Accounting for Growth from A to Z: Review Article on *Information Technology and the American Growth Resurgence*

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THE PERFORMANCE OF THE U.S. economy has, in many ways, been remarkable in the past decade. After a quarter century of sluggish growth, labour productivity growth accelerated in the mid-1990s and, to the surprise of many analysts, accelerated further after 2001. The mid-1990s pickup has been widely documented and there is a broad consensus that that speedup in growth was importantly driven by information technology (IT).[2] This growth resurgence and its sources are the focus of the book by Dale Jorgenson, Mun Ho, and Kevin Stiroh (JHS).[3] More than just telling that story, however, this book provides a detailed record of the methodology for analyzing economic growth that Dale Jorgenson has developed and advocated over the past several decades; this book is as much about methodology as it is about patterns of growth in the United States and other countries. The other story that is woven throughout the book is the history of economic growth analysis over the past fifty years, along with a recounting of some of the debates around key issues.

In this essay, I will start by reviewing the methodological contributions described in the book and highlight how the book could be relied on as "Users' Guide" to growth accounting at the aggregate and industry levels. The methodology described by JHS will be familiar to many readers; it was largely adopted by the Bureau of Labor Statistics (BLS) twenty years ago for its estimates of multifactor productivity and has been adopted as the gold standard by many researchers, including the writer of this review. Nevertheless, I will highlight areas where debate continues. I will then turn to the JHS story for how information technology transformed the economy. Again, much of this material will be familiar to many readers, and I will emphasize parts of the story that might be less well known or where I would tell the story a bit differently. Finally, I will discuss the strengths and weaknesses of the book, and comment on the roadmap for future research proposed by JHS.

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2 See Jorgenson and Stiroh (2000), Jorgenson, Ho and Stiroh (2002), Oliner and Sichel (2000 and 2002). In these papers, IT refers to computer hardware, software, and communications equipment. This category often also is referred to as information and communications technology, or ICT.

3 *Information Technology and the American Growth Resurgence*, Productivity, Volume 3, MIT Press, 2005, 400 pp., $50 US.

Using this Book as a Users' Guide to Growth Accounting

From time to time, I am asked to recommend a source that provides a comprehensive description of how to do growth accounting. This book is just such a source.

Aggregate Growth Accounting

Chapter 2 provides an overview of aggregate growth accounting, while chapters 5 and 6 describe the procedures for constructing capital services and labour input at the aggregate level and at the industry level.

A significant chunk of the methodological discussion in chapter 2 describes the basic measurement choices made by JHS (many of which also have been made by the statistical agencies in the United States). For example, JHS discuss the importance of breaking out IT and of using constant-quality prices for information technology and other capital goods. Breaking out IT is essential to gauge its influence on the economy and its role in the growth resurgence. And, constant-quality price indexes are essential for tracking the remarkable development of IT and also for being able to aggregate across vintages of capital. In chapter 1, JHS note where the National Income and Product Accounts (NIPA) in the United States have incorporated constant-quality price indexes; they also point to areas where they suspect that the price measures used in the NIPAs are inadequate.

In terms of measuring output, JHS focus on an output measure that differs from that used by the Bureau of Economic Analysis in the NIPAs. In particular, JHS advocate using an output measure that includes imputations for the service flows from durable goods used by households; for example, rather than include the purchase of an automobile by a household as consumption in the year of purchase, JHS include an imputation for the service flow from this automobile spread out over the life of the automobile. Conceptually, I am sympathetic to the JHS argument that the service flow from consumer durables should be included in output rather than the purchase of the durable. Indeed, this is the approach used in the NIPAs for housing. However, that conceptual purity does come at a cost: namely, analyses of the sources of growth by JHS must be adjusted in order to be compared with published output measures or with other analyses that rely on published output measures.

A key theme of the book is the importance of using capital services rather than the capital stock as a measure of capital input for growth analysis. Capital services is an aggregate of individual capital stocks weighted by the user cost of each type of capital. The difference in growth rates between capital services and the capital stock is capital quality, which captures the contribution of the changing composition of capital. Details of how to do these calculations are provided in chapter 5.

Another key theme is the importance of using labour input rather than hours as the measure of labour's contribution to growth. This approach divides workers into categories defined by sex, age, education, and employment class (employed, self-employed, etc.) and then weights up hours in each of these cells by wages for that cell. Assuming that wages provide a rough measure of marginal products, this procedure agregates different types of labour by marginal products. Details of how to do these calculations are provided in chapter 6.

