerial choices, and economic shocks. These firm- and industry-level changes then cumulate to determine aggregate TFP growth. We now turn our attention to industry data to trace aggregate TFP growth to its sources in the productivity growth of individual industries, as well as reallocations of output and inputs among industries.

104. Our approach utilizes the framework of Jorgenson, Gollop, and Fraumeni (1987) for quantifying the sources of economic growth for U.S. industries. The industry definitions and data sources have been brought up-to-date. The methodology of Jorgenson, Gollop, and Fraumeni for aggregating over industries is based on Domar's (1961) approach to aggregation. Jorgenson and Stiroh (2000) have presented summary data from our work; other recent studies of industry-level productivity growth include BLS (1999), Corrado and Slifman (1999), and Gullickson and Harper (1999). The remainder of this section summarizes our methodology and discusses the results.

a) Methodology

105. As with the aggregate production model discussed in Section II, we begin with an industry-level production model for each industry. A crucial distinction, however, is that industry output Q_I is measured using a "gross output" concept, which includes output sold to final demand as well as output sold to other industries as intermediate goods. Similarly, inputs include all production inputs, including capital services K_I and labor services L_I, as well as intermediate inputs, energy E_I and materials M_I, purchased from other industries.[43] Our model is based on the industry production function:

$$Q_i = A_i \cdot X_i(K_i, L_i, E_i, M_i) \qquad (7)$$

43 . This is analogous to the sectoral output concept used by BLS. See Gullickson and Harper (1999), particularly pp. 49-53 for a review of the concepts and terminology used by the BLS.

where time subscripts have been suppressed for clarity.

106. We can derive a growth accounting equation similar to Equation (2) for each industry to measure the sources of economic growth for individual industries. The key difference is the use of gross output and an explicit accounting of the growth contribution of intermediate inputs purchased from other industries. This yields:

$$(8) \qquad \Delta \ln Q_i = \overline{w}_{K_i} \Delta \ln K_i + \overline{w}_{L_i} \Delta \ln L_i + \overline{w}_{E_i} \Delta \ln E_i + \overline{w}_{M_i} \Delta \ln M_i + \Delta \ln A_i$$

where $\overline{w}_i$ is the average share of the subscripted input in the *i*th industry and the assumptions of constant returns to scale and competitive markets imply $\overline{w}_{K_i} + \overline{w}_{L_i} + \overline{w}_{E_i} + \overline{w}_{M_i} = 1$.

107. The augmentation factor ΔlnA_I represents the growth in output not explained by input growth and is conceptually analogous to the TFP concept used above in the aggregate accounts. It represents efficiency gains, technological progress, scale economies, and measurement errors that allow more measured gross output to be produced from the same set of measured inputs. We refer to this term as *industry productivity* or simply *productivity* to distinguish it from TFP, which is estimated from a value-added concept of output.[44]

108. Domar (1961) first developed an internally consistent methodology that linked industry-level productivity growth in Equation (8) with aggregate TFP growth in Equation (2). He showed that aggregate TFP growth can be expressed as a weighted average of industry productivity growth:

$$(9) \qquad \Delta \ln A = \sum_{i=1}^{37} \overline{w}_i \cdot \Delta \ln A_i, \quad \overline{w}_i = \frac{1}{2}\left(\frac{P_{i,t} \cdot Q_{i,t}}{P_{Y,t} \cdot Y_t} + \frac{P_{i,t-1} \cdot Q_{i,t-1}}{P_{Y,t-1} \cdot Y_{t-1}} \right)$$

where $\overline{w}_i$ is the "Domar weight", $P_i{\cdot}Q_i$ is current dollar gross output in sector *i*, and $P_Y{\cdot}Y$ is current dollar aggregate value-added. This simplified version of the aggregation formula given by Jorgenson, Gollop, and Fraumeni (1987), excludes re-allocations of value added, capital input, and labor input by sector. Jorgenson and Stiroh (2000) show that these terms are negligible for the period 1958-1996, which is consistent with the results of Jorgenson, Gollop, and Fraumeni (1987) and Jorgenson (1990) for periods of similar duration.

109. Domar weights have the notable feature that they do not sum to unity. This reflects the different output concepts used at the aggregate and industry levels in Equations (1) and (7), respectively. At the aggregate level, only primary inputs are included, while both primary and intermediate inputs are included in the industry production functions. For the typical industry, gross output considerably exceeds value added, so the sum of gross output across industries exceeds the sum of value added. This weighting methodology implies that economy-wide TFP growth can grow faster than productivity in any industry, since productivity gains are magnified as they work their way through the production process.[45]

110. In addition to providing an internally consistent aggregation framework, industry-level gross output allows an explicit role for intermediate goods as a source of industry growth. For example, Triplett

44 . BLS refers to this concept as *multi-factor productivity* (MFP).

45 . Jorgenson, Gollop, and Fraumeni (1987), particularly Chapter 2, provide details and earlier references; Gullickson and Harper (1999, pg. 50) discuss how aggregate productivity can exceed industry productivity in the Domar weighting scheme.

(1996) shows that a substantial portion of the price declines in computer output can be traced to steep price declines in semi-conductors, the major intermediate input in the computer-producing industry. Price declines in semi-conductors reflect technological progress – Moore's law in action. This should be measured as productivity growth in the industry that produces semi-conductors. By correctly accounting for the quantity and quality of intermediate inputs, the gross output concept allows aggregate TFP gains to be correctly allocated among industries.

b) Data sources

111. Our primary data include a set of inter-industry transactions accounts developed by the Employment Projections office at the BLS. These data cover a relatively short time period from 1977 to 1995. We linked the BLS estimates to industry-level estimates back to 1958, described by Stiroh (1998a), and extrapolated to 1996 using current BLS and BEA industry data.[46] This generated a time series for 1958 to 1996 for 37 industries, at roughly the two-digit Standard Industrial Classification (SIC) level, including Private Households and General Government.[47] Table 7 lists the 37 industries, the relative size in terms of 1996 value-added and gross output, and the underlying SIC codes for each industry.

112. Before proceeding to the empirical results, we should point out two limitations of this industry-level analysis. Due to the long lag in obtaining detailed inter-industry transactions, investment, and output data by industry, our industry data are not consistent with the BEA benchmark revision of NIPA published in December 1999; they correspond to the NIPA produced by BEA in November 1997. As a consequence, they are not directly comparable to the aggregate data described in Tables 1 through 6. Since the impact of the benchmark revision was to raise output and aggregate TFP growth, it is not surprising that the industry data show slower output and productivity growth. Second, our estimates of rental prices for all assets in this industry analysis are based on the industry-wide asset revaluation terms, as in Stiroh (1998a). They are not directly comparable to the aggregate data on capital input, where asset-specific revaluation terms are included in the rental price estimates. The use of industry-wide revaluation terms tends to reduce the growth in capital services since assets with falling relative prices, such as computers, have large service prices and rapid accumulation rates.

c) Empirical results

i) Sources of industry growth

113. Table 8 reports estimates of the components of Equation (8) for the period 1958-1996. For each industry, we show the growth in output, the contribution of each input (defined as the nominal share-weighted growth rate of the input), and productivity growth. We also report average labor productivity (ALP) growth, defined as real gross output per hour worked, and the Domar weights calculated from Equation (9). We focus the discussion of our results on industry productivity and ALP growth.

114. Industry productivity growth was the highest in two high-tech industries, Industrial Machinery and Equipment, and Electronic and Electric Equipment, at 1.5% and 2.0% per year, respectively. Industrial Machinery includes the production of computer equipment (SIC #357) and Electronic Equipment includes the production of semi-conductors (SIC #3674) and communications equipment (SIC #366). The enormous

46 . We are grateful to Mun Ho for his extensive contributions to the construction of the industry data.

47 . Appendix D provides details on the component data sources and linking procedures.

technological progress in the production of these high-tech capital goods has generated falling prices and productivity growth, and fueled the substitution towards information technology.

115. An important feature of these data is that we can isolate productivity growth for industries that produce intermediate goods, for example, Electronic and Electric Equipment.[48] Consider the contrast between computer production and semi-conductor production. Computers are part of final demand, sold as consumption and investment goods, and can be identified in the aggregate data, as we did in Table 2. Semi-conductors, on the other hand, do not appear at the aggregate level, since they are sold almost entirely as an input to computers, telecommunications equipment, and an increasingly broad range of other products such as machine tools, automobiles, and virtually all recent vintages of appliances. Nonetheless, improved semi-conductor production is an important source of aggregate TFP growth since it is ultimately responsible for the lower prices and improved quality of goods like computers produced for final demand.

116. The enormous price declines in computer equipment and the prominent role of investment in computers in the GDP accounts have led Gordon (1999b), Whelan (1999), and others to emphasize technological progress in the production of computers. Triplett (1996), however, quantifies the role of semi-conductors as an intermediate input and estimates that falling semi-conductor prices may account for virtually all of the relative price declines in computer equipment. He concludes, "productivity in the computer industry palls beside the enormous increases in productivity in the semi-conductor industry (Triplett (1996), pg. 137)."[49]

117. The decline in prices of semi-conductors is reflected in the prices of intermediate input into the computer industry, effectively moving productivity away from computers and toward semi-conductor production. Building on this observation, Oliner and Sichel (2000) present a model that includes three sectors – semi-conductor production, computer production, and other goods – and shows that semi-conductors productivity is substantially more important than computer productivity. Our complete industry framework with Domar aggregation over all industries captures the contributions of productivity growth from all industries.

118. The impact of intermediate inputs can be seen in Table 8 in the large contribution of material inputs in the Industrial Machinery industry. Since a substantial portion of these inputs consists of semi-conductors purchased from the Electronic Equipment industry, productivity gains that lower the price of semi-conductors increase the flow of intermediate inputs into the Industrial Machinery industry. By correctly accounting for these inputs, industry productivity growth in the Industrial Machinery industry falls, and we can rightly allocate technological progress to the Electronic Equipment industry, which produces semi-conductors. While this type of industry reallocation does not affect aggregate productivity growth, it is important to identify the sources of productivity growth and allocate this among industries in order to assess the sustainability of the recent acceleration.

119. The two high-tech industries also show high rates of average labor productivity (ALP) growth of 3.1% and 4.1% per year. This reflects an underlying relationship similar to Equation (3) for the aggregate data, where industry ALP growth reflects industry productivity growth, labor quality growth, and increases in input intensity, including increases in capital as well as intermediate inputs per hour worked. As implied

48 . Our industry classification is too broad to isolate the role of semi-conductors.

49 . This conclusion rests critically on the input share of semi-conductors in the computer industry. Triplett reports Census data estimates of this share at 15% for 1978-94, but states industry sources estimate this share to be closer to 45%. This has an important impact on his results. At one end of the spectrum, if no account is made for semi-conductor price declines, the relative productivity in computer equipment increases 9.1% for 1978-94. Assuming a 15% share for semi-conductors causes this to fall to 9%; assuming a 45% share causes a fall to 1%.

by Table 8, these industries showed rapid accumulation of capital and intermediate inputs, which raised ALP growth above productivity growth. It is also worthwhile to note that Communications, another high-tech industry, shows ALP growth much faster than industry productivity growth due to the rapid accumulation of inputs, notably intermediate materials. These results highlight the crucial importance of accounting for all inputs when examining the sources of industry growth.

120. Productivity growth in information technology provides a final perspective on the conclusions of Greenwood, Hercowitz, and Krusell (1997) and Hercowitz (1998). They argue that some 60% of postwar U.S. growth can be attributed to investment-specific (embodied) productivity growth, which they distinguish from input accumulation and (disembodied) productivity growth. As evidence, they note the relative price of equipment in the United States has fallen 3% per year, which they interpret as evidence of technical change that affect capital goods, but not consumption goods. Our decomposition, however, reveals that declines in the prices of investment goods are the consequence of improvements in industry (disembodied) productivity. Domar aggregation shows how these improvements contribute directly to aggregate TFP growth. There is no separate role for investment-specific technical change.

121. Other industries that show relatively strong productivity growth include Agriculture, Textile Mill Products, Rubber and Plastic, Instruments, Trade. All of these industries experienced productivity growth in the 1.0% per year range, and ALP growth in the 2-3% range. Industries with the slowest productivity growth include Petroleum and Gas, Construction, Printing and Publishing, and Government Enterprises, all of which showed a declines in productivity of nearly 0.5% per year.

122. It is worth emphasizing that nine industries showed negative productivity growth for the entire period, a counter-intuitive result, if we were to interpret productivity growth solely as technological progress. It is difficult to envision technology steadily worsening for a period of nearly 40 years as implied by these estimates. The perplexing phenomenon of negative technical progress was a primary motivation for the work of Corrado and Slifman (1999) and Gullickson and Harper (1999), who suggest persistent measurement problems as a plausible explanation. Corrado and Slifman (1999) conclude, "a more likely statistical explanation for the implausible productivity, profitability, and price trends…is that they reflect problems in measuring prices (pg. 331)." If prices are systematically overstated because quality change is not accurately measured, then output and productivity are correspondingly understated. We do not pursue this idea here, but simply point out that measurement problems are considered a reasonable explanation by some statistical agencies.[50]

123. An alternative interpretation for negative productivity growth is the possibility of declines in efficiency that have no association with technology. These might include lower quality of management and worsening of industrial organization through the growth of barriers to entry. This appears to be plausible explanation, given the widespread occurrence of negative productivity growth for extended periods of time. Until more careful research linking firm- and plant-level productivity to industry productivity estimates has been done, it would be premature to leap to the conclusion that estimates of economic performance should be adjusted so as to eliminate negative productivity growth rates, wherever they occur.

124. Low productivity growth rates are surprising in light of the fact that many of the affected industries are heavy investors in information technology. Stiroh (1998a), for example, reports nearly 80% of computer investment in the early 1990s was in three service-related industries, Trade, FIRE, and Services. Triplett (1999) reports a high concentration in service industries using the BEA's capital use survey. The apparent combination of slow productivity growth and heavy computer-use remains an

50 . Dean (1999) summarizes the BLS view on this issue. McGuckin and Stiroh (2000) attempt to quantify the magnitude of the potential mismeasurement effects.

important obstacle for new economy proponents who argue that the use of information technology is fundamentally changing business practices and raising productivity throughout the US economy.

ii) Comparison to other results

125. Before proceeding to the Domar aggregation results, it is useful to compare these results to three other recent studies – BLS (1999), Corrado and Slifman (1999) and Gullickson and Harper (1999). BLS (1999) reports industry productivity growth ("industry multifactor productivity" in their terminology) for 19 manufacturing industry for 1949-96. Corrado and Slifman (1999) report estimates of ALP growth for selected one- and two-digit SIC industries for the period 1977-97. Gullickson and Harper (1999) report industry productivity growth for certain one and two-digit SIC industries based on two output series for the period 1947-1992. Similar to BLS (1999), Gullickson and Harper use a "sectoral output" concept estimated by the Employment Projections staff at BLS and also, for 1977-92, use BEA's gross output series, "adjusted for consistency."[51] Note that none of these studies reflect the BEA benchmark revision of NIPA.

126. Time period, industry classification, and methodological differences make a definitive reconciliation to our results impossible. For example, BLS (1999) reports detailed manufacturing industries; Corrado and Slifman (1999) use a value-added concept, BEA's "gross product originating," for output; Gullickson and Harper (1999) use the same data sources as we do, but make different adjustments for consistency and do not account for labor quality growth. Nonetheless, it is useful to compare broad trends over similar time periods to assess the robustness of our findings.

127. We first consider the ALP estimates from Corrado and Slifman (1999). We can compare similar time periods, but there are relatively few overlapping industries since our industry breakdown focuses on manufacturing industries, while they provide details primarily for service industries. For comparable industries, however, the results are quite similar. For seven industries with comparable definitions, five show differences in ALP growth of less than 0.25% when we compare our estimates for 1977-96 to Corrado and Slifman's estimates for 1977-97 (Corrado and Slifman (1999, Table 2).[52] Our ALP growth rates for Communication and Trade are below theirs by 1.3% and 0.4%, respectively, for these periods.

128. Our productivity estimates for 1977-92 for the majority of industries are similar to those of Gullickson and Harper (1999). The range of discrepancies is somewhat greater due to the difficulty of linking the various data sets needed to estimate intermediate inputs and industry productivity growth. For 7 of the 11 comparable industries productivity differences are below 0.5%, while we found larger discrepancies for Metal Mining, Coal Mining, Petroleum and Gas, and Services.[53] Similar differences can also be seen in Gullickson and Harper's comparison of productivity growth estimated from the BLS and BEA gross output series, where they find differences of 0.5 percentage points or more in 17 out of 40 industries and aggregates. Methodological differences, such as the inclusion of labor quality growth in our estimates of labor input growth, contribute to this divergence, as do different methods for linking data sets.

129. Neither Corrado and Slifman (1999) nor Gullickson and Harper (1999) break out ALP growth or industry productivity growth for detailed manufacturing industries. To gauge these results, we have compared our manufacturing results to the manufacturing industry estimates in BLS (1999). For the 18

51 . See Gullickson and Harper (1999), particularly pp. 55-56, for details

52 . These five industries are Agriculture, Construction, Transportation, FIRE and Services. Note that our estimates for 1977-1996 are not given in Table 10.

