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Information Technology and Productivity Growth in Korea

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Information Technology and Productivity
Growth in Korea

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Preface

Ever since the information technology (IT) revolution was brought about by the computer, Internet, wireless communications, and other IT innovations, the impacts of information technology on productivity growth have attracted a considerable amount of attention among economists. A substantial number of studies on IT and productivity growth manifest such intensified interests in this subject. As a matter of fact, a number of recent studies, especially those on the U.S. economy, have found significant and positive relationships between IT and U.S. productivity growth.

The paper by Ky H. Yuhn and Seung-Rok Park investigates the effects of information technology (IT) on productivity growth in a highly digitalized economy. Some empirical evidence obtained from the U.S. experience represents partial truth. The profession needs additional evidence that corroborates the positive role of IT in productivity growth. The authors have done this task by presenting new evidence on the contribution of IT to productivity growth in the Korean economy. Their work contains several distinguishing features that contribute significantly to the existing literature:

First, by introducing a stochastic frontier production function and utilizing the latest developments in computer algorithms, this study has successfully unraveled the source of TFP growth and decomposed it into three parts; (1) technological change, (2) efficiency improvement, and (3) scale economies. This success in decomposing TFP into three components brings this study into prominence. In fact, this decomposition was one important missing element in most of the existing studies on the importance of IT in productivity growth.

Second, the authors have applied their model to Korea that has emerged as an Internet powerhouse since the late 1990s. Korea has been in the forefront of the IT Revolution and thus offers a good laboratory for investigating the impacts of information technology on productivity growth. Another merit of using Korean data is provided by the availability of vast panel data that include observations on 4,022 firms from 1996 to 2000.

The main conclusions drawn from the research can be summarized as follows: a strong relationship between IT and productivity growth was found in the Korean economy. A more surprising result is that productivity growth remained quite strong despite the 1997 financial crisis and the subsequent recession, and the collapse of the IT bubble in 2000. This study has also found that approximately 80% of TFP growth comes from technological change, 15% of

TFP growth is attributable to efficiency improvement, and the rest results from scale diseconomies. This finding indicates that the dominant source of TFP growth is technological change, but the proportion of efficiency improvement in TFP growth has continually increased. Efficiency improvement primarily represents improved management and organizational productivity.

I would like to express my sincere gratitude to the authors, Dr. Ky H Yuhn, a professor at Florida Atlantic University, and Dr. Seung Rok Park, a senior research fellow here at KERI for their enormous efforts in completing this study. However, the views expressed here are those of the authors and do not necessarily represent the views of the Korea Economic Research Institute as a whole.

Dr. Sung-Hee Jwa
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I. Introduction

The second half of the 1990s witnessed the coexistence of low inflation with low unemployment that had rarely happened before in the United States. After a quarter-century of the lackluster performance of productivity growth, the U.S. economy experienced a remarkable surge in productivity growth during this period. These major developments have convinced many people that some fundamental phenomena changed the U.S. economy in a profound way, transforming it into a new economy. In 1998, Federal Reserve Board Chairman Alan Greenspan described the New Economy's characteristics as including technological innovations that raise productivity and that have removed pricing power from the world's producers on a more lasting basis.[1)]

These features of the New Economy represent an apparent departure from the Old-Economy paradigm. Under the Old Economy, one could have only low inflation combined with high unemployment or vise versa, but not have both low inflation and low unemployment. To achieve a low level of unemployment, a certain rate of inflation would have to be tolerated, and policy could be directed toward achieving that level of unemployment. This formula was a stepping stone for U.S. economic policy for many decades. The New Economy has rendered this formula obsolete. The information technology (IT) revolution brought about by the

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1) See Greenspan (1998)

computer, Internet, wireless communications, and other recent major innovations was the underpinning of the New Economy.

Under the New Economy, new rules of competition, new sorts of organization, and new challenges for management are under way. In an information economy world, innovation is more important than mass production; investment buys new ideas rather than new machines; market power is increasingly based on new sorts of organization and management rather than the allocation of scarce material goods. Microsoft's rise epitomizes the power of ideas in the New Economy. Although Microsoft has annual sales of $31 billion, the market stock value of the company stands well over $254 billion–far more than either IBM whose market value is $134 billion with annual sales of $81 billion or General Motors whose market value is merely $19 billion with annual sales of $187 billion.[2)] This seeming paradox occurs because "the rules of competition are changing to favor companies like Microsoft over paragons of the Industrial Age" (John Browning).

In this paper, the New Economy is defined as having two major characteristics: (1) sustained productivity growth and (2) low inflation coexisting with low unemployment. These

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2) These numbers were taken from *The BusinessWeek*, Spring 2003. Annual sales represent those of 2002, and the market value is the share price multiplied by common shares outstanding as of February 28, 2003.

two characteristics are not separate, but interrelated. Steady productivity growth is a prerequisite for the coexistence of low inflation and low unemployment. Indeed, productivity growth is the single most important factor that enables a nation to achieve economic growth without inflation. It is the one that determines living standards in the long run. It is the one that affects the budget status, the financial health, stock market valuations, currency valuations, and many other things.

One of the interesting facets of the IT revolution is that it could have long-lasting impacts on productivity growth. The connection between industrial technology and productivity growth under the Old Economy is simple. A little more of investment produces a little more of equipment and plant, and there will be a slight increase in productivity. We have capital-deepening productivity growth. Since competition among business firms was mainly in production and selling, new developments in production and selling could have cyclical and erratic impacts on productivity growth. Productivity falls sharply during recessions mainly as a result of the unused capacity of equipment and plant, and employed workers. When the economy is booming, productivity tends to rise.

The connection between information technology and productivity growth under the New Economy is quite different. A slight investment in IT such as the Internet that may cost little could have an enormous impact on managerial and organizational advantages, aside from its effect on production. Thus, under the New Economy knowledge discovery and invention will have explosive and long-lasting impacts on productivity growth. There are several possible sources for the acceleration of productivity. First, IT-related investment could create 'network externalities' in which benefits increase dramatically as the number of users increases. Second, IT-related investment could generate 'increasing returns to scale' in which costs are reduced more than proportionally as the market grows in size. The fixed cost of IT-related investment may be large, but its marginal cost can be minimal. Finally, IT-related investment could involve 'spillover effects' in that it affects productivity growth not only in the IT sector itself, but also in other sectors of the economy that use IT applications. An IT innovation made anywhere in the world spreads around the world with warp speed.