With regard to the discussion of aggregate growth accounting, I suspect that experienced practitioners of conventional growth accounting will find these parts of the book a bit routine. On the other hand, readers new to the subject will find a thorough description of how to do growth accounting along with a discussion of key conceptual and empirical issues confronted in actually doing it. And, it must be recognized, that the methodology described here has not always been

accepted by researchers. Indeed, JHS provide an entertaining discussion at the end of chapter 2 about the evolution of thought about methodologies for growth analysis. As is clear from that discussion, elements of the methodology described by JHS were controversial when first introduced. And, the use of capital stocks (rather than capital services) still occasionally pops up in empirical work as does the use of hours rather than labour input.

One area where disagreement remains is with JHS' use of the production possibility frontier. This frontier describes efficient combinations of inputs and outputs for the economy as a whole and allows multiple inputs and multiple outputs. In contrast, Greenwood, Hercowitz, and Krussel in a series of papers have challenged the approach in JHS, highlighting the role of investment-specific technical change.[4] For the reasons described in Ho and Stiroh (2001) and Whelan (2003), I am a bit skeptical of the approach taken by Greenwood, Hercowitz, and Krussell. Having said that, this has been an area of active debate and JHS largely brush it off, rather than providing a serious critique in the book.

Industry-level Growth Accounting

For growth accounting at the industry level, a guide is provided by chapter 7 ("Productivity Growth for U.S. Industries"), along with the industry-specific parts of chapters 4, 5 and 6.

Chapter 4 ("The Changing Structure of Output and Intermediate Inputs") provides a detailed description of the methodology and data used for measuring industry output and intermediate input by industry. As discussed, JHS collapse the 192 industries in the input-output tables down to 44 industries, four of which produce IT — computers and office equipment, electronic components, telecommunications equipment, and computer services (which includes software). The remaining 40 industries are divided into 13 "IT-using" industries and 27 "non-IT" industries. IT-using industries are defined as those for which IT capital services amounted to 15 per cent of total capital services in 1995 at the beginning of the IT-related growth resurgence.

A couple of methodological points are worth noting. First, the analysis is done on the old SIC basis, rather than the newer NAICS basis. The original papers on which the book is based were done with the SIC data so it is easy to see why that is replicated here. However, there are also significant gaps in the availability of the NAICS industry data needed for this type of analysis, a serious shortcoming in the U.S. data system that should be resolved as quickly as possible.

Second, JHS express a strong preference for doing industry-level analysis using gross output and including intermediate inputs as well as capital and labour, rather than using value added and just accounting for capital and labour as inputs. They cite several reasons for preferring a gross output framework. Gross output provides a fuller description of what an industry actually produces (industries produce gross output, not value added). Also, the use of gross output makes it possible to track the role of intermediate inputs; this approach is particularly useful for IT industries where semiconductors are a very important intermediate input. Finally, although industry productivity figures based on value added can be combined easily to obtain aggregate productivity, strong restrictions on the industry production functions must be satisfied for this aggregation to be appropriate. And, as JHS show in chapter 8, these restrictions appear to be violated, raising questions about the validity of simple value added aggregation. On the other hand, gross output measures of labour productivity will be bounced around by swings in intermediate inputs, while value added measures of labour productivity will not. Thus, if a gross output measure is used, it is

4 For examples, see Greenwood, Hercowitz, and Krussell (1997 and 2000).

important to keep track of what is happening to intermediate inputs. On balance, I share JHS's preference for doing industry analysis on a gross output basis, whenever data on intermediate inputs is available.

JHS also discuss the various different sources of industry productivity data for the United States, and they discuss the relative merits and shortcomings of their data (derived from BEA and BLS data) compared with the BEA's industry accounts, the industry productivity figures produced by the BLS, and the industry data from the Federal Reserve's Productivity System, as described in Bartelsman and Beaulieu (2004). As JHS note, "The differences among these estimates can be sizable, but it has proven difficult to provide a comprehensive explanation." Gordon (2001) and others have encountered the same difficulties. These apparently inexplicable differences remain a source of continuing frustration for users of U.S. industry data. Although this probably will not happen any time soon, it would be useful for the statistical agencies to push ahead on the long, hard work of reconciling these differences.