53 . These seven other industries that are comparable are Agriculture, Nonmetallic Mining, Construction, Transportation, Communications, Trade, and FIRE.

industries that are comparable, ten showed productivity differences of less than 0.25% for 1979-96; two showed differences between 0.25% and 0.5%; and the remaining six industries, Textile Mills, Lumber and Wood, Petroleum Refining, Leather, Stone, Clay and Glass, and Instruments, showed differences greater than 0.5.[54]

iii) Domar aggregation

130. We now turn to the aggregation of industry productivity growth described by Equation (9). This is not directly comparable to our estimates of aggregate productivity, due to different vintages of data and a broader definition of output. Nonetheless, it is useful to quantify an industry’s contribution to aggregate TFP growth and to trace aggregate productivity growth back to its sources at the level of the individual industry. These results update the earlier estimates of Jorgenson, Gollop, and Fraumeni (1987). Gordon (1999b) presents a similar decomposition for ALP growth, although he focuses exclusively on the contribution from computer production.

131. We present our estimates of each industry’s contribution to aggregate TFP growth for the period 1958-96 in Chart 11. This follows Equation (9) by weighting industry productivity growth by the “Domar weight,” defined as industry gross output divided by aggregate value-added. Summing across industries gives an estimate of aggregate TFP growth of 0.48 for 1958-96. This is lower than the number implied by Table 2 for two reasons. First, the data are prior to the BEA benchmark revision, which raised output and TFP growth. Second, these estimates include a broader output concept that includes Government Enterprises, which we estimate has negative industry productivity growth, and the General Government, which has zero productivity growth by definition. The estimate is consistent, however, with the estimates in Ho, Jorgenson, and Stiroh (1999) and Jorgenson and Stiroh (1999), which are based on the same vintage of data.

132. The most striking feature of Chart 11 is the wide range of industry contributions. Trade, Industrial Machinery, and Electronic Equipment make the largest contribution, although for different reasons. Trade has solid, but not exceptionally strong productivity growth of almost 1% per year, but makes the largest contribution due to its large relative size; Trade receives a Domar weight of nearly 0.20. Industrial Machinery and Electronic Equipment, on the other hand, make important contributions due to their rapid productivity growth, 1.5% and 2.0%, respectively, in spite of their relative small sizes with Domar weights of 0.05 and 0.04, respectively. An industry's contribution to aggregate productivity growth depends on both productivity performance and relative size.

133. Chart 11 also highlights the impact of the nine industries that experienced negative productivity growth over this period. Again, both performance and relative size matter. Services makes a negative contribution of 0.07 due to its large weight and productivity growth of –0.19%. Construction, on the other hand, shows even slower industry productivity growth, –0.44% per year, but makes a smaller negative contribution, since it is so much smaller than Services. We can also do a “thought experiment” similar to Corrado and Slifman (1999) and Gullickson and Harper (1999) and imagine that productivity growth is zero in these nine industries rather than negative. By zeroing out the negative contributions, we find

54 . The 10 industries with small differences are Food Products, Apparel, Furniture and Fixtures, Paper Products, Printing and Publishing, Chemical Products, Primary Metals, Industrial and Commercial Machinery, Electronic and Electric Machinery, and Miscellaneous Manufacturing. The two industries with slightly larger differences are Rubber and Plastic, and Fabricated Metals.

aggregate TFP growth would have been 0.22% higher, an increase of nearly half.[55] Clearly, negative productivity growth in these industries is an important part of the aggregate productivity story.

134. Finally, these data enable us to provide some new perspective on an argument made by Gordon (1999b), who decomposes trend-adjusted ALP growth into a portion due to computer-production and a residual portion for the rest of the economy.[56] He finds the former accounts for virtually all of the productivity acceleration since 1997. While we cannot comment directly on his empirical estimates since our industry data end in 1996 and we examine TFP growth rather than ALP growth, we can point to an important qualification to his argument. The US economy is made up of industries with both positive and negative productivity growth rates, so that comparing one industry to the aggregate of all others necessarily involves aggregation over off-setting productivity trends. The fact that this aggregate does not show net productivity growth does not entail the absence of gains in productivity in any of the component industries, since these gains could be offset by declines in other industries.

135. Consider our results for 1958-96 and the importance of the negative contributions. The five industries with the largest, positive contributions – Trade, Electronic Equipment, Agriculture, Industrial Machinery, and Transport – cumulatively account for the sum across all industries, about 0.5% per year. Nonetheless, we find sizable productivity growth in some remaining industries that are offset by negative contributions in others. This logic and the prevalence of negative productivity growth rates at the industry level, in BLS (1999), Corrado and Slifman (1999), and Gullickson and Harper (1999), suggest that a similar argument could hold for ALP and for the most recent period. This raises the question of whether off-setting productivity growth rates are responsible for Gordon's finding that there is "*no* productivity growth in the 99 percent of the economy located outside the sector which manufactures computer hardware (Gordon (1999b, pg 1, italics in original))." Assessing the breadth of recent productivity gains and identifying the sources in productivity growth at the industry level remains an important question for future research.

V. Conclusions

136. The performance of the US economy in the late 1990s has been nothing short of phenomenal. After a quarter century of economic malaise, accelerating total factor productivity growth and capital deepening have led to a remarkable growth resurgence. The pessimism of the famous Solow (1987) paradox, that we see computers everywhere but in the productivity statistics, has given way to optimism of the information age. The productivity statistics, beginning in 1995, have begun to reveal a clearly discernible impact of information technology. Both labor productivity and TFP growth have jumped to rates not seen for such an extended period of time since the 1960s. While a substantial portion of these gains can be attributed to computers, there is growing evidence of similar contributions from software and communications equipment – each equal in importance to computers.

137. The forces shaping the information economy originate in the rapid progress of semi-conductor technology – Moore's Law at work. These gains are driving down relative prices of computers, software, and communications equipment and inducing massive investments in these assets by firms and households. Technological progress and the induced capital deepening are the primary factors behind accelerating

55 . This aggregate impact is smaller than that estimated by Gullickson and Harper (1999), partly because our shares differ due to the inclusion of a Household and Government industry. Also, as pointed out by Gullickson and Harper, a complete re-estimation would account for the change in intermediate inputs implied by the productivity adjustments.

56 . Oliner and Sichel (2000) argue that Gordon's conclusion is weakened by the new NIPA data released in the benchmark revision, which allow a larger role for ALP growth outside of computer production.

output growth in recent years. The sustainability of recent growth trends therefore hinges to a great degree on prospects for continuing progress, especially in the production of semi-conductors. While this seems plausible and perhaps even likely, the contribution of high-tech assets to the growth resurgence remains subject to considerable uncertainty, owing to incomplete information on price trends for these assets.

138. The strong performance of the US economy has not gone unnoticed. Forecasters have had to raise their projected growth rates and raise them again. The moderate speed limits set by Blinder (1997) and Krugman (1997), reflecting the best evidence available only a few years ago, have given way to the optimism of the ordinarily conservative community of official forecasters. Our review of the evidence now available suggests that the official forecasters are relying very heavily on a continuation of the acceleration in U.S. economic growth since 1995.

139. What are the risks to the optimistic view of future U.S. economic growth in the information age? Upward revision of growth projections seems a reasonable response as evidence accumulates of a possible break in trend productivity growth. Nonetheless, caution is warranted until productivity patterns have been observed for a longer time period. Should the pace of technological progress in high-tech industries diminish, economic growth would be hit with a double whammy – slower total factor productivity growth in important industries that produce high-tech equipment and slower capital accumulation in other sectors that invest in and use the high-tech equipment. Both factors have made important contribution to the recent success of the US economy, so that any slowdown would retard future growth potential.

140. At the same time we must emphasize that the uncertainty surrounding intermediate term projections has become much greater as a consequence of widening gaps in our knowledge, rather than changes in the volatility of economic activity. The excellent research that underlies estimates of prices and quantities of computer investment in NIPA has provided much needed illumination of the impact of information technology. But this is only part of the contribution of information technology to economic growth and may not be the largest part. As the role of technology continues to increase, ignorance of the most basic empirical facts about the information economy will plague researchers as well as forecasters. The uncertainties about past and future economic growth will not be resolved quickly. This is, of course, a guarantee that the lively economic debate now unfolding will continue for the foreseeable future.

141. The first priority for empirical research must be constant-quality price indexes for a wider variety of high-tech assets. These assets are becoming increasingly important in the US economy, but only a small portion have constant-quality price deflators that translate the improved production characteristics into accurate measures of investment and output. This echoes the earlier findings of Gordon (1990), who reported that official price measures substantially overstate price changes for capital goods. In fact, Gordon identified computers and communications equipment as two assets with the largest overstatements, together with aircraft, which we have not included.[57] Much remains to be done to complete Gordon's program of implementing constant-quality price deflators for all components of investment in NIPA.

142. The second priority for research is to decompose the sources of economic growth to the industry level. Fortunately, the required methodology required is well established and increasingly familiar. Domar aggregation over industries underlies back-of-the-envelope calculations of the contribution of information technology to economic growth in Section III, as well as the more careful and comprehensive view of the contributions of industry-level productivity that we have presented in Section IV. This view will require considerable refinement to discriminate among alternative perspectives on the rapidly unfolding information economy. However, the evidence already available is informative on the most important issue. This is the "new economy" view that the impact of information technology is like phlogiston, an invisible substance that spills over into every kind of economic activity and reveals its presence by increases in

57 . Gordon (1990), Table 12.3, p. 539.

industry-level productivity growth across the US economy. This view is simply inconsistent with the empirical evidence.

143. Our results suggest that while technology is clearly the driving force in the growth resurgence, familiar economic principles can be applied. Productivity growth in the production of information technology is responsible for a sizable part of the recent spurt in TFP growth and can be identified with price declines in high-tech assets and semi-conductors. This has induced an eruption of investment in these assets that is responsible for capital deepening in the industries that use information technology. Information technology provides a dramatic illustration of economic incentives at work! However, there is no corresponding eruption of industry-level productivity growth in these sectors that would herald the arrival of phlogiston-like spillovers from production in the information technology sectors.

144. Many of the goods and services produced using high-tech capital may not be adequately measured, as suggested in the already classic paper of Griliches (1994). This may help to explain the surprisingly low productivity growth in many of the high-tech intensive, service industries. If the official data are understating both real investment in high-tech assets and the real consumption of commodities produced from these assets, the under-estimation of U.S. economic performance may be far more serious than we have suggested. Only as the statistical agencies continue their slow progress towards improved data and implementation of state-of-the-art methodology will this murky picture become more transparent.

Appendix A - Estimating output

145. We begin with the National Income and Product Accounts (NIPA) as our primary source data. These data correspond to the most recent benchmark revision published by the Bureau of Economic Analysis (BEA) on October 29, 1999. These data provide measures of investment and consumption, in both current and chained 1996 dollars. The framework developed by Christensen and Jorgenson (1973), however, calls for a somewhat broader treatment of output than in the national accounts. Most important, consumers' durable goods are treated symmetrically with investment goods, since both are long-lived assets that are accumulated and provide a flow of services over their lifetimes. We use a rental price to impute a flow of consumers' durables services included in both consumption output and capital input. We also employ a rental price to make relatively small imputations for the service flows from owner-occupied housing and institutional equipment.

146. Table A-1 presents the time series of total output in current dollars and the corresponding price index from 1959-98. The table also includes the current dollar value and price index for information technology output components – computer investment, software investment, communications investments, computer and software consumption, and the imputed service flow of computer and software consumer durables – as described in Equation (4) in the text.

Appendix B - Estimating capital services

i) Capital services methodology

147. We begin with some notation for measures of investment, capital stock, and capital services, for both individual assets and aggregates. For individual assets:

$I_{i,t}$ = quantity of investment in asset *i* at time *t*

$P_{i,,t}$ = price of investment in asset *i* at time *t*

δ_i = geometric depreciation rate for asset *i*

$S_{i,t}$ = quantity of capital stock of asset *i* at time *t*

$P_{i,t}$ = price of capital stock of asset *i* at time *t*

$K_{i,t}$ = quantity of capital services from asset *i* at time *t*

$c_{i,t}$ = price of capital services from asset *i* at time *t*

where the *i* subscript refers to different types of tangible assets – equipment and structures, as well as consumers' durable assets, inventories, and land, all for time period *t*.

148. For economy-wide aggregates:

I_t = quantity index of aggregate investment at time *t*

$P_{I,t}$ = price index of aggregate investment at time *t*

S_t = quantity index of aggregate capital stock at time t

$P_{S,t}$ = price index of aggregate capital stock at time t

K_t = quantity index of aggregate capital services at time t

c_t = price of capital services at time t

$q_{K,t}$ = quality index of aggregate capital services at time t

149. Our starting point is investment in individual assets we assume that the price index for each asset measures investment goods in identically productive "efficiency units" over time. For example, the constant-quality price deflators in the NIPA measure the large increase in computing power as a decline in price of computers.[58] Thus, a faster computer is represented by more $I_{i,t}$ in a given period and a larger accumulation of $S_{i,t}$, as measured by the perpetual inventory equation:

$$\text{(B-1)} \qquad S_{i,t} = S_{i,t-1}(1-\delta_i) + I_{i,t} = \sum_{\tau=0}^{\infty}(1-\delta_i)^{\tau} I_{i,t-\tau}$$

where capital is assumed to depreciate geometrically at the rate δ_i.

150. Equation (B-1) has the familiar interpretation that the capital stock is the weighted sum of past investments, where weights are derived from the relative efficiency profile of capital of different ages. Moreover, since $S_{i,t}$ is measured in base-year efficiency units, the appropriate price for valuing the capital stock is simply the investment price deflator, $P_{i,t}$.. Furthermore, $S_{i,t}$ represents the installed stock of capital, but we are interested in $K_{i,t}$, the flow of capital services from that stock over a given period. This distinction is not critical at the level of individual assets, but becomes important when we aggregate heterogeneous assets. For individual assets, we assume the flow of capital services is proportional to the average of the stock available at the end of the current and prior periods:

$$\text{(B-2)} \qquad K_{i,t} = q_i \frac{\left(S_{i,t} + S_{i,t-1}\right)}{2}$$

where q_i denotes this constant of proportionality, set equal to unity. Note that this differs from our earlier work, *e.g.*, Jorgenson (1990), Jorgenson and Stiroh (1999), and Ho, Jorgenson, and Stiroh (1999), where capital service flows were assumed proportional to the lagged stock for individual assets.

151. Our approach assumes any improvement in input characteristics, such as a faster processor in a computer, is incorporated into investment $I_{i,t}$ via deflation of the nominal investment series. That is, investment deflators transform recent vintages of assets into an equivalent number of efficiency units of earlier vintages. This is consistent with the perfect substitutability assumption across vintages and our use of the perpetual inventory method, where vintages differ in productive characteristics due to the age-related depreciation term.

58 . See BLS (1997), particularly Chapter 14, for details on the quality adjustments incorporated into the producer prices indexes that are used as the primary deflators for the capital stock study. Cole *et al.* (1986) and Triplett (1986, 1989) provide details on the estimation of hedonic regressions for computers.

152. We estimate a price of capital services that corresponds to the quantity flow of capital services via a rental price formula. In equilibrium, an investor is indifferent between two alternatives: earning a nominal rate of return, i_t, on a different investment or buying a unit of capital, collecting a rental fee, and then selling the depreciated asset in the next period. The equilibrium condition, therefore, is:

$$\text{(B-3)} \qquad (1+i_t)P_{i,t-1} = c_{i,t} + (1-\delta_i)P_{i,t}$$

and rearranging yields a variation of the familiar cost of capital equation:

$$\text{(B-4)} \qquad c_{i,t} = (i_t - \pi_{i,t})P_{i,t-1} + \delta_i P_{i,t}$$

where the asset-specific capital gains term is $\pi_{i,t} = (P_{i,t} - P_{i,t-1}) / P_{i,t-1}$.

153. This formulation of the cost of capital effectively includes asset-specific revaluation terms. If an investor expects capital gains on his investment, he will be willing to accept a lower service price. Conversely, investors require high service prices for assets like computers with large capital losses. Empirically, asset-specific revaluation terms can be problematic due to wide fluctuations in prices from period to period that can result in negative rental prices. However, asset-specific revaluation terms are becoming increasingly important as prices continue to decline for high-tech assets. Jorgenson and Stiroh (1999), for example, incorporated economy-wide asset revaluation terms for all assets and estimated a relatively modest growth contribution from computers.