In an interesting study on the technology gap, Cummins and Violante (2002) have attempted to measure how much more productive the best available machines are than the average machine in use. Their study reveals that in the 1950s, the productivity of the best available equipment was about 8 percent greater than the average equipment in use, but by the early 1990s, the gap had widened to about 37 percent, and in the latter half of the 1990s, it widened further to about 40 percent in spite of massive capital spending boom. Their finding suggests that new equipment utilizing the large existing backlog of information technology can have explosive effects on productivity.

This promising and extensive opportunity is not a fantasy. It has been crystallizing in the United States since the mid-1990s. U.S. productivity increased at the annual rate of 2.5 percent from 1995 to 2000, compared with an anemic increase of only about 1.5 percent per year from 1973 to 1995. More surprisingly, productivity has grown even more strongly since 2000 than in the 1990s at a galloping pace of 3.4 percent per year. This phenomenon happened despite the recession that started in March 2001, and a slow recovery since the recession ended in November 2001. A number of recent studies have presented evidence that almost all of the productivity improvement was attributable to information technology. Many researchers are optimistic about the future, predicting the continuation and possible acceleration of the sizeable productivity advance that began in 1995.[3] The South Korean economy during the latter part of the 1990s may not fit exactly into the characterization of the New Economy, but there is no question that Korea has joined a new wave of changes brought by the New Economy.

However, the existing studies have one important missing

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3) Becker (*The BusinessWeek*, October 20, 2003)

element in the analysis of the importance of information technology in productivity growth. They have failed to unravel where productivity growth comes from. The main thrust of this study lies in addressing this important issue. The purpose of this study is two-fold. First, we disentangle the source of productivity-enhancing technology by decomposing productivity growth into three parts: (1) technological progress, (2) efficiency improvement, and (3) scale economies. Second, we investigate whether or not the much touted IT revolution during the second half of the 1990s has been led by large firms or small firms. These investigations will enable one to answer some puzzling phenomena observed in the New Economy. In particular, we propose the following two hypotheses and attempt to resolve the puzzles:

Hypothesis 1: Productivity growth under the New Economy is more robust to business cycles than under the Old Economy. A corollary to this proposition is that productivity growth is not likely to fall even in recession. Network externalities, increasing returns to scale, and information spillovers created by information technology will be major supporting pillars of productivity growth even in recession.

Hypothesis 2: Improvement in business (management and organization) efficiency plays a greater role in enhancing productivity growth under the New Economy than under the Old Economy. One possible explanation for this phenomenon is that IT applications could have enormous impacts on organizational advantages throughout the firm, eventually improving productivity.

In order to conduct an empirical analysis of our hypotheses, we utilize a stochastic frontier production function that allows one to decompose productivity growth into technological progress, efficiency improvement, and scale economies. To the best of my knowledge, this study is the first to employ such a frontier production function and sophisticated computer algorithms to analyze the contribution of information technology to productivity growth. Our study makes another contribution to the empirical literature. Most evidence on the link between the recent productivity surge and information technology comes from U.S. data. We apply our model to South Korea which "has rightfully been called an Internet paradise."[4)]

South Korea offers a good laboratory for investigating the impacts of information technology on productivity growth. South Korea has been in the forefront of the IT Revolution. Many South Korean IT industries stand on the top in the world marketplace. South Korea ranks in the first place in the production of DRAM chips, liquid crystal monitors for notebook computers and cellular phones, CD-Rom drives, TFT liquid crystal monitors, ODD, etc. South Korea has the

4) *The New York Times* (May 5, 2003)

highest penetration rate of the broadband Internet in the world. *The New York Times* (May 5, 2003) describes South Korea's success story as follows:

"With a hefty push from the government, South Korea's telecommunications providers have built the world's most comprehensive Internet network, supplying affordable and reliable access that far surpasses what is available in the United States, even in those homes that have their broadband setup. By embracing broadband so heartily, Koreans have turned their country into a test case for the visionaries who, just a few years ago, imagined a future of nearly infinite digital possibilities. While those dreams have hit speed bumps in the United States and elsewhere, South Korea–with Japan not far behind–is racing ahead. In the process, Koreans are offering a glimpse of what wired societies are supposed to look like, where fast Internet connections vastly increase access to information, help lift productivity and create new markets. America's uneven adoption of broadband has Silicon Valley executives looking at South Korea with envy."

An extension of the analysis of the IT impact on productivity growth to the most digitalized economy deserves several merits. First, the robustness of U.S. productivity growth during the latter half of the 1990s needs more evidence because the U.S. economy during this period navigated before the wind. By contrast, the Korean economy suffered from several external shocks such as the 1997 financial crisis and the 1998-99 recession even before the burst of the IT bubble in 2000. If productivity growth turned out to be robust to such external shocks, then this evidence would warrant the stability of published empirical results on the effect of information technology on productivity growth. Second, the availability of vast panel data on South Korean firms will significantly enhance the power of test: We have observations on 4,022 firms from 1996 to 2000.

Our empirical analysis shows that the average annual growth rate of total factor productivity (TFP) during the 1996-2000 period was about 2.3 percent, and 80 percent of the TFP growth is attributable to technological progress. This performance is roughly comparable to the U.S. productivity growth rate of 2.5 percent per year during the 1995-2000 period.[5] This magnitude of productivity growth represents a remarkable performance in light of the fact that the Korean economy suffered from two external shocks: the Asian financial crisis and the subsequent recession. It would not be possible for the economy to sustain such robust productivity growth under the Old Economy in the face of

5) The U.S. productivity growth rate is the growth rate of average labor productivity. It includes output growth that comes from both an increase in the quantity of labor and technological progress (together with efficiency improvement and scale economies). On the other hand, the Korean productivity growth rate is the growth rate of total factor productivity, and it includes only output growth that comes from technical progress, efficiency improvement, and scale economies.

economic hardships. Our empirical results also render support to our two hypotheses posed in this study. Information technology has already made a quantum difference in productivity growth.