As indicated above, JHS define the IT-producing sector as computers and office equipment, electronic components, telecommunications equipment, and computer services. Although JHS are using the narrowest breakdown for which the U.S. data system provides reasonably complete data, a limitation of this breakdown is that each of these industries covers widely different products with very different markets and price dynamics. This broad coverage is, perhaps, a particular problem for electronic components, an industry that is often used as a stand-in for semiconductors. In addition to including the microprocessor and memory chips that go into computers, this industry also covers much less complex products such as resistors and capacitors.[5] Thus, the electronic components industry is a bit broad for tracking the role of integrated circuits, particularly those important for computers.

As mentioned earlier, chapter 5 ("Capital Services and Information Technology") provides a full description of the methodology and necessary data for calculating capital services. The material here is fairly standard (although, again, Jorgenson and coauthors were the key developers and early advocates of this methodology). The one place where I would quibble with JHS is with their generally ready acceptance of geometric depreciation patterns. The BLS assumes non-geometric depreciation in their estimates of capital services. Of course, ultimately the pattern of depreciation is an empirical question, and there is disappointingly little work here since the comprehensive and impressive work of Hulten and Wykoff (1981a and 1981b). However, their work predated the IT revolution. Moreover, the empirical evidence that is available for depreciation patterns for IT products point in the direction of non-geometric depreciation. In particular, Oliner (1993) found a non-geometric pattern of depreciation for mainframe computers, and Doms, Dunn, Oliner, and Sichel (2004) and Antonopoulos and Sakellaris (2005) found a non-geometric pattern of depreciation for personal computers.

Chapter 6 ("Labor Input and the Returns to Education") describes the methodology and necessary data for calculating labour input at the aggregate and industry levels. A very important contribution in this chapter is the calculation of labour input and labour quality by industry. A handful of other studies have done that, but most studies of industry productivity have not tackled this because of the heavy data needs and complexities of the calculations. These results add some very interesting pieces to the story of how IT affected the economy in the past decade.

5 Nominal shipments of integrated circuits made up only about 57 per cent of shipments of Electronic Components in 2004.

Information Technology and the mid-1990s Growth Resurgence

As indicated above, JHS also tell the now well-known story of the mid-1990s growth resurgence and IT's role in that growth pickup. In the book, this story is woven through all of the chapters, and is summarized in chapter 1 ("Understanding the Information Age"). The story begins with the concept of "faster, better, cheaper," which describes the progression of semiconductor technology. In the mid-1990s, constant-quality prices of semiconductors started to fall more rapidly than they had in earlier years, leading to especially rapid declines in prices of IT capital goods. Firms responded to these price declines by increasingly substituting capital purchases toward IT capital, generating a surge in IT capital deepening.

In the JHS framework, the particularly rapid declines in semiconductor prices are taken as signaling especially rapid technological progress at producers of semiconductors, and this technological progress shows up as faster multifactor productivity growth in IT-producing industries. When JHS run the numbers, IT-related capital deepening and the IT-related boost to multifactor productivity growth account for an important part of the U.S. growth resurgence; hence, the conclusion that IT made a critical contribution to that resurgence.

JHS extend this story in a couple of directions. Chapter 3 ("Information Technology and Growth in the G7 Countries") presents aggregate growth accounting results for other large industrialized economies, extending through 2001. This analysis uses internationally harmonized prices developed by Schreyer (2000) and links the data across countries using OECD purchasing power parities for 1999. The basic story in the chapter is that the IT revolution is also evident in G7 countries other than the United States. Although the chapter is chock-full of tables and charts showing cross-country comparisons, it does not say much about why some countries appear to have benefited more than other countries from the IT revolution in the second half of the 1990s.[6]

As already described above, the other direction in which JHS extend the aggregate story is with industry detail, as summarized in chapter 7. Their basic result is that the 1995 revival of productivity growth in the United States was widespread across many industries and that IT played an important role in many of these industries. In their framework, more than three-fourths of the industries posted stronger growth in labour productivity after 1995 than before and about two-thirds posted an acceleration in multifactor productivity. This result has not gone unchallenged, as discussed in the next section.

JHS also highlight the considerable variation across industries in growth rates of labour productivity and multifactor productivity. Although Corrado and Slifman (1999) and others have suggested that persistent declines in the level of productivity in an industry seem implausible and could reflect mismeasurement, JHS argue that it likely reflects real changes in industries as they respond to industry-specific and macroeconomic shocks.