154. As discussed by Jorgenson and Yun (1991), tax considerations also play an important role in rental prices. Following Jorgenson and Yun, we account for investment tax credits, capital consumption allowances, the statutory tax rate, property taxes, debt/equity financing, and personal taxes, by estimating an asset-specific, after-tax real rate of return, $r_{i,t}$, that enters the cost of capital formula:

$$\text{(B-5)} \qquad c_{i,t} = \frac{1 - ITC_{i,t} - \tau_t Z_{i,t}}{1-\tau_t}\left[r_{i,t}P_{i,t-1} + \delta_i P_{i,t}\right] + \tau_p P_{i,t-1}$$

where $ITC_{i,t}$ is the investment tax credit, τ_t is the statutory tax rate, $Z_{i,t}$ is the capital consumption allowance, τ_p is a property tax rate, all for asset *i* at time *t*, and $r_{i,t}$ is calculated as:

$$\text{(B-6)} \qquad r_{i,t} = \beta[(1-\tau_t)i_t - \pi_{i,t}] + (1-\beta)\left[\frac{\rho_t - \pi_{i,t}(1-t_q^g)}{(1-t_q^e)\alpha + (1-t_q^g)(1-\alpha)}\right]$$

where β is the debt/capital ratio, i_t is the interest cost of debt, ρ_t is the rate of return to equity, α is the dividend payout ratio, and t_q^g and t_q^e are the tax rates on capital gains and dividends, respectively. $\pi_{i,t}$ is the inflation rate for asset *i*, which allows $r_{i,t}$ to vary across assets.[59]

59 . A complication, of course, is that ρ_t is endogenous. We assume the after-tax rate of return to all assets is the same and estimate ρ_t as the return that exhausts the payment of capital across all assets in the corporate sector. In addition, tax considerations vary across ownership classes, *e.g.*, corporate, non-corporate, and household. We account for these differences in our empirical work, but do not go into details here. See Jorgenson and Yun (1991, Chapter 2).

155. Equations (B-1) through (B-6) describe the estimation of the price and quantity of capital services for individual assets: $P_{i,t}$ and $I_{i,t}$ for investment; $P_{i,t}$ and $S_{i,t}$ for capital stock; and $c_{i,t}$ and $K_{i,t}$ for capital services. For an aggregate production function analysis, we require an aggregate measure of capital services, $K_t = f(K_{1,t}, K_{2,t}, ...K_{n,t})$, where n includes all types of reproducible fixed assets, consumers' durable assets, inventories, and land. We employ quantity indexes of to generate aggregate capital services, capital stock, and investment series.[60]

156. The growth rate of aggregate capital services is defined as a share-weighted average of the growth rate of the components:

$$\text{(B-7)} \qquad \Delta \ln K_t = \sum_i \bar{v}_{i,t} \Delta \ln K_{i,t}$$

where weights are value shares of capital income:

$$\text{(B-8)} \qquad \bar{v}_{i,t} = \frac{1}{2}\left(\frac{c_{i,t}K_{i,t}}{\sum_i c_{i,t}K_{i,t}} + \frac{c_{i,t-1}K_{i,t-1}}{\sum_i c_{i,t-1}K_{i,t-1}} \right)$$

and the price index of aggregate capital services is defined as:

$$\text{(B-9)} \qquad c_t = \frac{\sum_i c_{i,t}K_{i,t}}{K_t}$$

157. Similarly, the quantity index of capital stock is given by:

$$\text{(B-10)} \qquad \Delta \ln S_t = \sum_i \bar{w}_{i,t} \Delta \ln S_{i,t}$$

where the weights are now value shares of the aggregate capital stock:

$$\text{(B-11)} \qquad \bar{w}_{i,t} = \frac{1}{2}\left(\frac{P_{i,t}S_{i,t}}{\sum_i P_{i,t}S_{i,t}} + \frac{P_{i,t-1}S_{i,t-1}}{\sum_i P_{i,t-1}S_{i,t-1}} \right)$$

and the price index for the aggregate capital stock index is:

$$\text{(B-12)} \qquad P_{S,t} = \frac{\sum_i P_{i,t}S_{i,t}}{S_t}$$

158. Finally, the aggregate quantity index of investment is given by:

60 . See Diewert (1980) and Fisher (1992) for details.

$$\text{(B-13)} \quad \Delta \ln I_t = \sum_i \bar{u}_{i,t} \Delta \ln I_{i,t}$$

where the weights are now value shares of aggregate investment:

$$\text{(B-14)} \quad \bar{u}_{i,t} = \frac{1}{2}\left(\frac{P_{i,t} I_{i,t}}{\sum_i P_{i,t} I_{i,t}} + \frac{P_{i,t-1} I_{i,t-1}}{\sum_i P_{i,t-1} I_{i,t-1}} \right)$$

and the price index for the aggregate investment index is:

$$\text{(B-15)} \quad P_{I,t} = \frac{\sum_i P_{i,t} I_{i,t}}{I_t}$$

159. The most important point from this derivation is the difference between the growth rate of aggregate capital services, Equation (B-7), and the growth rate of capital stock, Equation (B-10); this reflects two factors. First, the weights are different. The index of aggregate capital services uses rental prices as weights, while the index of aggregate capital stock uses investment prices. Assets with rapidly falling asset prices will have relatively large rental prices. Second, as can be seen from Equation (B-2), capital services are proportional to a two-period average stock, so the timing of capital services growth and capital stock growth differ for individual assets. In steady-state with a fixed capital to output ratio, this distinction is not significant, but if asset accumulation is either accelerating or decelerating, this timing matters.

160. A second point to emphasize is that we can define an "aggregate index of capital quality," $q_{K,t}$, analogously to Equation (B-2). We define the aggregate index of capital quality as $q_{K,t}=K_t/((S_t+S_{t-1})/2)$, and it follows that the growth of capital quality is defined as:

$$\text{(B-16)} \quad \Delta \ln q_{K,t} = \Delta \ln K_t - \Delta \ln\left(\frac{(S_t + S_{t-1})}{2} \right) = \sum_i (\bar{v}_{i,t} - \bar{w}_{i,t}) \Delta \ln\left(\frac{(S_{t,i} + S_{t-1,i})}{2} \right)$$

161. Equation (B-16) defines growth in capital quality as the difference between the growth in capital services and the growth in average capital stock. This difference reflects substitution towards assets with relatively high rental price weights and high marginal products. For example, the rental price for computers is declining rapidly as prices fall, which induces substitution towards computers and rapid capital accumulation. However, the large depreciation rate and large negative revaluation term imply that computers have a high marginal product, so their rental price weight greatly exceeds their asset price weight. Substitution towards assets with higher marginal products is captured by our index of capital quality.

ii) Investment and capital data

162. Our primary data source for estimating aggregating the flow of capital services is the "Investment Estimates of Fixed Reproducible Tangible Wealth, 1925-1997" (BEA (1998b, 1998c)). These data contain historical cost investment and chain-type quantity indices for 47 types of non-residential assets, 5 types of residential assets, and 13 different types of consumers' durable assets from 1925 to 1997. Table B-1 shows

our reclassification of the BEA data into 52 non-residential assets, 5 residential assets, and 13 consumers' durable assets.[61]

163. Table B-2 presents the value and price index of the broadly defined capital stock, as well as individual information technology assets. Table B-3 presents similar data, but for capital service flows rather than capital stocks.[62] The price of capital stocks for individual assets in Table B-2 is the same as the investment price in Table A-1, but the prices differ for aggregates due to differences between weights based on investment flows and those based on asset stocks. The price index for investment grows more slowly than the price index for assets, since short-lived assets with substantial relative price declines are a greater proportion of investment.

164. An important caveat about the underlying the investment data is that it runs only through 1997 and is not consistent with the BEA benchmark revision in October 1999. We have made several adjustments to reflect the BEA revision, make the data consistent with our earlier work, and extend the investment series to 1998. First, we have replaced the Tangible Wealth series on "computers and peripherals equipment" and replaced it with the NIPA investment series for "computers and peripherals equipment," in both current and chained 1996 dollars. These series were identical in the early years and differed by about 5% in current dollars in 1997. Similarly, we used the new NIPA series for investment in "software," "communications equipment," and for personal consumption of "computers, peripherals, and software" in both current and chained 1996 dollars. These NIPA series enable us to maintain a complete and consistent time series that incorporates the latest benchmark revisions and the expanded output concept that includes software.

165. Second, we have combined investment in residential equipment with "other equipment," a form of non-residential equipment. This does not change the investment or capital stock totals, but reallocates some investment and capital from the residential to the non-residential category.

166. Third, we control the total value of investment in major categories – structures, equipment and software, residential structures, and total consumers' durables – to correspond with NIPA aggregates. This adjustment maintains a consistent accounting for investment and purchases of consumers' durables as inputs and outputs. Computer investment, software investment, communications investment, and consumption of computers, peripherals, and software series not adjusted.

167. Fourth, we extended the investment series through 1998 based on NIPA estimates. For example, the 1998 growth rate for other fabricated metal products, steam engines, internal combustion engines, metalworking machinery, special industry machinery, general industrial equipment, and electrical transmission and distribution equipment were taken from the "other" equipment category in NIPA. The growth rate of each type of consumers' durables was taken directly from NIPA.

168. These procedures generated a complete time series of investment in 57 private assets (29 types of equipment and software, 23 types of non-residential structures, and 5 types of residential structures) and consumption of 13 consumers' durable assets in both current dollars and chained-1996 dollars from 1925 to 1998. For each asset, we created a real investment series by linking the historical cost investment and the quantity index in the base-year 1996. Capital stocks were then estimated using the perpetual inventory method in Equation (B-1) and a geometric depreciation rate, based on Fraumeni (1997) and reported in Table B-1.

61 . Katz and Herman (1997) and Fraumeni (1997) provide details on the BEA methodology and underlying data sources.

62 . Note that these price indices have been normalized to equal 1.0 in 1996, so they do not correspond to the components of the capital service formula in Equation (B-5).

169. Important exceptions are the depreciation rates for computers, software, and autos. BEA (1998a) reports that computer depreciation is based on the work of Oliner (1993, 1994), is non-geometric, and varies over time. We estimated a best-geometric approximation to the latest depreciation profile for different types of computer assets and used an average geometric depreciation rate of 0.315, which we used for computer investment, software investment, and consumption of computers, peripherals, and software. Similarly, we estimated a best geometric approximation to the depreciation profile for autos of 0.272.

170. We also assembled data on investment and land to complete our capital estimates. The inventory data come primarily from NIPA in the form of farm and non-farm inventories. Inventories are assumed to have a depreciation rate of zero and do not face an investment tax credit or capital consumption allowance, so the rental price formula is a simplified version of Equation (B-5).

171. Data on land are somewhat more problematic. Through 1995, the Federal Reserve Board published detailed data on land values and quantities in its “Balance Sheets for the US Economy” study (Federal Reserve Board (1995, 1997)), but the underlying data became unreliable and are no longer published. We use the limited land data available in the “Flow of Funds Accounts of the United States” and historical data described in Jorgenson (1990) to estimate a price and a quantity of private land. As a practical matter, this quantity series varies very little, so its major impact is to slow the growth of capital by assigning a positive weight to the zero growth rate of land. Like inventories, depreciation, the investment tax credit, and capital consumption allowances for land are zero.

172. A final methodological detail involves negative service prices that sometimes result from the use of asset-specific revaluation terms. As can be seen from the simplified cost of capital formula in Equation (B-5), an estimated service price can be negative if asset inflation is high relative to the interest and depreciation rates. Economically, this is possible, implying capital gains were higher than expected. Negative service prices make aggregation difficult so we made adjustments for several assets. In a small number of cases for reproducible assets and inventories, primarily structures in the 1970s, we used smoothed inflation for surrounding years rather than the current inflation in the cost of capital calculation. For land, which showed large capital gains throughout and has no depreciation, we used the economy-wide rate of asset inflation for all years.

Appendix C - Estimating labor input

i) Labor input methodology

173. We again begin with some notation for measures of hours worked, labor inputs, and labor quality for worker categories:

$H_{j,t}$ = quantity of hours worked by worker category j at time t

$w_{j,t}$ = price of an hour worked by worker category j at time t

$L_{j,t}$ = quantity of labor services from worker category j at time t

and for economy-wide aggregates:

H_t = quantity of aggregate hours worked at time t

W_t = average wage of hours worked at time t

L_t = quantity index of labor input at time t

$P_{L,t}$ = price index of labor input at time t

$q_{L,t}$ = quality index of labor input at time t

174. In general, the methodology for estimating labor input parallels capital services, but the lack of an investment-type variable makes the labor input somewhat more straightforward. For each individual category of workers, we begin by assuming the flow of labor service is proportional to hours worked:

$$\text{(C-1)} \qquad L_{j,t} = q_{L,j} H_{j,t}$$

where $q_{L,j}$ is the constant of proportionality for worker category j, set equal to unity.

175. The growth rate of aggregate labor input is defined as the share-weighted aggregate of the components as:

$$\text{(C-2)} \qquad \Delta \ln L_t = \sum_j \bar{v}_{j,t} \Delta \ln L_{j,t}$$

where weights are value shares of labor income:

$$\text{(C-3)} \qquad \bar{v}_{j,t} = \frac{1}{2}\left(\frac{w_{j,t} L_{j,t}}{\sum_j w_{j,t} L_{j,t}} + \frac{w_{j,t-1} L_{j,t-1}}{\sum_j w_{j,t-1} L_{j,t-1}} \right)$$

and the price of aggregate labor input is defined as:

$$\text{(C-4)} \qquad P_{L,t} = \frac{\sum_j w_{j,t} L_{j,t}}{L_t}$$

176. We define the "aggregate index of labor quality", $q_{L,t}$, $q_{L,t}=L_t/H_t$, where H_t is the unweighted sum of labor hours:

$$\text{(C-5)} \qquad H_t = \sum_j H_{j,t}$$

177. The growth in labor quality is then defined as:

$$\text{(C-6)} \qquad \Delta \ln q_{L,t} = \sum_j \bar{v}_{j,t} \Delta \ln H_{j,t} - \Delta \ln H_t$$

178. Equation (C-6) defines growth in labor quality as the difference between weighted and unweighted growth in labor hours. As with capital, this reflects substitutions among heterogeneous types of labor with different characteristics and different marginal products. As described by Ho and Jorgenson (1999), one can further decompose labor quality into components associated with different characteristics of labor, such as age, sex, and education.

ii) Labor data

179. Our primary data sources are individual observations from the decennial Censuses of Population for 1970, 1980, and 1990, the NIPA, and the annual Current Population Survey (CPS). The NIPA provide totals for hours worked and the Census and CPS allows us to estimate labor quality growth. Details on the construction of the labor data are in Ho and Jorgenson (1999). Table C-1 reports the primary labor used in this study, including the price, quantity, value, and quality of labor input, as well as employment, weekly hours, hourly compensation, and hours worked.

180. Briefly, the Censuses of Population provide detailed data on employment, hours, and labor compensation across demographic groups in census years. The CPS data are used to interpolate similar data for intervening years and the NIPA data provide control totals. The demographic groups include 168 different types of workers, cross-classified by sex (male, female), class (employee, self-employed or unpaid), age (16-17, 18-24, 25-34, 45-54, 55-64,65+), and education (0-8 years grade school, 1-3 years high school, 4 years high school, 1-3 years college, 4 years college, 5+ years college).[63] Adjustments to the data include allocations of multiple job-holders, an estimation procedure to recover "top-coded" income data, and bridging to maintain consistent definitions of demographic groups over time.

181. These detailed data cover 1959 to 1995 and are taken from Ho and Jorgenson (1999). This allows us to estimate the quality of labor input for the private business sector, general government, and government enterprises, where only the private business sector index is used in the aggregate growth accounting results. For the years 1996-98, we estimate labor quality growth by holding relative wages across labor types constant, and incorporating demographic projections for the labor force. Hours worked by employees are taken from the latest data in the NIPA; hours worked by the self-employed are estimated by Ho and Jorgenson (1999).

Appendix D - Estimating industry-level productivity

182. Our primary data are annual time series of inter-industry transactions in current and constant prices, including final demands by commodity, investment and labor inputs by industry, and output by industry. The first building block is a set of inter-industry transactions produced by the Employment Projections Office at the Bureau of Labor Statistics (BLS). These data report intermediate inputs and total value-added (the sum of capital and labor inputs and taxes) for 185 industries from 1977 to 1995. A major advantage of this BLS inter-industry data is that they provide the necessary interpolations between benchmark years.

183. We aggregate the data from the "Make" and "Use" tables to generate inter-industry transactions for 35 private business industries at approximately the two-digit Standard Industrial Classification (SIC) level. These tables enable us to generate growth rates of industry outputs, growth rates of intermediate inputs, and shares of intermediate inputs as needed in Equation (29). They also provide control totals for value-added in each industry, the sum of the values of capital and labor services and taxes.

184. Estimation of capital services and labor input follows the procedures described above for each industry. We collected information from three sources to estimate prices and quantities of capital and labor inputs by industry. An industry-level breakdown of the value of capital and labor input is available in the "gross product originating" series described in Lum and Yuskavage (1997) of the BEA. Investments by asset classes and industries are from the BEA Tangible Wealth Survey (BEA (1998a), described by Katz

63 . There is also an industry dimension, which we do not exploit in this aggregate framework, but is used in the industry productivity analysis discussed below.

and Herman (1997)). Labor data across industries are from the decennial Census of Population and the annual Current Population Survey. We use employ the prices and quantities of labor services for each industry constructed by Ho and Jorgenson (1999).

185. We also generate capital and labor services for a Private Household sector and the Government sector.[64] For Private Households, the value of labor services equals labor income in BLS's private household industry, while capital income reflects the imputed flow of capital services from residential housing, consumers' durables, and household land as described above. For Government, labor income equals labor compensation of general government employees and capital income is an estimate flow of capital services from government capital.[65] Note Government Enterprises are treated as a private business industry and are separate from the General Government.

Appendix E - Extrapolation for 1999

186. Table 2 presents primary growth accounting results through 1998 and preliminary estimates for 1999. The data through 1998 are based on the detailed methodology described in Appendixes A-D; the 1999 data are extrapolated based on currently available data and recent trends.