The plan of the paper is as follows: In chapter II we discuss the importance of information technology in enhancing productivity and production potential. Chapter III briefly reviews the most recent literature on the role of information technology in productivity growth. In chapter IV we develop a theoretical model that allows one to unravel the source of productivity growth using a stochastic frontier production function. Chapter V presents empirical results, and concluding remarks and policy implications are presented in chapter VI.

II. Information Technology, Productivity Growth, and Production Potential : An Intuitive Exposition

The (average) productivity of labor is the most frequently cited measure of productivity. However, labor productivity is sometimes misleading and is not sufficient to explore the source of productivity growth. Labor productivity measures the amount of output per man/hour, and is obtained by dividing the total amount of output produced per hour by the number of workers. The labor productivity measure simply relates productivity to the quantity of labor. It does not take into account the quality or knowledge (education) level of a worker. For instance, it does not distinguish between an illiterate worker and a worker with a graduate degree.

Another weakness of the simple labor productivity measure is that it can increase even when there is no improvement in economic performance. When workers are laid off as a part of restructuring during recessions, labor productivity could increase even if there is no technological advance, and no improvement in economic performance. Finally, the labor productivity measure is not very informative about the sources of an increase in output per worker. It is not clear whether an increase in output per worker is due to an increase in the quantity of labor or due to an improvement of workers' skills.

Similarly, the (average) productivity of capital measures the amount of output per machine/hour, and is obtained by dividing the total amount of output produced per hour by the amount of physical capital such as tools and machines. It does not distinguish between one machine/hour of a calculator and one machine/hour of a computer.

Thus, labor productivity growth does not distinguish between output growth due to an increase in the quantity of physical labor and output growth due to a technological change. In other words, the labor productivity measure includes both output growth generated by an increase in the quantity of labor and output growth generated by technological innovations. It is total factor productivity (TFP) or multi-factor productivity (MFP) that determines a nation's potential output. TFP captures the increase in output brought about by technological progress, efficiency improvement, and scale economies. If both labor and capital increase, then output will also increase. An increase in output will be greater than or smaller than or equal to increases in labor and capital depending on economies of scale. However, there is a limit to increases in physical inputs (labor and capital), and therefore there is a limit to output growth that can be created by increases in physical inputs.

Consider the following simple production function in which value added output (GDP) is related to two primary inputs, labor and capital:

(1) $Y_t = f(L_t, K_t)$

where Y_t is GDP in period t, L_t is the quantity of labor in period t, and K_t is the quantity of capital in period t. The Solow decomposition of output growth implies that

(2) $\dot{Y}_t = S_L \dot{L}_t + S_K \dot{K}_t + T\dot{F}P_t$

where $\dot{Y}_t = (\Delta Y_t / Y_t)/\Delta t$ represents the growth rate of output per period, S_L is the share of output that goes to labor suppliers (workers), and S_K is the share of output that goes to capital suppliers. The term, $S_L \dot{L}_t + S_K \dot{K}_t$, represents the rate of economic growth that an economy can attain by increasing the quantities of physical labor and capital inputs. In South Korea, S_L has been estimated to be 0.65, and S_K to be 0.35.

The (maximum) growth rate of labor can be approximated by the growth rate of population. On the other hand, the maximum growth rate of capital in South Korea can be calculated from the acceleration model of investment which is given by

(3) $\Delta K_t = I_t = \alpha \Delta Y_t$

An increase in capital (ΔK_t) is equal to investment (I_t), and investment is equal to the acceleration coefficient (α) times an increase in output (GDP). We can convert the discrete-time version of the acceleration principle into a continuous-time representation:

(4) $\dot{K}_t = \alpha \dot{Y}_t$

The long-run average growth rate of Korean GDP (Y_t) from 1961 to 2000 was 7.0 percent per year, and the Korean coefficient of acceleration roughly ranges between 1.3 and 4.6. Thus, the maximum growth rate of capital input (assuming that α = 2.0) is

(5) $\dot{K}_t^{\max} = (2.0)(7.0\%) \approx 14.0\%$

We'll first figure out the potential growth rate of the Korean economy during the period of the 1960s-1980s. During this period, the maximum growth rate of the labor force was estimated to be about 2.5 percent, and the maximum growth rate of the capital stock to be 14.0 percent. Thus, the maximum rate of economic growth per year that could be achieved by increases in physical labor and capital inputs during period of rapid industrialization was

(6) $S_L \dot{L}_t + S_K \dot{K}_t = (0.65)\,(2.5\%) + (0.35)\,(14.0\%) \approx 6.5\%$

Thus, if there were no TFP growth, the maximum rate of economic growth per year would be 6.5 percent.

However, since the 1997 financial crisis, the Korean economy has shown a slowdown in its growth potential. First, the growth of the labor force has slowed down substantially. Second, business investment has increased at a snail's pace. Many people believe that the annual growth rate of capital has recently reduced to less than 10 percent. If the labor force grows at the rate of 1.5 percent per annum, and the capital stock grows at the rate of 8 percent per annum, then the maximum rate of economic growth attributable to increases in physical factor inputs will drop to

(0.65) (1.5%) + (0.35) (8.0%) = 3.8%

In this study, it is projected that the maximum rate of economic growth attributable to increases in the quantities of labor and capital will be 4.0 percent over the next 10 years or so.

Here we can highlight the surprising role of total factor productivity in economic growth. The Solow growth accounting equation implies that

$$(7) \quad \begin{aligned} \dot{Y}_t &= S_L \dot{L}_t + S_K \dot{K}_t + T\dot{F}P_t \\ &= 4.0\% + T\dot{F}P_t \end{aligned}$$

If TFP increased at the rate of 1 percent per year, the Korean economy could grow at the annual rate of 5.0 percent. If the TFP growth rate increases to 2.5 percent, the potential growth rate of the Korean economy will jump to almost 6.5 percent. Indeed, Korean TPF grew at an annual rate of 2.4 percent during the second half of the 1990s, and most of the productivity spurt was believed to be attributable to information technology. Thus, information technology is a crucial element that determines a nation's production potential.