JHS emphasize that most industries responded to the rapid declines in IT prices and shifted toward IT investment. On the labour side, JHS describe a similar evolution within and across industries, summarizing the story for labour input as one of "... rapid changes and reallocation, particularly toward information age industries that either produce or consume information technology most intensively. This expansion of the IT group involved a disproportionate number of young well-educated workers and pays them relatively well." These parts of the book should be broadly comforting to econ-

6 For an interesting discussion of these issues, see van Ark and Inklaar (2005).

omists, as they suggest that markets work and firms respond to price and demand signals.

Critiques of the JHS Story

The broad JHS story about the mid-1990s growth resurgence and the role of IT in that pickup generally sounds right to me, and my work with Stephen Oliner has largely reached the same conclusions. However, challenging questions have been raised about aspects of these results. Of course, these challenges apply to most of the work on aggregate growth accounting, including my work with Stephen Oliner. Critiques fall into a handful of categories. One strand expresses general discomfort with the assumptions underlying the neoclassical framework and with the causal interpretations that have been attached to it. Another strand questions the conclusion that the growth resurgence was widespread across industries. McKinsey Global Institute (2001) makes each of these arguments and Farrell, Baily, and Remes (2005) suggest that the conventional framework overstates the role of IT; instead, they emphasize the role of managerial expertise in key industries.

Another area of concern raised by many researchers about the framework in JHS — such as Gordon (2003) — is the potential importance of learning and possible lags between the installation of IT and the generation of productivity benefits, a phenomenon not captured in the framework used by JHS. Criticism also has focused on the role of adjustment costs, with important contributions by Basu, Fernald, and Shapiro (2001) and Kiley (2001).

Finally, business investment in intangible capital is not fully captured in the NIPAs and therefore is not fully captured by the conventional growth accounting framework using NIPA data. Brynjolfsson and Hitt (2005), Nakamura (1999, 2001, and 2003), and Corrado, Hulten, and Sichel (2005 and 2006) have focused on the role of business investment in intangible capital that often accompanies investments in IT. Because these intangible investments are largely missed by the official published data and because learning lags likely are important for intangibles, conventional growth accounting — such as that in JHS and in Oliner and Sichel — could be misattributing the sources and timing of contributions from different factors.

For the most part, these critiques have not been fully integrated into the growth accounting framework and, in my judgment, there is no consensus that these critiques overturn the essentials of the story described above for the role of IT in the mid-1990s growth resurgence. But, clearly, more work is needed to nail this down.

One piece of these critiques warrants further discussion. As indicated, McKinsey Global Institute (2001) raised a series of questions about the type of results in JHS. Although by this time, the McKinsey study is a bit out of date, it received a lot of attention at the time, and was widely perceived (and perhaps intended) as a challenge to aggregate and industry growth accounting results that highlighted the role of IT in the growth resurgence. And, it captured a sentiment that appears to have gained currency over time. Thus, even though the book does not focus on these issues, I will discuss the McKinsey report in a little more detail.

As indicated, the McKinsey report questions the JHS conclusion that the growth resurgence was widespread. In particular, McKinsey argued that the mid-1990s acceleration in labour productivity could be accounted for by developments in just a handful of industries: retail trade, wholesale trade, semiconductor manufacturing, computer manufacturing, telecommunications services, and securities. McKinsey also argued that IT was just one of the driving factors behind the productivity pickup in the mid-1990s.

Regarding the point about how widespread was the acceleration in labour productivity, one interpretation of the McKinsey study is that the

disagreement really represents a difference in interpretation, rather than a difference in the underlying numbers. Indeed, McKinsey showed that industries accounting for 70 per cent of employment experienced an acceleration in labour productivity in the second half of the 1990s, similar to the JHS result. Of course, the remaining industries experienced flat or decelerating productivity so that the net pickup was less than that coming from the industries that experienced an acceleration. McKinsey chose to focus on the net result; namely, that six industries could account for the net acceleration. Other industries also saw an acceleration, but in McKinsey's classification scheme, those pickups were netted against the industries with decelerations in productivity.

Whether the McKinsey approach or that in JHS is to be preferred depends on the question being asked. In my view, if one wants to gauge how widespread was the productivity resurgence across industries, it does not seem particularly helpful to focus on the net result, implicitly canceling a number of industries with an acceleration in productivity with a number of other industries that experienced a deceleration. Of course, if one wants to gauge what industries led the productivity resurgence, then McKinsey's approach seems reasonable.