187. Our approach for extrapolating growth accounting results through 1999 was to estimate 1999 shares and growth rates for major categories like labor, capital, and information technology components, as well as the growth in output. The 1999 labor share was estimated from 1995-98 data, hours growth are from BLS (2000), and labor quality growth came from the projections described above. The 1999 growth rates of information technology outputs were taken from the NIPA, and shares were estimated from 1995-98 data. The 1999 growth rates of information technology inputs were estimated from recent investment data and the perpetual inventory method, and shares were estimated from 1995-98 data. The 1999 growth of other capital were estimates from NIPA investment data for broad categories like equipment and software, non-residential structures, residential structures, as well as consumers' durable purchases; the income share was calculated from the estimated labor share. Output growth was estimated from growth in BLS business output and BEA GDP, with adjustment made for different output concepts. Finally, TFP growth for 1999 was estimated as the difference in the estimated output growth and share-weighted input growth.

64 . The Private Household and Government sectors include only capital and labor as inputs. Output in these sectors is defined via a Tornqvist index of capital and labor inputs, so productivity growth is zero by definition.

65 . BEA includes a similar imputation for the flow of government capital services in the national accounts, but our methodology includes a return to capital, as well as depreciation as estimated by BEA.

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TABLES AND FIGURES

Table 1: Average Growth Rates of Selected Outputs and Inputs

	1990-95		1995-98	
	Prices	**Quantities**	**Prices**	**Quantities**
		Outputs		
Private Domestic Output (Y)	1.70	2.74	1.37	4.73
Other (Y_n)	2.01	2.25	2.02	3.82
Computer and Software Consumption (C_c)	-21.50	38.67	-36.93	49.26
Computer Investment (I_c)	-14.59	24.89	-27.58	38.08
Software Investment (I_s)	-1.41	11.59	-2.16	15.18
Communications Investment (I_m)	-1.50	6.17	-1.73	12.79
Computer and Software CD Services (D_c)	-19.34	34.79	-28.62	44.57
		Inputs		
Total Capital Services (K)	0.60	2.83	2.54	4.80
Other (K_n)	1.00	1.78	4.20	2.91
Computer Capital (K_c)	-10.59	18.16	-20.09	34.10
Software Capital (K_s)	-2.07	13.22	-0.87	13.00
Communications Capital (K_m)	3.10	4.31	-7.09	7.80
Total Consumption Services (D)	1.98	2.91	-0.67	5.39
Non-Computer and Software (D_n)	2.55	2.07	0.54	3.73
Computer and Software CD Services (D_c)	-19.34	34.79	-28.62	44.57
Labor (L)	2.92	2.01	2.80	2.81

Notes: CD refers to consumers' durable assets. All values are percentages.

Table 2: Growth in U.S. Private Domestic Output and the Sources of Growth, 1959-99

	1959-98	**1959-73**	**1973-90**	**1990-95**	**1995-98**	**Preliminary* 1995-99**
Growth in Private Domestic Output Growth (Y)	3.630	4.325	3.126	2.740	4.729	4.763
Contribution of Selected Output Components						
Other (Y_n)	3.275	4.184	2.782	2.178	3.659	3.657
Computer and Software Consumption (C_c)	0.035	0.000	0.023	0.092	0.167	0.175
Computer Investment (I_c)	0.150	0.067	0.162	0.200	0.385	0.388
Software Investment (I_s)	0.074	0.025	0.075	0.128	0.208	0.212
Communications Investment (I_m)	0.060	0.048	0.061	0.053	0.122	0.128
Computer and Software CD Services (D_c)	0.036	0.000	0.023	0.089	0.187	0.204
Contribution of Capital Services (K)	1.260	1.436	1.157	0.908	1.611	1.727
Other (K_n)	0.936	1.261	0.807	0.509	0.857	0.923
Computers (K_c)	0.177	0.086	0.199	0.187	0.458	0.490
Software (K_s)	0.075	0.026	0.071	0.154	0.193	0.205
Communications (K_m)	0.073	0.062	0.080	0.058	0.104	0.109
Contribution of CD Services (D)	0.510	0.632	0.465	0.292	0.558	0.608
Other (D_n)	0.474	0.632	0.442	0.202	0.370	0.403
Computers and Software (D_c)	0.036	0.000	0.023	0.089	0.187	0.204
Contribution of Labor (L)	1.233	1.249	1.174	1.182	1.572	1.438
Aggregate Total Factor Productivity (TFP)	0.628	1.009	0.330	0.358	0.987	0.991
Growth of Capital and CD Services	4.212	4.985	3.847	2.851	4.935	5.286
Growth of Labor Input	2.130	2.141	2.035	2.014	2.810	2.575
Contribution of Capital and CD Quality	0.449	0.402	0.405	0.434	0.945	1.041
Contribution of Capital and CD Stock	1.320	1.664	1.217	0.765	1.225	1.293
Contribution of Labor Quality	0.315	0.447	0.200	0.370	0.253	0.248
Contribution of Labor Hours	0.918	0.802	0.974	0.812	1.319	1.190
Average Labor Productivity (ALP)	2.042	2.948	1.437	1.366	2.371	2.580

Notes: A contribution of an output and an input is defined as the share-weighted, real growth rate. CD refers to consumers' durable assets. All values are percentages. 1995-99 results include preliminary estimates for 1999; see the Appendix for details on estimation and data sources.

Table 3: The Sources of ALP Growth, 1959-98

Variable	1959-98	1959-73	1973-90	1990-95	1995-98
Growth of Private Domestic Output (*Y*)	3.630	4.325	3.126	2.740	4.729
Growth in Hours (*H*)	1.588	1.377	1.689	1.374	2.358
Growth in ALP (*Y/H*)	2.042	2.948	1.437	1.366	2.371
ALP Contribution of Capital Deepening	1.100	1.492	0.908	0.637	1.131
ALP Contribution of Labor Quality	0.315	0.447	0.200	0.370	0.253
ALP Contribution of TFP	0.628	1.009	0.330	0.358	0.987

Notes: ALP Contributions are defined in Equation (3). All values are percentages.

Table 4: Impact of Alternative Deflation of Software and Communications Equipment on the Sources of U.S. Economic Growth, 1959-98

	Base Case				Moderate Price Decline				Rapid Price Decline			
	1959-73	**1973-90**	**1990-95**	**1995-98**	**1959-73**	**1973-90**	**1990-95**	**1995-98**	**1959-73**	**1973-90**	**1990-95**	**1995-98**
Growth in Private Domestic Output Growth (*Y*)	4.33	3.13	2.74	4.73	4.35	3.30	2.90	4.89	4.36	3.38	3.03	5.07
Contribution of Selected Output Components												
Other (Y_n)	4.18	2.78	2.18	3.66	4.12	2.76	2.17	3.66	4.08	2.75	2.16	3.66
Computer and Software Consumption (C_c)	0.00	0.02	0.09	0.17	0.00	0.02	0.09	0.17	0.00	0.02	0.09	0.17
Computer Investment (I_c)	0.07	0.16	0.20	0.39	0.07	0.16	0.20	0.39	0.07	0.16	0.20	0.39
Software Investment (I_s)	0.03	0.08	0.13	0.21	0.04	0.14	0.22	0.29	0.05	0.17	0.29	0.40
Communications Investment (I_m)	0.05	0.06	0.05	0.12	0.12	0.19	0.13	0.21	0.16	0.25	0.19	0.27
Computer and Software CD Services (D_c)	0.00	0.02	0.09	0.19	0.00	0.02	0.09	0.19	0.00	0.02	0.09	0.19
Contribution of Capital Services (*K*)	1.44	1.16	0.91	1.61	1.54	1.39	1.15	1.83	1.61	1.51	1.32	2.09
Other (K_n)	1.26	0.81	0.51	0.86	1.25	0.80	0.51	0.86	1.25	0.79	0.51	0.85
Computers (K_c)	0.09	0.20	0.19	0.46	0.09	0.20	0.19	0.46	0.09	0.20	0.19	0.46
Software (K_s)	0.03	0.07	0.15	0.19	0.05	0.15	0.28	0.29	0.06	0.18	0.36	0.45
Communications (K_m)	0.06	0.08	0.06	0.10	0.16	0.25	0.18	0.23	0.22	0.34	0.27	0.33
Contribution of CD Services (*D*)	0.63	0.47	0.29	0.56	0.63	0.46	0.29	0.56	0.63	0.46	0.29	0.56
Non-Computers and Software (D_n)	0.63	0.44	0.20	0.37	0.63	0.44	0.20	0.37	0.63	0.44	0.20	0.37
Computers and Software (D_c)	0.00	0.02	0.09	0.19	0.00	0.02	0.09	0.19	0.00	0.02	0.09	0.19
Contribution of Labor (*L*)	1.25	1.17	1.18	1.57	1.25	1.17	1.18	1.57	1.25	1.18	1.18	1.57
Aggregate Total Factor Productivity (*TFP*)	1.01	0.33	0.36	0.99	0.94	0.27	0.27	0.93	0.88	0.22	0.23	0.85
Growth of Capital and CD Services	4.99	3.85	2.85	4.94	5.24	4.40	3.43	5.44	5.41	4.70	3.84	6.02
Growth of Labor Input	2.14	2.04	2.01	2.81	2.14	2.04	2.01	2.81	2.14	2.04	2.01	2.81
Contribution of Capital and CD Quality	0.40	0.41	0.43	0.95	0.48	0.59	0.63	1.11	0.54	0.70	0.78	1.34
Contribution of Capital and CD Stock	1.66	1.22	0.77	1.23	1.68	1.26	0.82	1.28	1.69	1.27	0.84	1.31
Contribution of Labor Quality	0.45	0.20	0.37	0.25	0.45	0.20	0.37	0.25	0.45	0.20	0.37	0.25
Contribution of Labor Hours	0.80	0.97	0.81	1.32	0.80	0.97	0.81	1.32	0.80	0.98	0.81	1.32
Average Labor Productivity (*ALP*)	2.95	1.44	1.37	2.37	2.98	1.61	1.52	2.53	2.99	1.69	1.65	2.72

Notes: Base Case uses official NIPA price data. Moderate Price Decline uses pre-packaged software deflator for all software and annual price changes of -10.7% for communications equipment. Rapid Price Decline uses annual price changes of -16% for software and -17.9% for communications equipment. See text for details and sources. A contribution is defined as the share-weighted, real growth rate. CD refers to consumers' durable assets. All values are percentages.

Table 5: Information Technology Decomposition of TFP Growth for Alternative Deflation Cases, 1990-98

	Base Case		Moderate Price Decline		Rapid Price Decline	
	1990-95	**1995-98**	**1990-95**	**1995-98**	**1990-95**	**1995-98**
Aggregate TFP Growth	0.36	0.99	0.27	0.93	0.23	0.85
			TFP Contribution			
Information Technology	0.25	0.44	0.46	0.64	0.64	0.86
Computers	0.16	0.32	0.16	0.32	0.16	0.32
Software	0.05	0.08	0.17	0.18	0.28	0.34
Communications	0.04	0.04	0.13	0.13	0.21	0.20
Non-Information Technology	0.11	0.55	-0.19	0.29	-0.41	-0.01
			Relative Price Change			
Computers	-16.6	-29.6	-16.6	-29.6	-16.6	-29.6
Software	-3.4	-4.2	-11.3	-9.7	-18.0	-18.0
Communications	-3.5	-3.8	-12.7	-12.7	-19.9	-19.9
			Average Nominal Share			
Computers	0.96	1.09	0.96	1.09	0.96	1.09
Software	1.54	1.88	1.54	1.88	1.54	1.88
Communications	1.05	1.02	1.05	1.02	1.05	1.02

Notes: Base Case uses official NIPA price data. Moderate Price Decline uses pre-packaged software deflator for all software and -10.7% for communications equipment. Rapid Price Decline uses -16% for software and -17.9% for communications equipment. See text for details and sources. A TFP contribution is defined as the share-weighted, growth rate of relative prices.

Table 6: Growth Rates of Output, Inputs, and Total Factor Productivity
Comparison of BLS, CBO, and Jorgenson-Stiroh

	BLS Nonfarm Bus	CBO Overall Economy			CBO Nonfarm Business			Jorgenson-Stiroh	
	1990-1999	1980-90	1990-99	1999-2010	1980-90	1990-99	1999-2010	1980-90	1990-98
Real Output	3.74	3.0	2.9	3.1	3.2	3.4	3.5	3.48	3.55
Labor Input								2.14	2.34
Hours Worked	1.68	1.6	1.2	1.1	1.6	1.5	1.2	1.81	1.76
Labor Quality								0.33	0.58
Capital Input					3.6	3.6	4.4	3.57	3.68
TFP - not adjusted for labor quality					0.9	1.2	1.4	0.91	0.97
TFP - adjusted for labor quality								0.73	0.63
ALP	2.06	1.4	1.7	1.9	1.5	1.9	2.3	1.67	1.79

Note: CBO estimates refer to "potential" series that are adjusted for business cycle effects. Growth rates do not exactly match Table 5 since discrete growth rate are used here for consistency with CBO's methodology. Hours worked for CBO Overall Economy refers to potential labor force.

Table 7: 1996 Value-Added and Gross Output by Industry

Industry	SIC Codes	Value-Added	Gross Output
Agriculture	01-02, 07-09	133.3	292.2
Metal Mining	10	8.8	10.7
Coal Mining	11-12	14.7	21.1
Petroleum and Gas	13	57.4	83.3
Nonmetallic Mining	14	10.5	17.0
Construction	15-17	336.0	685.5
Food Products	20	147.2	447.6
Tobacco Products	21	26.7	32.7
Textile Mill Products	22	19.9	58.9
Apparel and Textiles	23	40.7	98.5
Lumber and Wood	24	34.2	106.7
Furniture and Fixtures	25	23.4	54.5
Paper Products	26	68.3	161.0
Printing and Publishing	27	113.5	195.6
Chemical Products	28	184.0	371.2
Petroleum Refining	29	44.7	184.3
Rubber and Plastic	30	64.1	148.9
Leather Products	31	3.4	8.1
Stone, Clay, and Glass	32	40.4	79.1
Primary Metals	33	57.6	182.1
Fabricated Metals	34	98.4	208.8
Industrial Machinery and Equipment	35	177.8	370.5
Electronic and Electric Equipment	36	161.9	320.4
Motor Vehicles	371	84.9	341.6
Other Transportation Equipment	372-379	68.0	143.8
Instruments	38	81.3	150.0
Miscellaneous Manufacturing	39	24.8	49.3
Transport and Warehouse	40-47	258.6	487.7
Communications	48	189.7	315.8
Electric Utilities	491, %493	111.8	186.7
Gas Utilities	492, %493, 496	32.9	57.9
Trade	50-59	1,201.2	1,606.4
FIRE	60-67	857.8	1,405.1
Services	70-87, 494-495	1,551.9	2,542.8
Goverment Enterprises		95.2	220.2
Private Households	88	1,248.4	1,248.4
General Government		1,028.1	1,028.1

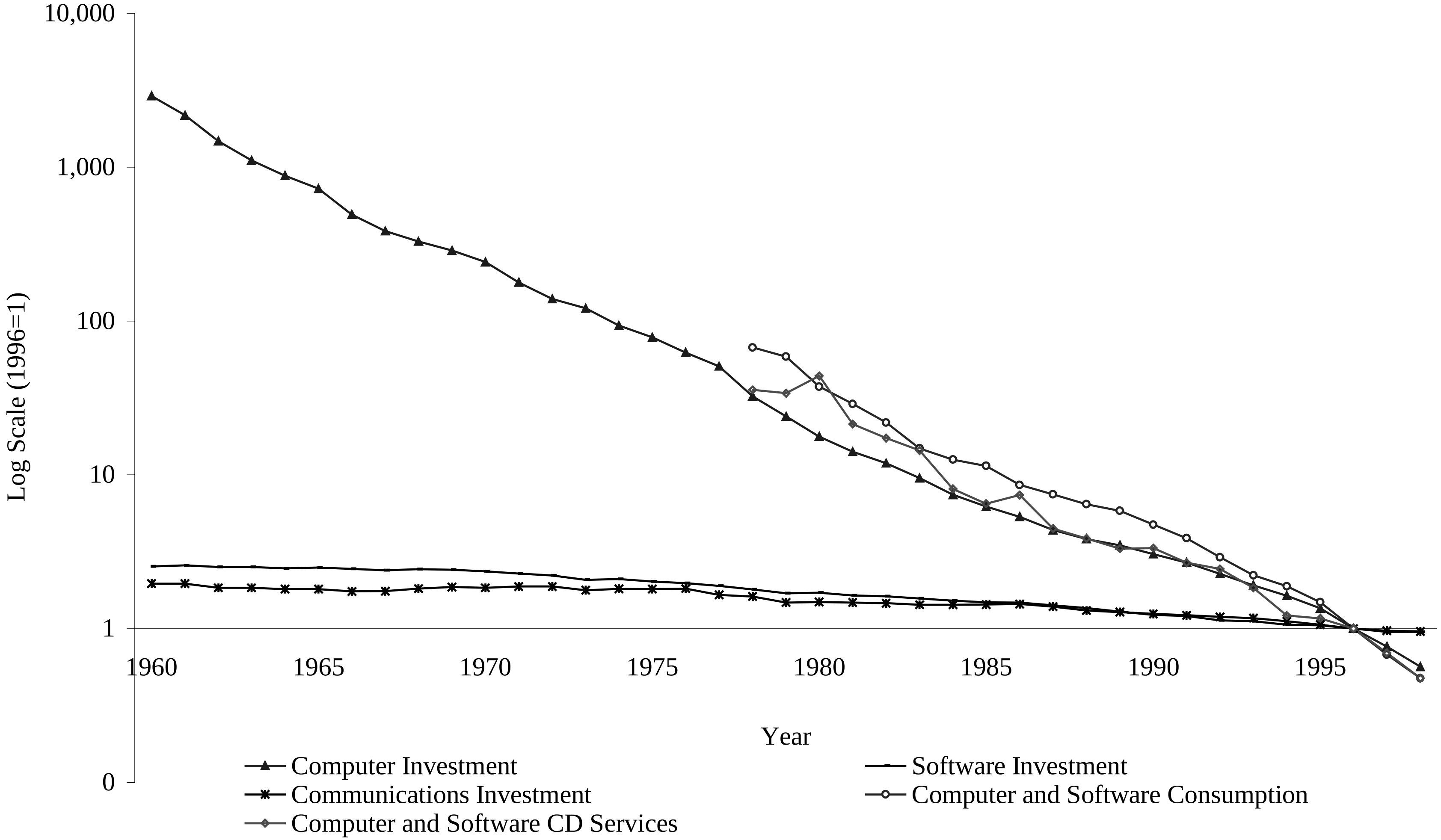
Note: All values are in current dollars. Value-added refers to payments to capital and labor; Gross output includes payments for intermediate inputs.