Lau (1996) proposed a hypothesis arguing that physical capital, human capital, and technological change are sources of economic growth that change sequentially according to the phase of a nation's economic development. Park (2001) has applied Lau's hypothesis to the Korean economy, showing that the principle source of South Korea's economic growth has changed sequentially in the past three decades according to the different stages of development. Physical capital accumulation and labor input seem to have been the main sources of economic growth in the early stage of development while total factor productivity growth driven by technological change and efficiency improvement became more important in later development stages. This implies that developing countries might have achieved rapid economic growth without innovative technological change during the catch-up period, and thus strategies allowing for easier means of technological progress were adopted, which will later give way to creative innovation when other means of technological change become exhausted.

Is it possible for the Korean economy to achieve such a high growth rate of TFP? The main purpose of this study is to delve into this possibility and to offer some clue to reaching such a goal. Historically, the growth rate of the Korean economy averaged 7.0 percent during the period of rapid industrialization (1961-1990). This implies that Korean TFP grew at the annual rate of about 0.5 percent on the average during this period under the premise that the potential growth rate due to increases in physical factor inputs was 6.5 percent during this period. As we demonstrated, if Korean TFP grows at the rate of 2 percent per year, it is possible for the Korean economy to achieve an annual growth rate of 6.0 percent over the next 10 years or so.

This size of TFP growth (2%) can also have a sizable effect on Korean jobs. Okun's Law quantifies the relationship between output growth and unemployment as follows:

(8) $\Delta Y_t / Y_t = \alpha - \beta \Delta U_t$

where Y_t is GDP, U_t is the unemployment rate, and β is Okun's coefficient. It follows from Okun's Law that

(9) $\Delta U_t = \alpha / \beta - (1/\beta)(\Delta Y_t / Y_t)$

Blanchard (2003, p.185) has estimated the reciprocal of Okun's coefficient $(1/\beta)$ for Japan to be 0.12 during the

1981-2000 period.

Using this approximation for the Korean labor market, Okun's Law implies that a one-percentage point increase in GDP could lead to a 0.12 percentage point decrease in the unemployment rate. Currently, the Korean labor force is approximately 25 million. Thus, a one-percentage point increase in GDP will create (0.12%) (25 million) = 30,000 jobs. Here we have a simple, but surprising multiplier result. If TFP grows at the annual rate of 2 percent, the growth rate of GDP will increase by 2 percentage points, and 60,000 more jobs will be created.

Then what is total factor productivity (TFP)? Where does TFP growth come from? There are three major sources of TFP growth: (1) technological progress, (2) efficiency improvement, and (3) scale economies. Technological progress is the dominant source of TFP growth, and information technology is the underpinning of technological progress. Thus, information technology is a primary contributor to TFP growth. For example, video conference allows workers to work faster and more efficiently from home. By reducing information and transactions costs, information technology greatly improves productivity. In chapter IV, we develop a theoretical model of the decomposition of TFP growth into the three sources.

III. A Brief Review of the Literature

There has been a proliferation of the literature on the role of information technology in productivity growth and economic growth. This chapter reviews the literature that is directly relevant for our study. While many recent studies have found that information technology actually plays an important role in productivity growth and economic growth, earlier studies that mainly investigated the relationship between computer investment and productivity growth before the advent of the IT revolution were generally skeptical about the contribution of information technology to a nation's economic growth. The productivity paradox of information technology represents such skeptical views. Some earlier studies presented evidence that information technology only contributed a small share to the whole pie of a nation's economic growth rate. This proposition is known as the productivity paradox of information technology.

The productivity paradox indicates that IT has a small or even no contribution to productivity growth in particular and to economic growth in general. The quip attributed to Nobel laureate Robert Solow that we see computer everywhere except in the productivity statistics captures this perspective quite vividly. Roach (1991), in his study on American white-collar workers' productivity concluded that with the advent of IT, the investment in IT in offices increased, and this made office work more capital intensive than production work. However, output per information worker decreased by 6.6 percent between the mid-1970s and 1986 while output per production worker grew by 16.9 percent. The conclusion of Roach has provided the basis for many of the arguments that IT has not helped U.S. productivity growth or even that IT investments have been counterproductive.

Loveman (1988) estimated that the contribution of IT capital to output was approximately zero over the five-year period studied in almost every sub-sample he examined. His finding further corroborates the productivity paradox: while firms have a great desire to invest intensively in IT, measured productivity gains are insignificant. Bailey and Gordon (1988) found no significant contribution of computerization to productivity growth. Morris and Berndt (1990) asserted that additional IT investments were a factor in the decline of productivity, arguing that estimated marginal benefits of investment in IT are less than the estimated marginal costs. Wolff (1991) found that total factor productivity growth was negative in the insurance industry during the 1948-1986 period even though it ranked fourth among 64 industries in terms of computer investment. Berndt and Morrison (1995) found negative correlations between high-tech capital investment in U.S. manufacturing industries and labor productivity. Gordon (2000) argued that despite the growing use of computers and other information technology, the trend or long-term growth rate of average labor productivity outside the durable-goods manufacturing sector had not accelerated significantly in recent years.

Wolff's (2003) recent study has claimed that there has been little evidence of a payoff to computer investment in terms of productivity growth by citing the famous Solow quip. However, it is worth noting that his study focused on the period prior to the productivity growth surge of the late 1990s. He has examined the relation of skills, education, and computerization to productivity growth and other indicators of technological change at the industry level. Industries that have had the greatest investment in computers (namely, financial services) have ranked among the lowest in terms of conventionally measured productivity growth. Somewhat surprisingly, Wolff's results indicate that computers and related IT investments are not significantly linked to productivity growth at the industry level. He also finds evidence that there is virtually no correlation between the growth of total factor productivity and the skills or educational attainment of workers. These findings are intriguing because economists typically rely on education as a proxy for skills.

We have reviewed some literature that has found no significant relationship between IT and productivity economic growth. However, on closer examination, this productivity paradox has many flaws. There is one prominent common thing in all of the studies that have found the productivity paradox: they all focus on the performance of the U.S. productivity in the past decades of the 1970s, 1980s and early 1990s. This fact indicates that the conclusions of these studies about the role of IT on productivity and economic growth have been seriously flawed. The decades of the1970s, 1980s, and early 1990s witnessed the ever-first intensive investment in IT. However, the benefits from IT can take several years to produce results: new technologies may not have an immediate impact. Brynjolfsson (2004) has recently done an econometric study which finds lags of two-to-three years before the strongest organizational impacts of IT can be felt. Moreover, a survey of executives suggests that many expect it to take as much as five years for IT investments to pay off. Those studies which conclude that IT plays no role in improving productivity have not accounted for the lags of investment and the arrival of the IT revolution, and therefore their conclusions are not convincible.