Also, even though the McKinsey study had language raising questions about the aggregate growth accounting results of the type in JHS, McKinsey did not directly challenge these results. The JHS analysis is based on the premise that, over time, firms earn a normal return (net of depreciation) on all investments including IT. Results in that framework can be misleading if capital or the rate of return are mismeasured, but McKinsey does not claim that this is so. Indeed, the report argues that IT behaves much like other capital, which is a maintained assumption of conventional growth accounting. Thus, the McKinsey study does not really contradict the aggregate implications of studies such as JHS. McKinsey does, importantly, point out a host of other developments that contributed to the late 1990s pickup in productivity growth, including competitive pressures, regulatory changes, and managerial expertise leading to improved efficiency of critical processes. I can not speak for JHS, but for my part, these other sources of the productivity improvement seem complementary to the role of IT. Indeed, it would be difficult to imagine IT boosting productivity growth without improved efficiency of critical processes.

I will now turn to one part of the story told by JHS (and, for that matter, by Oliner and Sichel in earlier work) that, over time, I have become a little less comfortable with. This piece is the linkage between constant-quality semiconductor prices and the pace of technological progress in the semiconductor industry.[7] As evidence of the speedup in technological progress, JHS cite the mid-1990s shift from a three-year product cycle for semiconductors to a two-year cycle as described in the 2003 Edition of the International Technology Roadmap for Semiconductors. However, the 2005 Edition of the Roadmap has, based on some new information from chip-producing companies, shifted the timing of the switch in product cycles from the mid-1990s to the late 1990s, somewhat muddying the linkage between the shift in product cycles and the observed pattern of semiconductor prices. Moreover, many other factors affect the pace of decline in constant-quality prices for semiconductors. For example, Aizcorbe, Oliner, and Sichel (2006) highlight the role of time-varying markups for semiconductors, a factor that could make price movements alone an inadequate proxy for technical progress. And, Basu, Fernald, Fisher, and Kimball (2005) highlight a

7 For a fuller discussion of these issues, see Aizcorbe, Oliner, and Sichel (2006).

number of reasons why IT price trends could be a poor proxy for technological progress.[8]

As a further example of the rather loose linkage between the trends described in the Roadmaps and constant-quality prices of semiconductors, consider the slowdown in the rate of decline in constant-quality semiconductor prices that occurred in 2001.[9] The latest Roadmap (along with consultations with people in the industry) suggests that there was not a slowdown in the pace of technological progress in semiconductors around 2001. Thus, it appears that the slower pace of decline that began at that time must be coming from other factors. All told, this new evidence has left me more cautious about how tightly we ought to connect the type of information in the Roadmaps with semiconductor prices, and, conversely, with how tightly we ought to connect swings in constant-quality semiconductor prices to the pace of technical progress in the semiconductor industry.

Strengths and Weaknesses of the Book

The primary strengths of the book include its comprehensiveness, the consistency of methodology, and its care with data. This book is a very good place to look for a careful and thorough description of state-of-the-art growth analysis at the aggregate and industry levels. It also provides the most comprehensive description that I have seen of the myriad ways in which information technology affected almost all aspects of the economy in the past decade. Having said that, the book does have a couple of weaknesses. Because the book is, essentially, a compendium of work completed by JHS over a number of years, the book does not cover some of the most recent issues and debates in much depth. In particular, the sources of the further pickup in growth of labour and multifactor productivity that began after 2001 is not discussed at all nor is there much discussion about why some countries appear to have benefited more from the IT revolution than did other countries.[10] And, as discussed above, issues surrounding intangible capital are not mentioned in the volume by JHS, and the book provides relatively little discussion about the role of adjustment costs.

Finally, the volume by JHS highlights several areas where further progress by the measurement research community and the statistical agencies would be most welcome. These include development of reliable constant-quality price indexes for a wider range of capital goods where technology is changing rapidly, the need for more detailed industry classifications for the high-tech sector, and the need to extend the complete set of industry accounts on a NAICS basis back to 1947. I would like to add a few more items to the list. For starters, there is a need for additional work on depreciation, particularly for IT capital, but for other types of capital as well. In addition, my Federal Reserve colleagues Carol Corrado and Lawrence Slifman frequently mention some key measurement issues that are worth repeating here. First, for many high-tech categories (like communications equipment), the product lists used by the Census Bureau are woefully out of date. These are the product lists that are used when information on nominal shipments is collected from businesses in a variety of Census programs. For

8 Feenstra, Reinsdorf, Slaughter, and Harper (2005) point to another possible source of slippage between IT price declines and the pace of technological progress; namely, that changes in the terms of trade appear to be an important source of IT price declines and that, therefore, the conventional framework may have overstated the role of technological progress.