Table 8: Sources of U.S. Economic Growth by Industry, 1958-96

Industry	Output Growth	Contributions of Inputs: Capital	Labor	Energy	Materials	Productivity Growth	ALP Growth	Domar Weight
Agriculture	1.70	0.19	-0.13	-0.04	0.51	1.17	3.21	0.062
Metal Mining	0.78	0.73	-0.07	-0.07	-0.26	0.44	0.99	0.003
Coal Mining	2.35	0.82	0.00	0.06	0.63	0.84	2.32	0.005
Petroleum and Gas	0.43	0.61	-0.01	0.06	0.20	-0.44	0.88	0.022
Nonmetallic Mining	1.62	0.59	0.18	0.06	0.34	0.46	1.52	0.003
Construction	1.43	0.07	0.87	0.02	0.91	-0.44	-0.38	0.113
Food Products	2.20	0.21	0.18	0.00	1.27	0.54	1.59	0.076
Tobacco Products	0.43	0.59	0.05	0.00	-0.01	-0.20	0.88	0.004
Textile Mill Products	2.23	0.12	0.02	0.01	0.86	1.23	2.54	0.013
Apparel and Textiles	2.03	0.24	0.17	0.00	0.82	0.80	2.01	0.022
Lumber and Wood	2.24	0.21	0.33	0.02	1.70	-0.02	1.55	0.015
Furniture and Fixtures	2.91	0.31	0.58	0.02	1.44	0.56	1.78	0.007
Paper Products	2.89	0.50	0.40	0.05	1.51	0.42	1.96	0.022
Printing and Publishing	2.51	0.55	1.20	0.02	1.19	-0.44	0.14	0.024
Chemical Products	3.47	0.74	0.47	0.09	1.58	0.58	2.02	0.048
Petroleum Refining	2.21	0.44	0.24	0.49	0.71	0.33	0.80	0.033
Rubber and Plastic	5.17	0.47	1.16	0.08	2.43	1.04	1.94	0.016
Leather Products	-2.06	-0.11	-1.13	-0.02	-1.08	0.28	2.08	0.004
Stone, Clay, and Glass	1.86	0.26	0.37	0.00	0.82	0.41	1.30	0.014
Primary Metals	1.14	0.13	0.05	-0.03	0.77	0.22	1.51	0.040
Fabricated Metals	2.28	0.26	0.28	0.00	1.09	0.65	1.88	0.035
Industrial Machinery and Equipment	4.79	0.52	0.75	0.02	2.04	1.46	3.15	0.048
Electronic and Electric Equipment	5.46	0.76	0.65	0.03	2.04	1.98	4.08	0.036
Motor Vehicles	3.61	0.28	0.29	0.02	2.78	0.24	2.28	0.043
Other Transportation Equipment	1.31	0.23	0.37	0.00	0.52	0.18	1.00	0.027
Instruments	5.23	0.65	1.44	0.03	1.99	1.12	2.57	0.017
Miscellaneous Manufacturing	2.53	0.34	0.41	0.00	0.95	0.82	2.08	0.008
Transport and Warehouse	3.25	0.20	0.72	0.12	1.34	0.86	1.74	0.061
Communications	5.00	1.62	0.53	0.02	1.95	0.88	3.93	0.033
Electric Utilities	3.22	1.01	0.20	0.67	0.83	0.51	2.52	0.026
Gas Utilities	0.56	0.66	-0.04	0.14	0.05	-0.24	0.94	0.016
Trade	3.66	0.62	0.83	0.04	1.19	0.98	2.49	0.195
FIRE	3.42	1.14	0.94	0.00	1.52	-0.18	0.66	0.131
Services	4.34	0.84	1.70	0.07	1.92	-0.19	0.92	0.208
Goverment Enterprises	2.86	1.24	1.08	0.23	0.83	-0.52	0.49	0.022
Private Households	3.50	3.55	-0.06	0.00	0.00	0.00	5.98	0.137
General Government	1.35	0.60	0.75	0.00	0.00	0.00	0.46	0.131

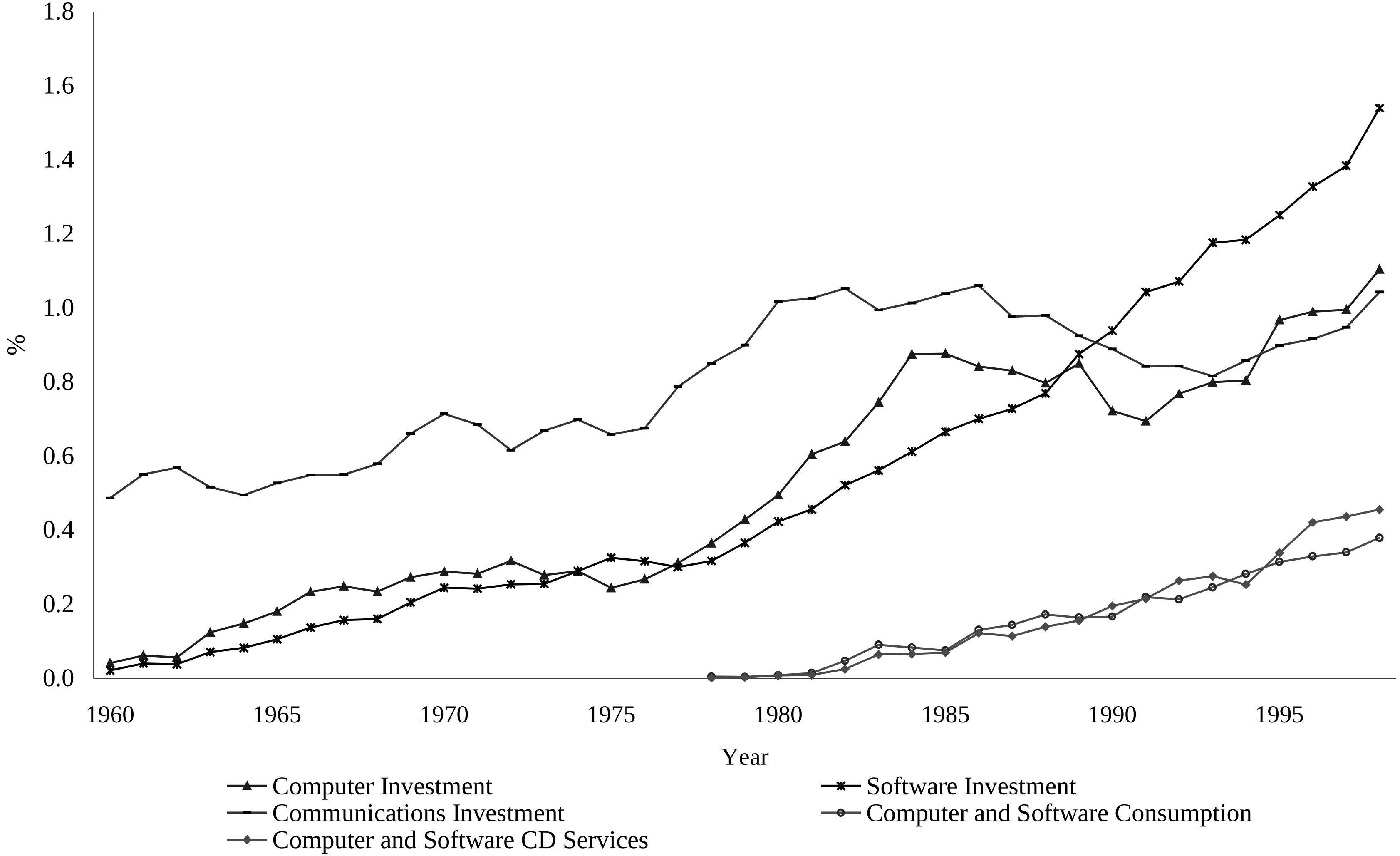
Output Growth is the average annual growth in real gross output. Contributions of Inputs are defined as the average, share-weighted growth of the input. Productivity Growth is defined in Equation (8). ALP Growth is the growth in average labor productivity. Domar Weight is the average ratio of industry gross output to aggregate value added as defined in Equation (9). All numbers except Domar Weights are percentages.

Chart 1: Relative Prices of Information Technology Outputs, 1960-98



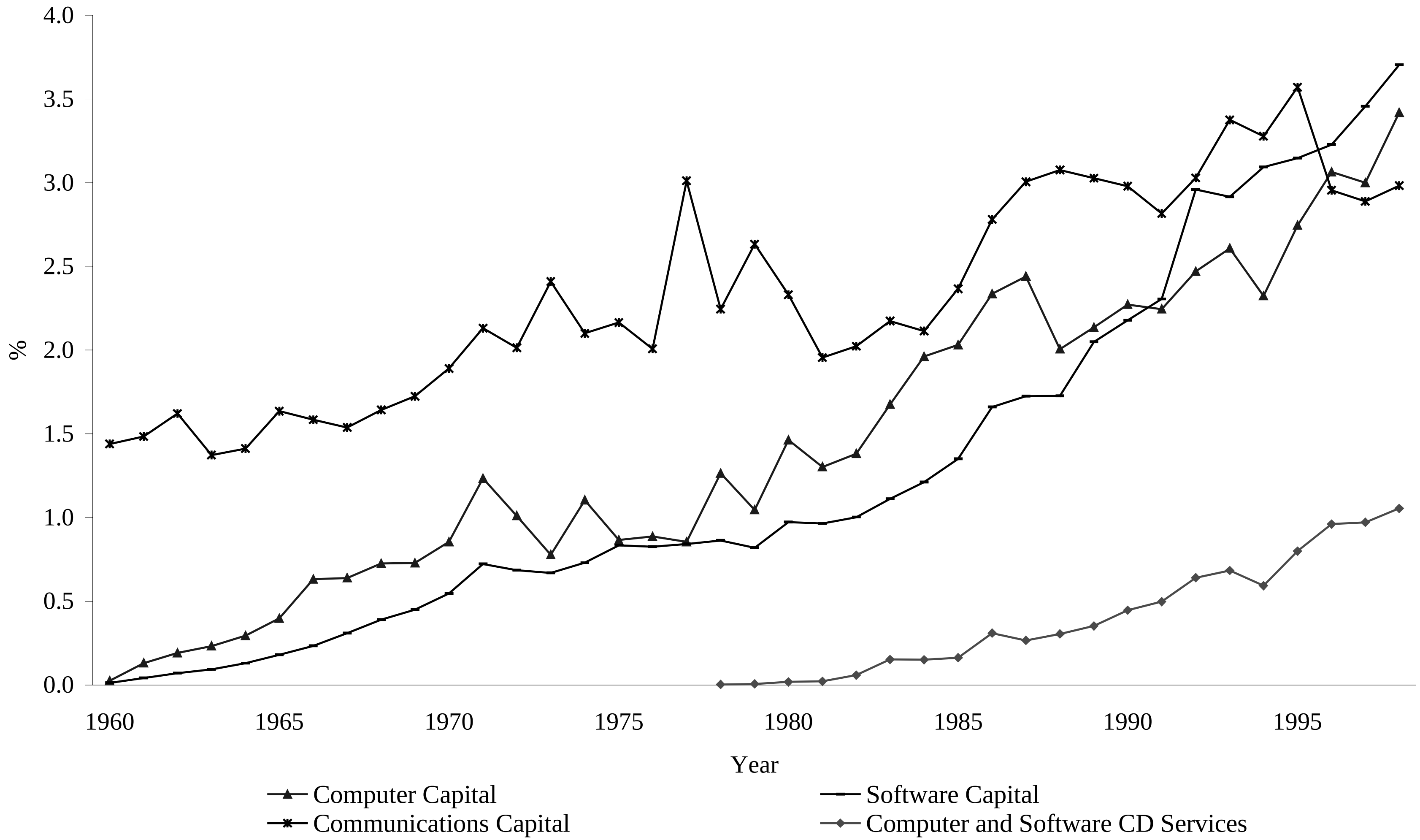
Notes: All prices indexes are relative to the output price index.

Chart 2: Output Shares of Information Technology, 1960-98



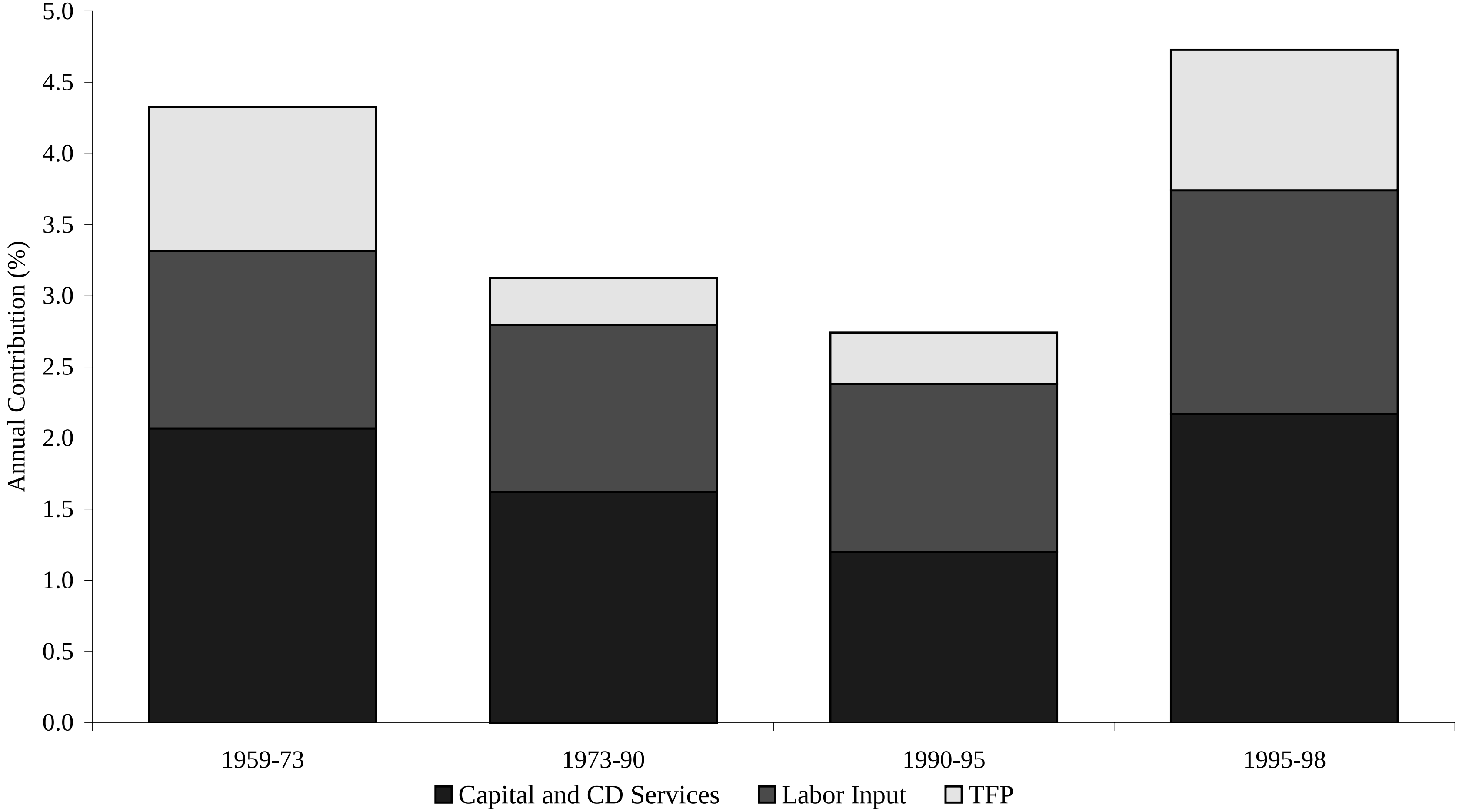
Notes: Share of current dollar output.