Another and maybe most important cause that has made those researchers come up with the conclusion that IT has very small or even no contribution to productivity and economic growth is measurement error. Because the benefits that IT brings about are mostly intangible, output may not have been measured correctly. These benefits include increased quality, product variety, creation of new products, improved customer service, speed and responsiveness (Brynjolfsson, 2004). They are poorly accounted for in productivity statistics and therefore this leads to underestimates of IT productivity.

It is also important to realize that firm-level effects and industry-level effects can be different. IT effects are most likely to be felt directly at the firm level. Because each firm makes its own different investment in IT to improve the quality of its products, there will be low quality products and good ones in the whole market. When firms with high quality products and firms with low quality products are combined together in the industry data, both the IT investment and the difference in revenues will be averaged out, and a lower correlation between IT and measured output will be detected (Brynjolfsson, 2000). Therefore, firm-level data are much more reliable than industry-level data. Moreover, IT may be beneficial to individual firms but unproductive from the standpoint of the industry or the economy as a whole (Brynjolfsson). For example, by applying IT to its market research activities or quality management activities, a firm may increase its product prices, which virtually has no effect on the total output.

A number of more recent studies that focus on productivity growth since the birth of the IT revolution in the mid-1990s have found positive effects of information technology on productivity growth. Baily (2001), Oliner and

Sickel (2000, 2003), Stiroh (2001), Jorgenson, Ho and Stiroh (2003) have extensively investigated the surge in productivity growth in the United States during the second half of the 1990s. From 1995 to 2000, output per man/hour (labor productivity) grew at an average annual rate of about 2.5 percent compared with increases of only about 1.5 percent per year from 1973 to 1995.

Most of these studies arrive at the conclusion that the substantial portion of the productivity growth spurt during the 1995-2000 period was due to technological advances embodied in increased computer and Internet investment. In particular, Jorgenson, Ho and Stiroh (2003) and Oliner and Sichel (2003) have been concerned with whether the impacts of information technology on productivity growth could hold even in recessions and continue in the future. They have found that productivity growth remains surprisingly strong even in recession. According to the estimate of the Bureau of Labor Statistics (2002), business sector productivity grew by 1.9 percent in 2001 when the official recession started. They argue that information technology has played a central role in the robust growth of labor productivity. One possible explanation for this trend is that large investments in communications equipment and software made during the late 1990s continued to boost output for several years after the purchases were made. Oliner and Sichel's (2003) study shows that the capital deepening contribution from computer hardware, software, and telecommunications equipment to labor productivity growth for the 1995-2000 period exceeded the contribution from all other capital assets.

Jorgenson, Ho and Stiroh have projected the future of U.S. productivity growth. Their projection of labor productivity growth and output growth varies depending on uncertainties about future technological changes in the production of IT equipment and related investment patterns, in particular, the product cycle of semiconductors, the most important IT component. Their projection of trend labor productivity growth for the next decade (2001-2010) is 2.21 percent per year (pessimistic projection: 1.33 percent, optimistic projection: 2.92 percent), slightly below the average of the 1995-2000 period of 2.5 percent per year. The projection of output growth for the next decade is 3.3 percent per year (pessimistic projection: 2.43 percent, optimistic projection: 4.02 percent), compared with the 1995-2000 average of 4.6.

Oliner and Sichel have raised questions about the strength of the impacts of information technology on productivity growth and the sustainability of the rapid productivity growth of the late 1990s. To assess the robustness of the role of information technology in the productivity revival since the mid-1990s, they have extended the sample period through 2001 (1995-2001) and confirmed that output per hour (labor productivity) accelerated substantially after 1995, driven in large part by greater use of IT capital goods by businesses throughout the economy and by more rapid efficiency gains in the production of IT goods. To assess whether the pickup in productivity growth since the mid-1990s is sustainable, they have analyzed the steady-state properties of a multi-sector growth model and found that the pace of technological progress in high-tech industries–especially semiconductors–likely will be a key factor in productivity growth going forward. Their projection of future productivity growth reveals that labor productivity growth ranges from 2 percent to 2.75 percent per year, depending on the pace of technological advances in the semiconductor industry. They have concluded that a significant portion--and possibly all--of the mid-1990s' productivity resurgence is sustainable.

Gramlich (2003) discussed why productivity defied past patterns by holding up during the 2001 recession. He argues that although productivity is very important in determining aggregate supply, productivity matters for aggregate demand as well. Productivity innovations should be at least somewhat capitalized in the stock market, possibly overcapitalized in the stock market. These wealth effects can then lead to spending--consumption, investment, and so forth. Productivity growth is affected not only by capital-deepening technology, but also by new IT and new ways of coordinating the activities of the firm. Finally, he notes that the finding that information technology has a very significant impact on the recent productivity growth is surprising because even though IT capital is such a small share of total capital, yet increases in IT capital have been responsible for a large part of the productivity growth.

Rivlin (2003) has argued that one important implication of the New Economy is that inflation may no longer be a serious macro problem, and consequently the focus of the central bank might have to shift from controlling inflation to the harder problem of restricting excessive investment and the results of irrational exuberance. Unfortunately, monetary policymakers have less influence over such factors than over inflation. She has also discussed that the increased competitiveness in which both IT and more open borders contributed to lower inflation, because IT and globalization make it easier for buyers and sellers to find each other and make it harder for sellers to control over price. Litan and Rivlin (2001) projected that over the next five years (2004-2008), increasing use of Internet technology could make an additional contribution to productivity growth by 0.25 percent to 0.5 percent.