9 See Aizcorbe, Oliner, and Sichel (2006) for evidence of the statistical significance of the mid-1990s and 2001 break in the trend of constant-quality semiconductor prices.

10 But see Stiroh (2006) for an analysis of the industry composition of the resurgence in labour productivity growth in the 2000s.

example, there are more than a dozen detailed product categories listed under the umbrella category "Broadcast, studio, and related electronic equipment" where nominal shipments totaled a bit less than $3 billion in 2004. But a host of leading edge products for data communication — including routers, gateways, bridges, and terminal servers — are lumped together in a single category, in which nominal shipments were more than $10 billion in 2004. This state of affairs does not make sense, and the current classification scheme limits our ability to track the new economy because we do not even know nominal shipments of key IT products at any significant level of detail. Moreover, as JHS point out, we also know very little about prices of these leading edge products.

Also, the BLS and the Census Bureau use different lists of establishments for their various surveys, and they also have taken different approaches to dealing with the conversion from the SIC system to NAICS. This creates some non-comparabilities between the shipments or output data that come from Census' surveys and the hours data that come from BLS surveys. And, these non-comparabilities complicate efforts to match industries at a detailed level and to create productivity statistics at a detailed industry level. Resolving these issues would significantly facilitate analysis of productivity developments.

References

Aizcorbe, Ana, Stephen Oliner and Daniel Sichel (2006) "Shifting Trends in Semiconductor Prices and the Pace of Technological Progress," mimeo, January.

Antonopoulos, Christos and Plutarchos Sakellaris (2005) "Estimating Computer Depreciation Using Online Auction Data," mimeo, Athens University of Economics and Business.

Bartelsman, Eric and J. Joseph Beaulieu (2004) "A Consistent Accounting of U.S. Productivity Growth," Federal Reserve Economics and Finance Discussion paper #2004-55.

Basu, Susanto, John Fernald, Jonas Fisher and Miles Kimball (2005) "Sector-Specific Technical Change," paper presented at the NBER Summer Institute, July 21.

Basu, Susanto, John Fernald and Matthew Shapiro (2001) "Productivity Growth in the 1990s: Technology, Utilization, or Adjustment?" *Carnegie-Rochester Conference Series on Public Policy*, Volume 55, Issue 1, pp. 117-165.

Brynjolfsson, Erik and Lorin Hitt (2005) "Remarks," in *Measuring Capital in the New Economy*, Carol Corrado, John Haltiwanger and Daniel Sichel (eds.), Studies in Income and Wealth, Vol. 65 (Chicago: The University of Chicago Press) pp. 557-575.

Corrado, Carol, Charles Hulten and Daniel Sichel (2005) "Measuring Capital and Technology: An Expanded Framework," in *Measuring Capital in the New Economy*, Carol Corrado, John Haltiwanger and Daniel Sichel (eds.), Studies in Income and Wealth, Vol. 65 (Chicago: The University of Chicago Press) pp. 11-45.

Corrado, Corrado, Charles Hulten and Daniel Sichel (2006) "Intangible Capital and Economic Growth, NBER working paper #11948.

Corrado, Carol and Larry Slifman (1999) "A Decomposition of Productivity and Costs." *American Economic Review* 89, No. 2, May, pp. 328-332.

Doms, Mark, Wendy Dunn, Stephen Oliner and Daniel Sichel (2004) "How Fast Do Personal Computers Depreciate? Concepts and New Estimates," in *Tax Policy and the Economy*, James M. Poterba (ed.), National Bureau of Economic Research and the MIT Press, pp. 37-79.

Farrell, Diana, Martin Baily and Jaana Remes (2005) "U.S. Productivity After the Dot.Com Bust," McKinsey Global Institute.

Feenstra, Robert, Marshall Reinsdorf, Matthew Slaughter and Michael Harper (2005) "Terms of Trade Gains and U.S. Productivity Growth," paper presented at the NBER Summer Institute, July 26.

Gordon, Robert J. (2001) "Did the Productivity Revival Spill Over from Manufacturing to Services? Conflicting Evidence from Three Data Sources," paper presented at the NBER Summer Institute, July 27.