Chart 3: Input Shares of Information Technology, 1960-98



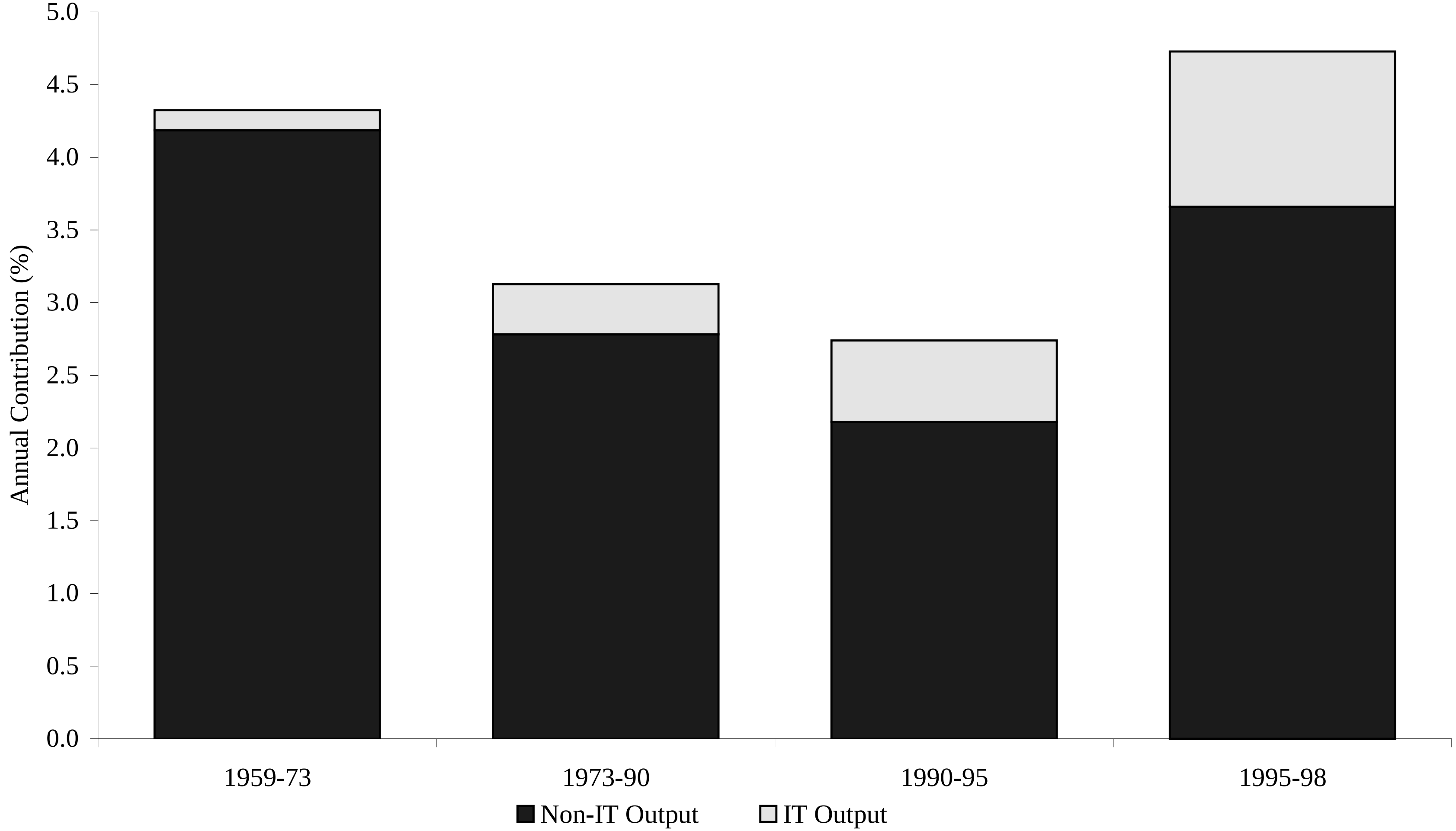
Notes: Share of current dollar capital and consumers' durable services.

Chart 4: Sources of U.S. Economic Growth, 1959-98



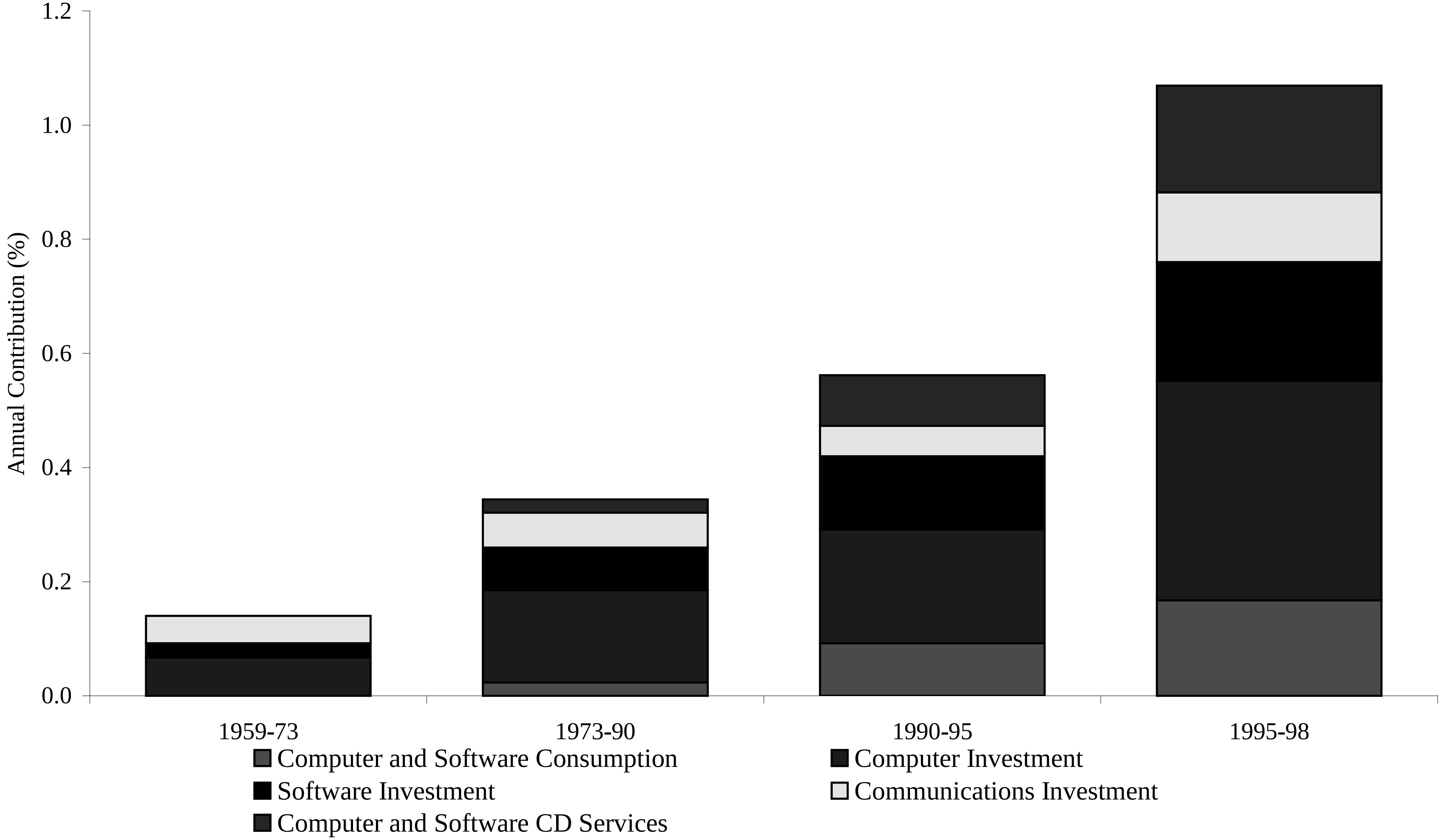
Notes: An input's contribution is the average share-weighted, annual growth rate. TFP defined in Equation (2) in text.

Chart 5: Output Contribution of Information Technology, 1959-98



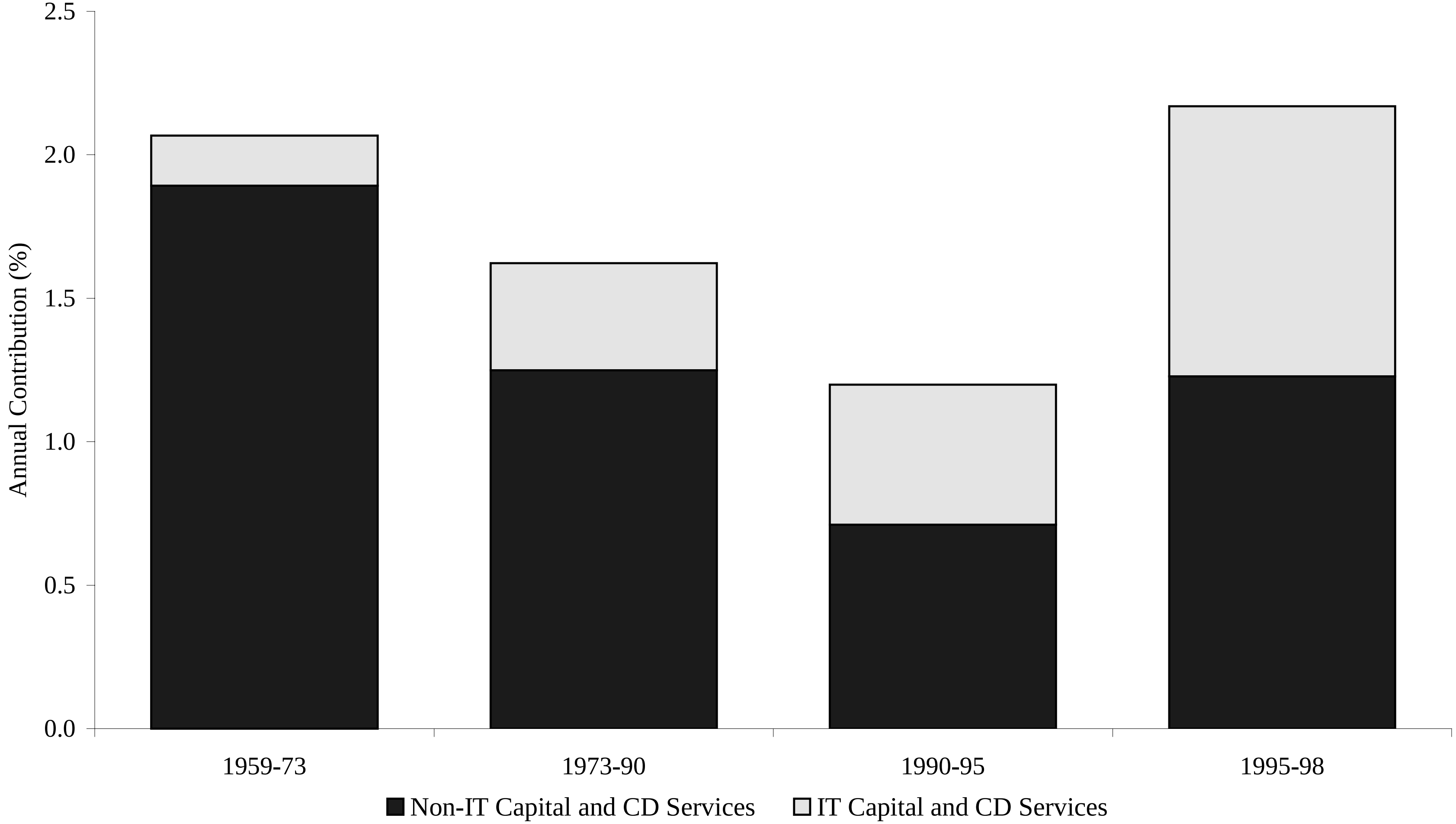
Notes: An output's contribution is the average share-weighted, annual growth rate.

Chart 6: Output Contribution of Information Technology Assets, 1959-98



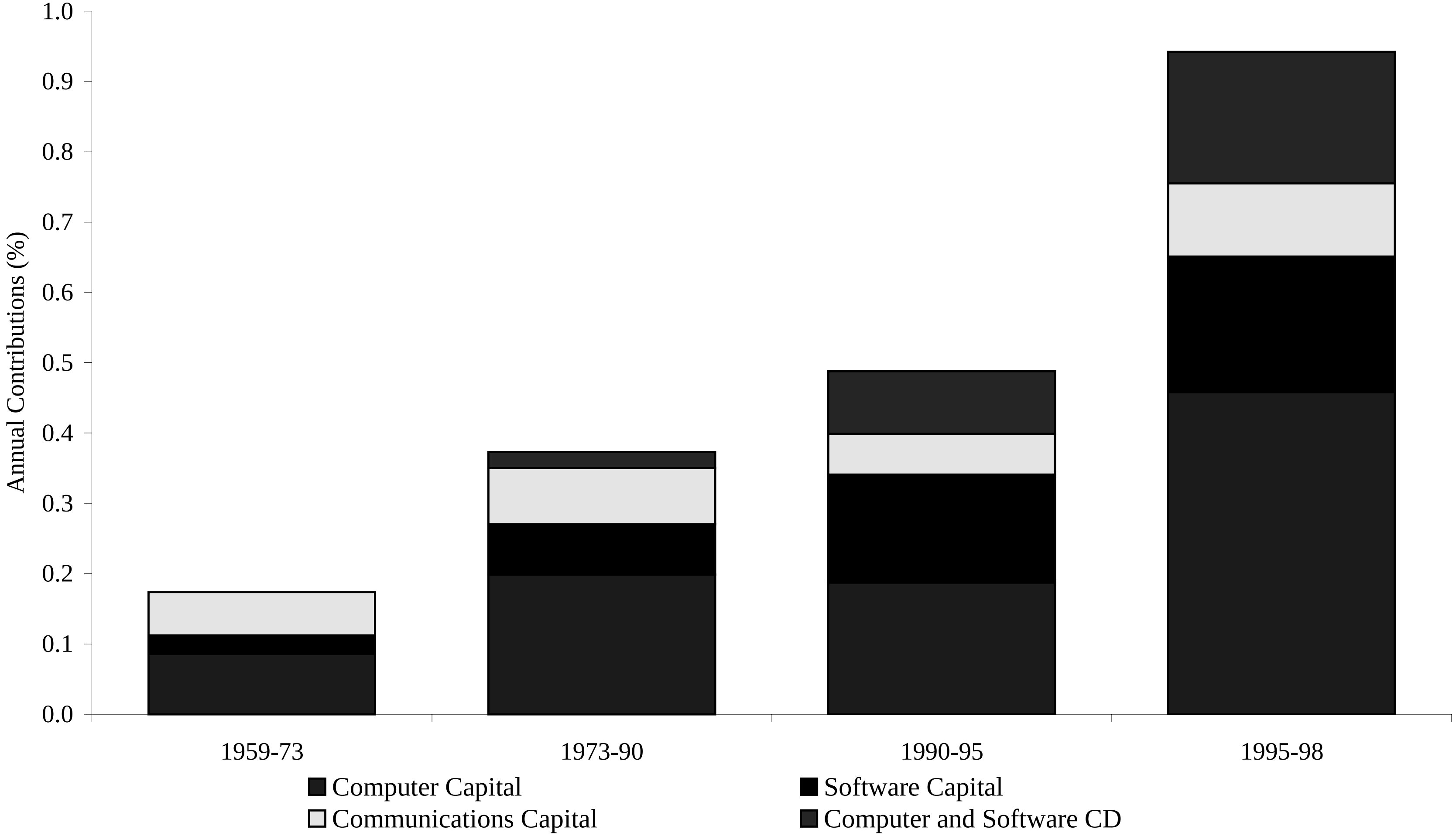
Notes: An output's contribution is the average share-weighted, annual growth rate.