In addition to those studies that focus on the productivity growth surge during the latter part of the 1990s, a large number of studies have investigated the linkage between information technology and productivity growth. For example, Siegel and Griliches (1992) and Steindel (1992) reported a positive and significant relationship between computer investment and industry-level productivity growth. Oliner and Sichel (1994) found a significant contribution of computers to aggregate U.S. output growth. Lichtenberg (1995) estimated firm-level production functions and found an excess return to IT equipment. Brynjolfsson and Hitt (1996, 1998) found a positive association between IT investment and firm-level productivity growth over the period from 1987 to 1994 when accompanied by organizational changes. Lehr and Lichtenberg (1999), using firm-level data among service industries from 1977 to 1993, presented evidence that computers contributed positively to productivity. Brynjolfsson (2000) asserts that IT through its direct effects on firms' organizational improvement enables firms to increase its productivity growth by reducing costs and more importantly increasing output quality. Ten Raa and Wolff (2001) found strong productivity spillovers between the computer-producing sector and sectors using computers and concluded that the computer sector was the leading sector during the 1980s as a source of economy-wide productivity growth.

IV. Methodology

1. Decomposition of Total Factor Productivity Growth

An increase in output can be decomposed into two parts: (1) an output increase associated with increases in factor inputs and an output increase attributed to other sources than factor inputs. An increase in output that is attributable to other sources than factor inputs is often identified as total factor productivity (TFP) or multi-factor productivity (MFP). In the Neoclassical tradition such as the Solow growth model, TFP is usually measured as a residual between output growth and factor input growth, and this unexplained residual is often termed an ignorance term because the content of the residual has been rarely known. This study is intended to unveil the sources of the ignorance term.[6)]

We consider a simple production function that uses a single factor input x to produce single output y.

(10) $y_t = f(x_t)$

where y_t is the amount of output produced in period t, and x_t is the amount of input used in period t. This production function represents a frontier production

6) The discussion of this chapter is heavily drawn from Kumbhakar and Lovell (2000).

function which is the locus of the most efficient production level.

Suppose there is an expansion of output from y_t (point A in the diagram) to y_{t+1} (point B in the diagram) between two time points, t and $t+1$. Also we assume that the actual level of output does not correspond to the most technically efficient level of output. That is, the levels of output in points A and B involve technical inefficiency. When there is only an increase in factor inputs without technological change, the production point will shift from point A to point C.

Now suppose technological change occurs between t and $t+1$. Then the production function shifts outwardly from $f(x_t)$ to $f(x_{t+1})$, and the level of output at point B is greater than that of output at point A.

(11) $y_{t+1} \rangle y_t$

However, because of the existence of inefficiency in production, actual levels of output will lie below the frontier production functions. That is, the actual production at the two points involves technical inefficiency.

$y_t \langle f(x_t)$ at production point A and

$y_{t+1} \langle f(x_{t+1})$ at production point B

Since the distance between the point on the frontier production function and actual output measures the degree of technical inefficiency, this distance becomes smaller as technical inefficiency decreases at the two production points between t and $t+1$. Put differently, the ratio of the actual output level to the frontier production level in B is greater than that in A as technical efficiency improves between t and $t+1$.

(12) $y_t / f(x_t) \langle\, y_{t+1} / f(x_{t+1})$

Finally, if there are economies of scale in the production process given inputs, this should lead to higher output. If a firm enjoys greater economies of scale between the two production points, then output per input at point B should be greater than that at point A.

(13) $y_t / x_t \langle\, y_{t+1} / x_{t+1}$

One attractive feature of this study compared with existing studies should be apparent. Previous studies are only concerned with dividing output growth into output growth attributable to factor input growth and output growth attributable to total factor productivity growth, but this study is concerned with unraveling the source of total factor productivity (ignorance term) into technological progress, efficiency improvement, and economies of scale.

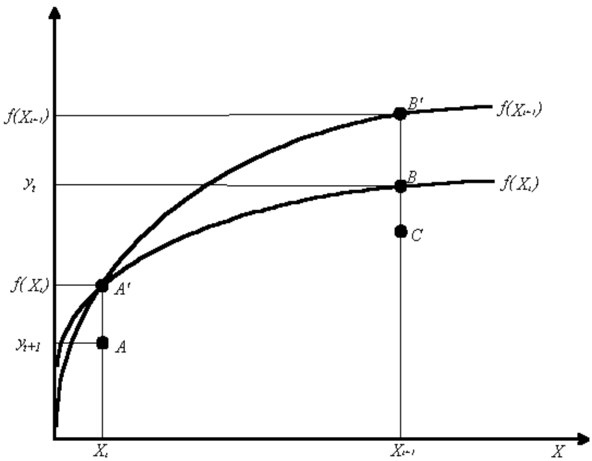
In order to decompose total factor productivity into the three parts, we first start with a determinsitic frontier production function as follows:

(14) $y_t = f(x_t, t)e^{-ut}$

where y_t is the deterministic part of the stochastic frontier function, x_t is a vector of factor inputs, $x = (x_1, x_2, \ldots, x_n)$, t is a trend variable as a proxy for technological change, and $u_t\ (u_t \geq 0)$ measures productive inefficiency. Technological change need not necessarily be neutral. If technological change is neutral, the production function takes the following form:

(15) $y_t = f(x_t, t)e^{-ut} = A(t)g(x_t, t)e^{-ut}$

<Figure 1> The Frontier Production Function


$f(X_{t-1})$
y_t
$f(X_t)$
y_{t+1}
B'
B
C
A'
A
$f(X_{t-1})$
$f(X_t)$
X_t
X_{t-1}
X

Technological change (ΔTC) is represented by a shift of the production function:

(16) $\Delta TC = \partial f(x_t, t) / \partial t$

where $\Delta TC \rangle 0$, $\Delta TC = 0$, $\Delta TC \langle 0$ indicate that the frontier production function shifts upwardly, remains unchanged, or shifts downwardly, respectively, as a result of technological change.

A change in productive inefficiency (ΔTIE) is measured as

(17) $\Delta TIE = \partial u_t / \partial t$

where $\Delta TIE \langle 0$, $\Delta TIE = 0$, $\Delta TIE \rangle 0$ imply that productive inefficiency decreases, remains unchanged or increases over time. This also indicates whether the actual production point moves toward or recedes from the frontier production function or whether the extent to which the actual production point deviates from the efficient production point decreases or increases.

As discussed before, total factor productivity (TFP) growth is defined as the difference between output growth and the portion of output growth not attributed to increases in factor inputs.