Gordon, Robert J. (2003) "Exploding Productivity Growth: Context, Causes, and Implications," *Brookings Papers on Economic Activity* 2003:2 (Washington, D.C.:The Brookings Institution) pp. 207-298.

Greenwood, Jeremy, Zvi Hercowitz and Per Krussell (1997) "Long-Run Implications of Investment-Specific Technological Change," *American Economic Review* 87, no. 3, June, pp. 342-362.

Greenwood, Jeremy, Zvi Hercowitz and Per Krussell (2000) "Th e Role of Investment-Specific Technological Change in the Business Cycle," *European Economic Review* 44, no. 1, January, pp. 91-115.

Ho, Mun S. and Kevin J. Stiroh (2001) "The Embodiment Controversy: You Can't Have Two Prices in a One-Sector Model," mimeo, May.

Hulten, Charles R. and Frank C. Wykoff (1981a) "The Estimation of Economic Depreciation Using Vintage Asset Prices: An Application of the Box-Cox Power Transformation," *Journal of Econometrics* 15, April, pp. 367-96.

Hulten, Charles R. and Frank C. Wykoff (1981b) "The Measurement of Economic Depreciation." In *Depreciation, Inflation, and the Taxation of Income from Capital*, Charles R. Hulten (ed.) (Washington, D.C.: The Urban Institute Press) pp. 81-125.

International Technology Roadmap for Semiconductors (2003) 2003 Edition, Sematech Corporation, Austin, TX, December.

International Technology Roadmap for Semiconductors (2005) 2005 Edition, Sematech Corporation, Austin, TX, December.

Jorgenson, Dale W. and Kevin J. Stiroh (2000) "U.S. Economic Growth in the New Millenium," *Brookings Papers on Economic Activity* 2000:1, pp. 125-211.

Jorgenson, Dale W., Mun S. Ho and Kevin J. Stiroh (2002) "Projecting Productivity Growth: Lessons from the U.S. Growth Resurgence," *Atlanta Fed Economic Review*, Third Quarter, pp. 1-14.

Kiley, Michael (2001) "Computers and Growth with Frictions: Aggregate and Disaggregate Evidence," *Carnegie-Rochester Conference Series on Public Policy*, Vol. 55, Issue no. 1, pp. 171-215.

McKinsey Global Institute (2001) *U.S. Productivity Growth, 1995-2000: Understanding the Contribution of Information Technology Relative to Other Factors (*Washington, DC: McKinsey Global Institute) October.

Nakamura, Leonard (1999) "Intangibles: What Put the *New* in the New Economy?" Federal Reserve Bank of Philadelphia *Business Review*, July/August, pp. 3-16.

Nakamura, Leonard (2001) "What is the US Gross Investment in Intangibles? (At Least) One Trillion Dollars a Year!" Federal Reserve Bank of Philadelphia Working Paper No. 01-15.

Nakamura, Leonard (2003) "The Rise in Gross Private Investment in Intangible Assets Since 1978," mimeo, Federal Reserve Bank of Philadelphia.

Oliner, Stephen D. (1993) "Constant-Quality Price Change, Depreciation, and Retirement of Mainframe Computers," in *Price Measurements and Their Uses*, Murray F. Foss, Marilyn E. Manser and Allan H. Young (eds.) (Chicago: University of Chicago Press) pp. 19-61.

Oliner, Stephen D. and Daniel E. Sichel (2000) "The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?" *Journal of Economic Perspectives* 14, Fall, pp. 3-22.

Oliner, Stephen D. and Daniel E. Sichel (2002) "Information Technology and Productivity: Where are We Now and Where are We Going?" *Atlanta Fed Economic Review*, Third Quarter, pp. 15-44.

Schreyer, Paul (2000) "The Contribution of Information and Communication Technology to Output Growth: A Study of the G7 Countries," OECD, Paris, May.

Stiroh, Kevin J. (2006) "The Industry Origins of the Second Surge of U.S. Productivity Growth," mimeo, January.

van Ark, Bart and Robert Inklaar (2005) "Catching Up or Getting Stuck? Europe's Troubles to Exploit ICT's Productivity Potential," Research Memorandum GD-79, Groningen Growth and Development Centre, September.

Whelan, Karl (2003) "A Two-Sector Approach to Modeling U.S. NIPA Data," *Journal of Money, Credit, and Banking*, Volume 35, No. 4, August, pp. 627-656.