Chart 7: Input Contribution of Information Technology, 1959-98



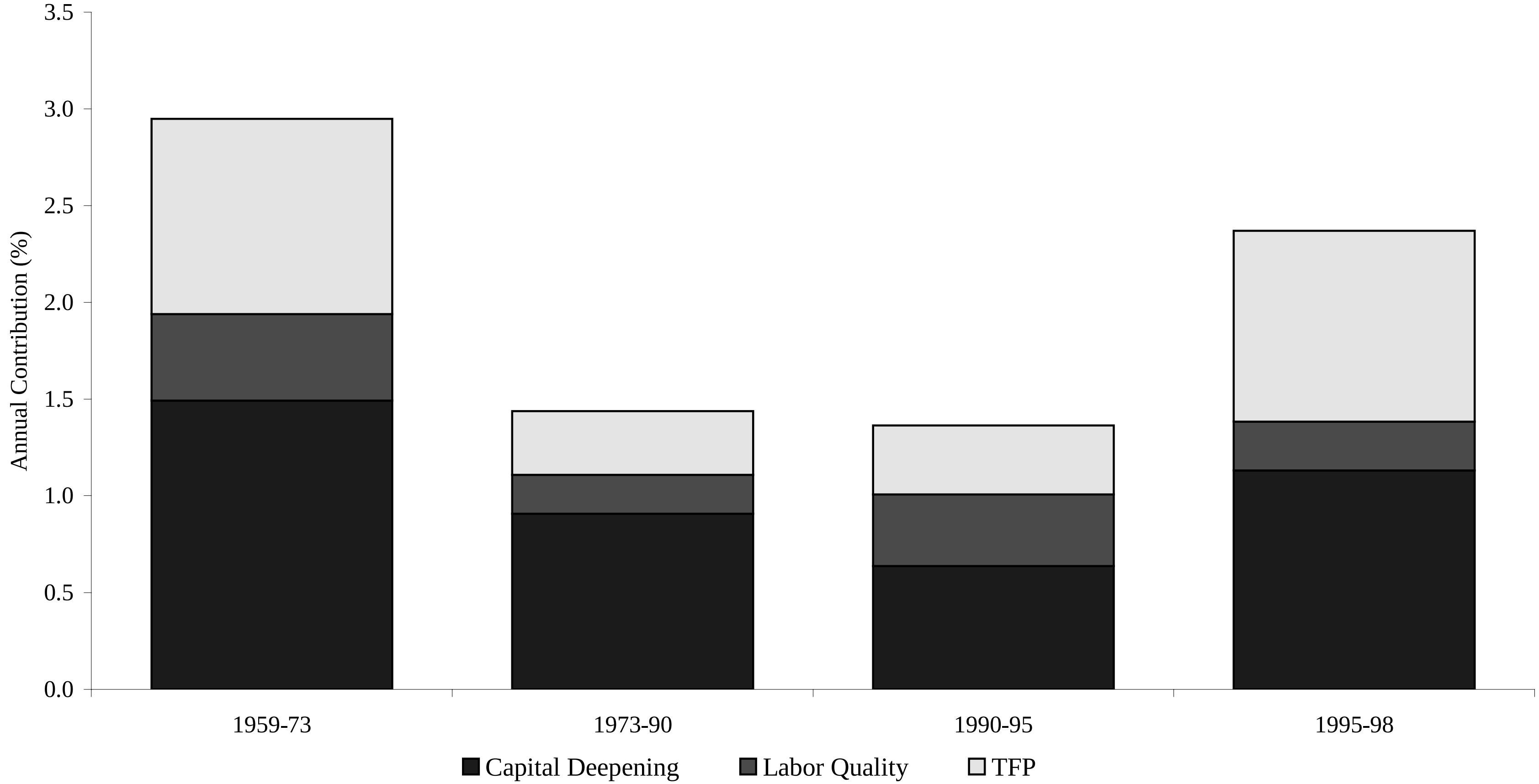
Notes: An input's contribution is the average share-weighted, annual growth rate.

Chart 8: Input Contribution of Information Technology Assets, 1959-98



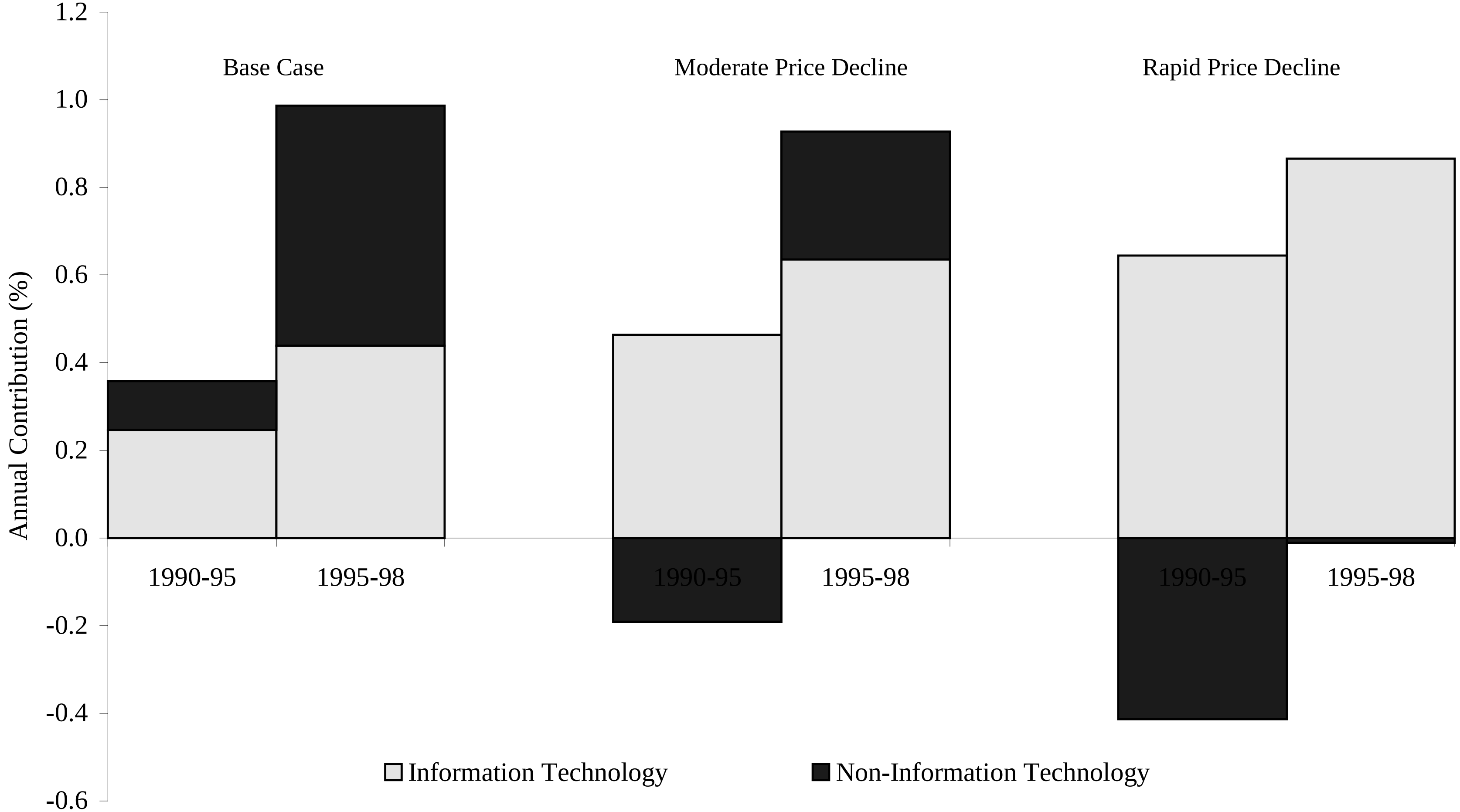
Notes: An input's contribution is the average share-weighted, annual growth rate.

Chart 9: Sources of U.S. Labor Productivity Growth, 1959-98



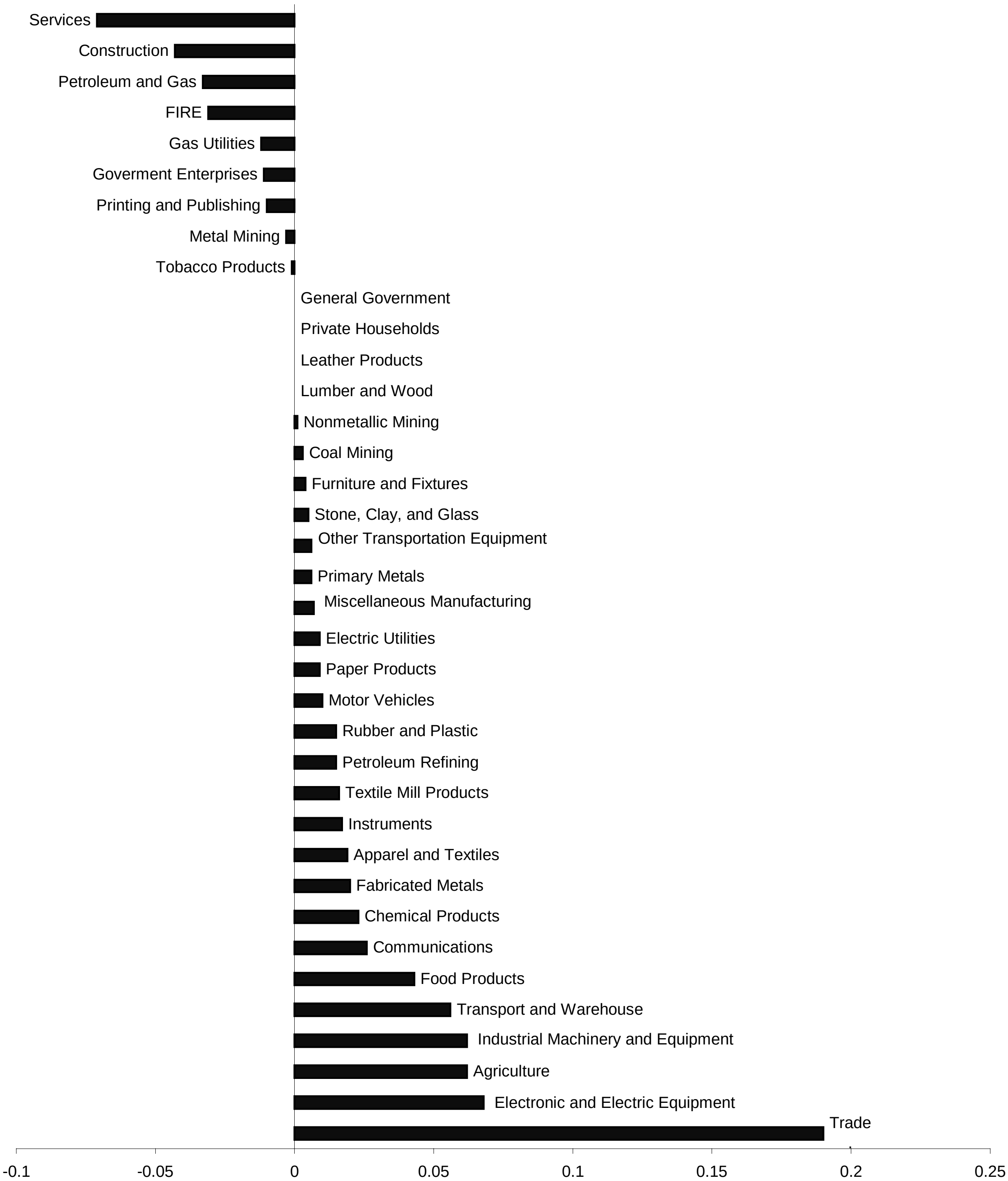
Notes: Annual contributions are defined in Equation (3) in text.

Chart 10: TFP Decomposition for Alternative Deflation Cases



Notes: Annual contribution of information technology is the share-weighted decline in relative prices.

Chart 11: Industry Contributions to Aggregate Total Factor Productivity Growth, 1958-96



Each industry's contribution is calculated as the product of industry productivity growth and the industry Domar weight, averaged for 1958-1996.

Table A-1: Private Domestic Output and High-Tech Assets

	Private Domestic Output		Computer Investment		Software Investment		Communications Investment		Computer & Software Consumption		Computer & Software Consumption Services	
Year	Value	Price	Value	Price	Value	Price	Value	Price	Value	Price	Value	Price
1959	484.1	0.25	0.00	0.00	0.00	0.00	1.80	0.47	0.00	0.00	0.00	0.00
1960	472.8	0.24	0.20	697.30	0.10	0.61	2.30	0.47	0.00	0.00	0.00	0.00
1961	490.1	0.24	0.30	522.97	0.20	0.62	2.70	0.47	0.00	0.00	0.00	0.00
1962	527.1	0.25	0.30	369.16	0.20	0.63	3.00	0.46	0.00	0.00	0.00	0.00
1963	562.1	0.25	0.70	276.29	0.40	0.63	2.90	0.46	0.00	0.00	0.00	0.00
1964	606.4	0.26	0.90	229.60	0.50	0.64	3.00	0.47	0.00	0.00	0.00	0.00
1965	664.2	0.26	1.20	188.74	0.70	0.65	3.50	0.47	0.00	0.00	0.00	0.00
1966	728.9	0.27	1.70	132.70	1.00	0.66	4.00	0.47	0.00	0.00	0.00	0.00
1967	763.1	0.28	1.90	107.71	1.20	0.67	4.20	0.49	0.00	0.00	0.00	0.00
1968	811.0	0.28	1.90	92.00	1.30	0.68	4.70	0.51	0.00	0.00	0.00	0.00
1969	877.7	0.29	2.40	83.26	1.80	0.70	5.80	0.54	0.00	0.00	0.00	0.00
1970	937.9	0.31	2.70	74.81	2.30	0.73	6.70	0.57	0.00	0.00	0.00	0.00
1971	991.5	0.32	2.80	56.98	2.40	0.73	6.80	0.60	0.00	0.00	0.00	0.00
1972	1,102.9	0.33	3.50	45.93	2.80	0.73	6.80	0.62	0.00	0.00	0.00	0.00
1973	1,255.0	0.36	3.50	43.53	3.20	0.75	8.40	0.64	0.00	0.00	0.00	0.00
1974	1,345.9	0.38	3.90	35.55	3.90	0.80	9.40	0.69	0.00	0.00	0.00	0.00
1975	1,472.7	0.42	3.60	32.89	4.80	0.85	9.70	0.76	0.00	0.00	0.00	0.00
1976	1,643.0	0.44	4.40	27.47	5.20	0.87	11.10	0.80	0.00	0.00	0.00	0.00
1977	1,828.1	0.47	5.70	23.90	5.50	0.89	14.40	0.78	0.00	0.00	0.00	0.00
1978	2,080.4	0.50	7.60	16.17	6.60	0.90	17.70	0.81	0.10	33.68	0.02	17.84
1979	2,377.8	0.56	10.20	13.40	8.70	0.95	21.40	0.83	0.10	32.81	0.07	19.01
1980	2,525.9	0.59	12.50	10.46	10.70	1.01	25.70	0.88	0.20	22.11	0.20	25.93
1981	2,825.6	0.65	17.10	9.19	12.90	1.07	29.00	0.96	0.40	18.79	0.25	13.90
1982	2,953.5	0.69	18.90	8.22	15.40	1.12	31.10	1.01	1.40	15.12	0.74	11.96
1983	3,207.7	0.72	23.90	6.86	18.00	1.13	31.90	1.03	2.90	10.71	2.07	10.39
1984	3,610.3	0.75	31.60	5.55	22.10	1.14	36.60	1.07	3.00	9.41	2.37	6.07
1985	3,844.1	0.76	33.70	4.72	25.60	1.13	39.90	1.09	2.90	8.68	2.70	4.93
1986	3,967.4	0.76	33.40	4.06	27.80	1.12	42.10	1.10	5.20	6.54	4.84	5.61
1987	4,310.8	0.79	35.80	3.46	31.40	1.12	42.10	1.10	6.20	5.91	4.91	3.54
1988	4,766.1	0.84	38.00	3.21	36.70	1.14	46.70	1.10	8.20	5.41	6.65	3.24
1989	5,070.5	0.86	43.10	3.00	44.40	1.11	46.90	1.10	8.30	5.02	7.89	2.85
1990	5,346.8	0.89	38.60	2.72	50.20	1.09	47.50	1.11	8.90	4.22	10.46	2.97
1991	5,427.2	0.91	37.70	2.45	56.60	1.10	45.70	1.11	11.90	3.53	11.66	2.44
1992	5,672.4	0.92	43.60	2.09	60.80	1.04	47.80	1.10	12.10	2.68	14.96	2.25
1993	5,901.8	0.93	47.20	1.78	69.40	1.04	48.20	1.09	14.50	2.07	16.26	1.71
1994	6,374.4	0.96	51.30	1.57	75.50	1.02	54.70	1.07	18.00	1.81	16.14	1.17
1995	6,674.4	0.97	64.60	1.31	83.50	1.02	60.00	1.03	21.00	1.44	22.64	1.13
1996	7,161.2	1.00	70.90	1.00	95.10	1.00	65.60	1.00	23.60	1.00	30.19	1.00
1997	7,701.8	1.02	76.70	0.78	106.60	0.97	73.00	0.99	26.20	0.69	33.68	0.71
1998	8,013.3	1.01	88.51	0.57	123.41	0.96	83.60	0.97	30.40	0.48	36.53	0.48

Notes: Values are in billions of current dollars. All price indexes are normalized to 1.0 in 1996.