(18) $T\dot{F}P_t = y_t - \sum S_i x_{it}$

where the dot indicates the growth rate per unit time. On the other hand, S_i indicates the cost share of the ith factor input.

(19) $S_i = (w_i x_i)/C$

where $C = \sum w_i x_i$ is total cost, and $w = (w_1, w_2, \ldots, w_n)$ is a vector of factor prices.

We take the logarithms of both sides of Eq. (14) to obtain

(20) $\ln y_t = \ln f(x_t, t) - u_t$

Totally differentiating Eq. (20) with respect to time yields

(21) $d \ln y_t / dt = (\partial \ln f / \partial x_1)(dx_1/dt) + \ldots + (\partial \ln f / \partial x_n)(dx_n/dt) + \partial \ln f / \partial t - du_t/dt$

After some mathematical manipulation, we obtain the following relationship:

(22) $\dot{y}_t = \varepsilon_1 \dot{x}_1 + \ldots + \varepsilon_n \dot{x}_n + \Delta TC - \Delta TIE = \sum \varepsilon_i \dot{x}_i + \Delta TC - \Delta TIE$

where $\varepsilon_i = \partial \ln f / \partial \ln x_i$ is the output elasticity of factor input i.

Substituting Eq. (22) into Eq. (18) gives

(23) $T\dot{F}P = \Delta TC - \Delta TIE + \sum \varepsilon_i \dot{x}_i - \sum S_i \dot{x}_i$

We can transform Eq. (23) into the following form:

(24) $T\dot{F}P = \Delta TC - \Delta TIE + \sum \varepsilon_i \dot{x}_i - (\varepsilon_i / \varepsilon)\dot{x}_i + (\varepsilon_i / \varepsilon)\dot{x}_i - \sum S_i \dot{x}_i$

$$= \Delta TC - \Delta TIE + \sum(\varepsilon - 1)(\varepsilon_i / \varepsilon)\dot{x}_i + \sum(\varepsilon_i / \varepsilon - S_i)\dot{x}_i$$

where ε is the sum of the output elasticities of factor inputs:

(25) $\varepsilon = \varepsilon_1 + \varepsilon_2 + \ldots + \varepsilon_n = \sum \varepsilon_i$

If $\varepsilon > 1$, the frontier production function exhibits increasing returns to scale (IRTS).

If $\varepsilon = 1$, the frontier production function exhibits constant returns to scale (CRTS).

If $\varepsilon < 1$, the frontier production function exhibits decreasing returns to scale (DRTS).

Thus, Eq. (24) suggests that total factor productivity growth $(T\dot{F}P)$ can be decomposed into four parts:

(1) ΔTC : technological change (or technological progress)

(2) ΔTIE : productive inefficiency change (or simply inefficiency increase)

(3) $\sum(\varepsilon - 1)(\varepsilon_i / \varepsilon)\dot{x}_i$: economies of scale and

(4) $\sum(\varepsilon_i / \varepsilon - S_i)\dot{x}_i$: allocative efficiency

Technological change occurs when knowledge discovery and invention are made. Efficiency improvement may be due largely to improved management or organizational productivity rather than to important technological advances. Economies of scale occur when production costs are reduced more than proportionally as output increases.

So far, we have not explicitly discussed allocative efficiency which is given by

(26) $(\varepsilon_1/\varepsilon - S_1)\dot{x}_1 + (\varepsilon_2/\varepsilon - S_2)\dot{x}_2 + \ldots + (\varepsilon_n/\varepsilon - S_n)\dot{x}_n$

In order to obtain the measure of allocative efficiency, we first calculate the difference between the output elasticity of factor input $i\,(\varepsilon_i)$ divided by and the cost share of factor input $i\,(S_i)$. We multiply this difference by the growth rate of factor input $i\,(x_i)$. The sum of these products represents allocative efficiency. If producers allocate factor inputs efficiently, then $\varepsilon_i/\varepsilon$ should approach S_i, and the term $\Sigma(\varepsilon_i/\varepsilon - S_i)\,x_i$ will vanish. In many empirical studies, the information on the prices of factor inputs and output is not obtained regardless of whether allocative efficiency exists or not.

If there is no allocative inefficiency, the equation representing TFP growth simplifies to

(27) $T\dot{F}P = \Delta TC - \Delta TIE + \Sigma(\varepsilon - 1)(\varepsilon_i/\varepsilon)\dot{x}_i$

If there is no productive inefficiency, TFP growth becomes

(28) $T\dot{F}P = \Delta TC + \Sigma(\varepsilon - 1)(\varepsilon_i/\varepsilon)\dot{x}_i$

That is, TFP growth is composed of technological change and economies of scale. Finally, if there is no productive inefficiency, and production technology exhibits constant returns to scale (CRTS), TFP growth is equal to technological change.

(29) $\dot{TFP} = \Delta TC$

We assume that there is no allocative inefficiency.

2. Measurement of Technical Efficiency

Farrell (1957) pioneered in establishing the notion and measurement of technical inefficiency (or efficiency), and his work was refined by subsequent studies such as Fare, Grosskopf, and Lovell (1984, 1985), Lovell (1993), Greene (1997), Kumbhakar and Lovell (2000) and others. Farrell distinguished between technical efficiency and allocative efficiency. Technical efficiency refers to a firm's ability to produce maximum output given the levels of inputs, and allocative efficiency refers to a firm's ability to achieve the optimal combination of factor inputs given the prices of inputs. He defined the sum of these two measures of efficiency as total economic efficiency.

Since Aigner, Lovell, and Schmidt (1977) and Meeusen and van den Broeck (1977) developed the stochastic frontier production function to measure such efficiency, the methodology has been further refined and generalized by Forsund, Lovell, and Schmidt (1980), Schmidt (1986), Baur (1990), Battese (1992), Greene (1993, 1997), and others. The stochastic frontier production function is constructed based upon the premise that a firm has technical inefficiency in the process of producing a particular product.

Several studies including Pitt and Lee (1981) and Kalirajan (1981) attempt to disentangle the sources of such inefficiency in two steps. In the first step, one formulates a stochastic frontier production function and obtains the measure of technical inefficiency. In the second step, one investigates the relationship between the measure of technical inefficiency and explanatory variables which are thought to be related to technical inefficiency. However, one problem with this methodology is that it is at variance with the maintained assumption that the measure of technical inefficiency estimated through the stochastic frontier function is independently identically distributed.