Table B-1: Investment and Capital Stock by Asset Type and Class

Asset	Geometric Depreciation Rate	1998 Investment	1998 Capital Stock
Total Capital	na		27,954.7
Fixed Reproducible Assets	na	4,161.7	20,804.2
Equipment and Software		829.1	4,082.0
Household furniture	0.1375	2.3	13.1
Other furniture	0.1179	37.6	224.4
Other fabricated metal products	0.0917	15.9	134.5
Steam engines	0.0516	2.7	60.1
Internal combustion engines	0.2063	1.6	6.9
Farm tractors	0.1452	10.8	60.7
Construction tractors	0.1633	2.9	15.3
Agricultural machinery, except tractors	0.1179	13.1	89.2
Construction machinery, except tractors	0.1550	20.6	99.5
Mining and oilfield machinery	0.1500	2.4	15.6
Metalworking machinery	0.1225	37.1	228.6
Special industry machinery, n.e.c.	0.1031	38.6	288.7
General industrial, including materials handl	0.1072	34.5	247.5
Computers and peripheral equipment	0.3150	88.5	164.9
Service industry machinery	0.1650	17.9	92.0
Communication equipment	0.1100	83.6	440.5
Electrical transmission, distribution, and ind	0.0500	26.7	313.0
Household appliances	0.1650	1.5	6.9
Other electrical equipment, n.e.c.	0.1834	15.2	64.5
Trucks, buses, and truck trailers	0.1917	104.5	367.0
Autos	0.2719	19.4	70.2
Aircraft	0.0825	23.0	174.5
Ships and boats	0.0611	3.0	48.4
Railroad equipment	0.0589	5.3	69.1
Instruments (Scientific & engineering)	0.1350	30.9	172.6
Photocopy and related equipment	0.1800	22.6	103.0
Other nonresidential equipment	0.1473	35.4	184.3
Other office equipment	0.3119	8.4	24.5
Software	0.3150	123.4	302.4
Non-Residential Structures		2,271.3	5,430.6
Industrial buildings	0.0314	36.4	766.6
Mobile structures (offices)	0.0556	0.9	9.8
Office buildings	0.0247	44.3	829.8
Commercial warehouses	0.0222	0.0	0.0
Other commercial buildings, n.e.c.	0.0262	55.7	955.8
Religious buildings	0.0188	6.6	155.3
Educational buildings	0.0188	11.0	157.4

Table B-1: Investment and Capital Stock by Asset Type and Class - continued

Asset	Geometric Depreciation Rate	1998 Investment	1998 Capital Stock
Hospital and institutional buildings	0.0188	17.76	355.12
Hotels and motels	0.0281	17.08	210.57
Amusement and recreational buildings	0.0300	9.14	103.55
Other nonfarm buildings, n.e.c.	0.0249	2.07	67.68
Railroad structures	0.0166	5.78	210.36
Telecommunications	0.0237	13.19	282.09
Electric light and power (structures)	0.0211	12.12	490.04
Gas (structures)	0.0237	4.96	170.98
Local transit buildings	0.0237	0.00	0.00
Petroleum pipelines	0.0237	1.11	39.20
Farm related buildings and structures	0.0239	4.59	202.73
Petroleum and natural gas	0.0751	22.12	276.99
Other mining exploration	0.0450	2.03	38.96
Other nonfarm structures	0.0450	6.39	107.70
Railroad track replacement	0.0275	0.00	0.00
Nuclear fuel rods	0.0225	0.00	0.00
Residential Structures		363.18	8,309.62
1-to-4-unit homes	0.0114	240.27	5,628.27
5-or-more-unit homes	0.0140	21.11	871.81
Mobile homes	0.0455	14.64	147.17
Improvements	0.0255	86.29	1,634.15
Other residential	0.0227	0.87	28.23
Consumers Durables		698.20	2,981.97
Autos	0.2550	166.75	616.53
Trucks	0.2316	92.53	327.85
Other (RVs)	0.2316	18.63	64.98
Furniture	0.1179	56.02	372.26
Kitchen Appliance	0.1500	29.83	161.75
China, Glassware	0.1650	29.65	141.44
Other Durable	0.1650	64.03	309.67
Computers and Software	0.3150	30.40	52.30
Video, Audio	0.1833	75.15	289.22
Jewelry	0.1500	44.58	228.38
Ophthalmic	0.2750	16.53	53.44
Books and Maps	0.1650	25.34	132.51
Wheel Goods	0.1650	48.76	231.66
Land	0.0000		5,824.18
Inventories	0.0000		1,326.31

Note: Values of investment and capital stock is in millions of current dollars. Equipment and Software and Other nonresidential equipment includes NIPA residential equipment.
Source: BEA (1998a, 1999b, 1999c) and author calculations.

Table B-2: Total Capital Stock and High-Tech Assets

	Total Stock of Capital and CD Assets		Computer Capital Stock		Software Capital Stock		Communications Capital Stock		Computer & Software CD Stock	
Year	Value	Price	Value	Price	Value	Price	Value	Price	Value	Price
1959	1,300.3	0.17	0.00	0.00	0.00	0.00	9.97	0.47	0.00	0.00
1960	1,391.0	0.18	0.20	697.30	0.10	0.61	11.11	0.47	0.00	0.00
1961	1,478.5	0.18	0.40	522.97	0.27	0.62	12.53	0.47	0.00	0.00
1962	1,583.6	0.19	0.50	369.16	0.39	0.63	14.06	0.46	0.00	0.00
1963	1,667.7	0.19	0.95	276.29	0.67	0.63	15.50	0.46	0.00	0.00
1964	1,736.0	0.19	1.44	229.60	0.97	0.64	16.99	0.47	0.00	0.00
1965	1,848.3	0.19	2.01	188.74	1.37	0.65	18.56	0.47	0.00	0.00
1966	2,007.7	0.20	2.67	132.70	1.95	0.66	20.69	0.47	0.00	0.00
1967	2,150.6	0.21	3.38	107.71	2.55	0.67	23.21	0.49	0.00	0.00
1968	2,394.9	0.22	3.88	92.00	3.09	0.68	26.38	0.51	0.00	0.00
1969	2,670.4	0.24	4.81	83.26	3.98	0.70	30.57	0.54	0.00	0.00
1970	2,874.8	0.24	5.66	74.81	5.12	0.73	35.16	0.57	0.00	0.00
1971	3,127.9	0.26	5.75	56.98	5.91	0.73	39.66	0.60	0.00	0.00
1972	3,543.0	0.28	6.68	45.93	6.86	0.73	43.77	0.62	0.00	0.00
1973	4,005.0	0.30	7.83	43.53	8.04	0.75	48.30	0.64	0.00	0.00
1974	4,250.3	0.31	8.28	35.55	9.77	0.80	55.98	0.69	0.00	0.00
1975	4,915.0	0.35	8.85	32.89	11.89	0.85	64.49	0.76	0.00	0.00
1976	5,404.1	0.37	9.46	27.47	13.52	0.87	71.56	0.80	0.00	0.00
1977	6,151.9	0.41	11.34	23.90	15.01	0.89	76.27	0.78	0.00	0.00
1978	7,097.4	0.45	12.86	16.17	17.00	0.90	88.54	0.81	0.10	33.68
1979	8,258.3	0.50	17.50	13.40	21.01	0.95	101.62	0.83	0.17	32.81
1980	9,407.4	0.56	21.85	10.46	25.93	1.01	122.33	0.88	0.28	22.11
1981	10,771.2	0.62	30.26	9.19	31.72	1.07	146.61	0.96	0.56	18.79
1982	11,538.6	0.66	37.45	8.22	38.14	1.12	168.74	1.01	1.71	15.12
1983	12,033.2	0.67	45.29	6.86	44.40	1.13	185.59	1.03	3.73	10.71
1984	13,247.3	0.71	56.70	5.55	52.68	1.14	207.81	1.07	5.25	9.41
1985	14,837.5	0.77	66.72	4.72	61.66	1.13	228.43	1.09	6.21	8.68
1986	15,985.5	0.81	72.77	4.06	69.38	1.12	246.93	1.10	8.41	6.54
1987	17,137.5	0.85	78.26	3.46	79.17	1.12	262.59	1.10	11.40	5.91
1988	18,632.2	0.90	87.79	3.21	91.54	1.14	280.64	1.10	15.35	5.41
1989	20,223.2	0.96	99.26	3.00	105.64	1.11	297.05	1.10	18.06	5.02
1990	20,734.0	0.96	100.29	2.72	121.57	1.09	311.95	1.11	19.30	4.22
1991	21,085.3	0.97	99.42	2.45	140.37	1.10	324.37	1.11	22.97	3.53
1992	21,296.9	0.96	101.84	2.09	151.41	1.04	334.48	1.10	24.05	2.68
1993	21,631.7	0.96	106.68	1.78	173.39	1.04	342.48	1.09	27.20	2.07
1994	22,050.0	0.96	115.74	1.57	191.63	1.02	353.46	1.07	34.28	1.81
1995	23,346.7	0.99	130.78	1.31	215.13	1.02	362.23	1.03	39.71	1.44
1996	24,300.2	1.00	139.13	1.00	239.73	1.00	380.00	1.00	42.49	1.00
1997	26,070.4	1.04	150.57	0.78	266.63	0.97	407.58	0.99	46.20	0.69
1998	27,954.7	1.08	164.87	0.57	302.41	0.96	440.52	0.97	52.30	0.48

Notes: Values are in billions of current dollars. Total capital stock includes reproducible assets, consumers' durable assets (CD), land, and inventories. All price indexes are normalized to 1.0 in 1996.

Table B-3: Total Capital Services and High-Tech Assets

	Total Service Flow from Capital and CD Assets		Computer Capital Service Flow		Software Capital Service Flow		Communications Capital Service Flow		Computer & Software CD Service Flow	
Year	Value	Price	Value	Price	Value	Price	Value	Price	Value	Price
1959	214.7	0.32	0.00	0.00	0.00	0.00	2.55	0.50	0.00	0.00
1960	183.7	0.26	0.05	407.59	0.02	0.64	2.65	0.47	0.00	0.00
1961	192.3	0.26	0.25	602.38	0.08	0.61	2.85	0.45	0.00	0.00
1962	211.9	0.28	0.41	480.68	0.15	0.65	3.44	0.48	0.00	0.00
1963	241.7	0.30	0.56	291.73	0.22	0.60	3.32	0.42	0.00	0.00
1964	260.2	0.31	0.77	196.86	0.34	0.59	3.68	0.42	0.00	0.00
1965	289.2	0.32	1.15	169.47	0.52	0.64	4.73	0.50	0.00	0.00
1966	315.4	0.33	1.99	161.83	0.74	0.65	5.00	0.48	0.00	0.00
1967	333.8	0.33	2.13	103.65	1.03	0.68	5.14	0.45	0.00	0.00
1968	330.2	0.31	2.40	81.43	1.29	0.69	5.43	0.44	0.00	0.00
1969	349.2	0.31	2.54	63.64	1.57	0.69	6.02	0.44	0.00	0.00
1970	382.5	0.33	3.27	61.40	2.09	0.74	7.23	0.48	0.00	0.00
1971	391.4	0.32	4.83	68.40	2.83	0.83	8.34	0.51	0.00	0.00
1972	439.6	0.35	4.44	45.09	3.01	0.77	8.86	0.51	0.00	0.00
1973	517.9	0.38	4.02	30.87	3.47	0.77	12.48	0.68	0.00	0.00
1974	546.6	0.38	6.04	36.38	3.99	0.78	11.48	0.58	0.00	0.00
1975	619.2	0.42	5.36	26.49	5.17	0.88	13.41	0.64	0.00	0.00
1976	678.1	0.44	6.01	24.25	5.60	0.84	13.61	0.62	0.00	0.00
1977	742.8	0.47	6.35	19.16	6.26	0.86	22.37	0.94	0.00	0.00
1978	847.5	0.51	10.71	20.84	7.31	0.91	19.02	0.72	0.02	17.84
1979	999.1	0.57	10.45	12.30	8.19	0.89	26.30	0.89	0.07	19.01
1980	1,026.9	0.56	15.03	10.96	9.99	0.93	23.94	0.72	0.20	25.93
1981	1,221.4	0.66	15.92	7.33	11.76	0.94	23.89	0.64	0.25	13.90
1982	1,251.7	0.65	17.29	5.47	12.54	0.87	25.32	0.62	0.74	11.96
1983	1,359.1	0.71	22.77	5.06	15.11	0.92	29.54	0.67	2.07	10.39
1984	1,570.1	0.79	30.79	4.54	19.02	0.99	33.20	0.70	2.37	6.07
1985	1,660.5	0.79	33.72	3.43	22.41	0.99	39.30	0.77	2.70	4.93
1986	1,559.9	0.71	36.44	2.82	25.88	0.99	43.39	0.79	4.84	5.61
1987	1,846.6	0.80	45.07	2.76	31.84	1.07	55.49	0.94	4.91	3.54
1988	2,185.3	0.89	43.85	2.18	37.72	1.11	67.22	1.07	6.65	3.24
1989	2,243.0	0.89	47.89	1.97	45.96	1.16	67.90	1.02	7.89	2.85
1990	2,345.0	0.90	53.28	1.89	51.07	1.10	69.86	1.00	10.46	2.97
1991	2,345.8	0.88	52.65	1.69	54.07	1.01	66.05	0.91	11.66	2.44
1992	2,335.4	0.86	57.69	1.60	69.11	1.12	70.72	0.94	14.96	2.25
1993	2,377.4	0.85	62.00	1.42	69.32	0.98	80.23	1.02	16.26	1.71
1994	2,719.5	0.94	63.16	1.17	84.14	1.05	89.16	1.09	16.14	1.17
1995	2,833.4	0.94	77.77	1.11	89.18	0.99	101.18	1.17	22.64	1.13
1996	3,144.4	1.00	96.36	1.00	101.46	1.00	92.91	1.00	30.19	1.00
1997	3,466.3	1.05	103.95	0.77	119.80	1.04	100.13	1.00	33.68	0.71
1998	3,464.8	0.99	118.42	0.61	128.32	0.97	103.35	0.94	36.53	0.48

Note: Values are in billions of current dollars. Service prices are normalized to 1.0 in 1996. Total service flows include reproducible assets, consumers' durable assets (CD), land, and inventories. All price indexes are normalized to 1.0 in 1996.

Table C-1: Labor Input

Year	Labor Input: Price	Labor Input: Quantity	Labor Input: Value	Labor Input: Quality	Employment	Weekly Hours	Hourly Compensation	Hours Worked
1959	0.15	1,866.7	269.8	0.82	58,209	38.0	2.3	115,167
1960	0.15	1,877.5	289.1	0.82	58,853	37.7	2.5	115,403
1961	0.16	1,882.0	297.7	0.83	58,551	37.4	2.6	113,996
1962	0.16	1,970.7	315.3	0.86	59,681	37.5	2.7	116,348
1963	0.16	2,000.2	320.4	0.86	60,166	37.5	2.7	117,413
1964	0.17	2,051.4	346.2	0.87	61,307	37.4	2.9	119,111
1965	0.18	2,134.8	375.1	0.88	63,124	37.4	3.0	122,794
1966	0.19	2,226.9	413.7	0.89	65,480	37.1	3.3	126,465
1967	0.19	2,261.8	429.3	0.90	66,476	36.8	3.4	127,021
1968	0.21	2,318.8	480.8	0.91	68,063	36.5	3.7	129,194
1969	0.22	2,385.1	528.6	0.91	70,076	36.4	4.0	132,553
1970	0.24	2,326.6	555.6	0.90	69,799	35.8	4.3	130,021
1971	0.26	2,318.3	600.2	0.90	69,671	35.8	4.6	129,574
1972	0.28	2,395.5	662.9	0.91	71,802	35.8	5.0	133,554
1973	0.29	2,519.1	736.4	0.91	75,255	35.7	5.3	139,655
1974	0.32	2,522.2	798.8	0.91	76,474	35.0	5.7	139,345
1975	0.35	2,441.8	852.9	0.92	74,575	34.6	6.3	134,324
1976	0.38	2,525.6	964.2	0.92	76,925	34.6	7.0	138,488
1977	0.41	2,627.2	1,084.9	0.92	80,033	34.6	7.5	143,918
1978	0.44	2,783.7	1,232.4	0.93	84,439	34.5	8.1	151,359
1979	0.48	2,899.6	1,377.7	0.93	87,561	34.5	8.8	157,077
1980	0.52	2,880.8	1,498.2	0.94	87,788	34.1	9.6	155,500
1981	0.55	2,913.8	1,603.9	0.94	88,902	33.9	10.2	156,558
1982	0.60	2,853.3	1,701.6	0.94	87,600	33.6	11.1	153,163
1983	0.64	2,904.9	1,849.0	0.94	88,638	33.9	11.9	156,049
1984	0.66	3,095.5	2,040.2	0.95	93,176	34.0	12.4	164,870
1985	0.69	3,174.6	2,183.5	0.95	95,410	33.9	13.0	168,175
1986	0.75	3,192.8	2,407.1	0.95	97,001	33.5	14.2	169,246
1987	0.74	3,317.1	2,464.0	0.96	99,924	33.7	14.1	174,894
1988	0.76	3,417.2	2,579.5	0.96	103,021	33.6	14.3	179,891
1989	0.80	3,524.2	2,827.0	0.96	105,471	33.7	15.3	184,974
1990	0.84	3,560.3	3,001.9	0.97	106,562	33.6	16.1	186,106
1991	0.88	3,500.3	3,081.4	0.97	105,278	33.2	16.9	181,951
1992	0.94	3,553.4	3,337.0	0.98	105,399	33.2	18.3	182,200
1993	0.95	3,697.5	3,524.4	0.99	107,917	33.5	18.8	187,898
1994	0.96	3,806.4	3,654.6	0.99	110,888	33.6	18.9	193,891
1995	0.98	3,937.5	3,841.2	1.00	113,707	33.7	19.3	199,341
1996	1.00	4,016.8	4,016.8	1.00	116,083	33.6	19.8	202,655
1997	1.02	4,167.6	4,235.7	1.01	119,127	33.8	20.3	209,108
1998	1.06	4,283.8	4,545.7	1.01	121,934	33.7	21.3	213,951

Notes: Quantity of labor input is measured in billions of 1996 dollars; value of labor input is measured in billions of current dollars. Employment is thousands of workers, hourly compensation is in dollars, and hours worked is in millions. Price of labor input and index of labor quality are normalized to 1.0 in 1996.

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