In order to overcome this problem, we slightly modify the frontier production function of Eq. (14). Following Kumbhakar, Ghosh and McGukin (1991) and Kumbhakar and Lovell (2000), we specify a stochastic frontier production function as.

(30a) $y_{it} = f(x_{it}, t)\, e^{vit - uit}$ or

(30b) $\ln y_{it} = \ln f(x_{it}, t) + v_{it} - u_{it}$

where y_{it} represents output produced by firm i in period t, x_{it} is a $(1 \times K)$ vector representing firm i's factor inputs employed in period t, and β is a $(K \times 1)$ vector of parameters to be estimated. v_{it} and u_{it} are random errors. It is assumed that v_{it} and u_{it} are independent. The first error component (v_{it}) represents white noise in the production process and is independently and identically distributed normal random errors that satisfy the classical Gauss-Markov conditions.

(31) $v_{it} \sim iid\, N(0, \sigma_v^2)$

The second component of the error term, u_{it}, is a non-negative random variable which measures technical inefficiency. Its values smaller than 0 are truncated.

(32) $u_{it} \sim iid\, N^+(\mu, \sigma_u^2)$

The term u_{it} is related to some exogenous variables (z_{it}) that are thought to be the source of technical inefficiency:

(33) $u_{it} = z_{it}\delta + \varepsilon_{it}$

The random error term, ε_{it}, has a normal distribution with a mean of 0 and variance of σ_ε^2. This specification implies that u_{it} has mean $z_{it}\delta\ (=\mu)$ and variance $\sigma_\varepsilon^2\ (=\sigma_u^2)$. The truncated point is $-z_{it}\delta$ with $\varepsilon_{it} \geq -z_{it}\delta$.

(34) $u_{it} \sim N^+(z_{it}\delta, \sigma_u^2)$

We follow Battese and Coelli (1992) in specifying the composite error component representing technical inefficiency. The technical inefficiency term (u_{it}) is specified as

(35) $u_{it} = u_i\,\eta(t)$

where u_i varies across firms, but remains the same over time, and $\eta(t)$ is a function of time:

(36) $\eta(t) = e^{-\eta(t-T)}$

Thus, u_{it} is specified as

(37) $u_{it} = u_i e^{-\eta(t-T)}$

Based on the maintained assumptions on v_{it} and u_{it}, the probability density function (pdf) of the composite error term $(v_{it} - u_{it})$ can be defined, and the following log likelihood function can be derived.

(38) $\ln L = \alpha - (1/2)\ln(\sigma_v^2 + \sigma_u^2) - \Sigma \ln \Phi(z_{it}\,\delta/\sigma_u) + \Sigma \ln\Phi(\mu^*_{it}/\sigma^*)$
$- (1/2)\ \Sigma[(\varepsilon_{it} + z_{it}\,\delta)^2/(\sigma_v^2 + \sigma_u^2)]$

where $\mu^*_{it} = (\sigma_v^2 z_{it}\,\delta - \sigma_u^2\,\varepsilon_{it})/(\sigma_v^2 + \sigma_u^2)$ and $\sigma^{*2} = (\sigma_v^2 \sigma_u^2)/(\sigma_v^2 + \sigma_u^2)$. The residual term, ε_{it}, is obtained from the estimated production function:

(39) $\varepsilon_{it} = \ln y_{it} - x_{it}\beta$

By the use of the maximum likelihood method, we can obtain the ML estimates of β, δ, σ_u^2, σ_v^2. Thus, we obtain the estimates of the parameters of the stochastic frontier production function, the measure of technical inefficiency of individual firms as well as the estimates of the parameters of the regression model that explains technical inefficiency. This study employs the algorithm developed by Battese and Coelli (1993) to estimate the maximum likelihood function. The estimation of the maximum likelihood function can be further simplified by reparameterization with $\sigma_S^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2/\sigma_v^2$ because the ML function can be formulated as a function of σ_S^2 and γ.

So far, we have been concerned with the measurement of technical inefficiency. Since $u_{it} = u_i\ e^{-\eta(t-T)}$ represents technical *inefficiency* (TIE) of the ith producer, the technical *efficiency* (TE) of the ith producer can be defined as $-u_{it} = -u_i\ e^{-\eta(t-T)}$

and its predictor is provided by

$$E\left[\exp(-u_i)\middle|(v_{it}-u_{it})\right]=\left\{\exp\left[-\mu_{it}^{*}+(1/2)\sigma^{*2}\right]\right\}\left\{\Phi\left[(\mu^{*}_{it}/\sigma^{*})-\sigma^{*}\right]/\Phi(\mu_i^{*}/\sigma^{*})\right\}$$

where $\mu^{*}_{it}=(\sigma_v^{2}Z_{it}\delta-\sigma_u^{2}\varepsilon_{it})/(\sigma_v^{2}+\sigma_u^{2})$ and $\sigma^{*2}=(\sigma_v^{2}\sigma_u^{2})/(\sigma_v^{2}-\sigma_u^{2})$.

In order to estimate the stochastic frontier production function, we specify the production function in translog form:

$$
\begin{aligned}
\ln y_{it} &= \alpha_0 + \sum \alpha_k \ln x_{kit} + \alpha_t t + (1/2) \sum\sum \beta_{kj} \ln x_{kit} \ln x_{jit} \\
(40) \qquad & + (1/2)\beta_{tt} t^2 + \sum \beta_{kt} \ln x_{kit}\, t + v_{it} - u_{it} \\
& k, j = 1, 2, \ldots, K, \quad i = 1, 2, \ldots, N, \quad and \quad t = 1, 2, \ldots, T
\end{aligned}
$$

We may impose several parametric restrictions.

(1) If β_{kt} = for all k factors, then technological change is neutral.

(2) If $\alpha_t = \beta_{tt} = \beta_{kt} = 0$ for all factors, there is no technological change

The maximum likelihood estimation of the frontier translog function enables one to express the components of total factor productivity growth as a function of estimated parameters.

(41a) $\Delta TC = \partial \ln y_{it} / \partial t = \alpha_t + \beta_{tt}\, t + \sum \beta_{kt} \ln x_{kit}$

(41b) $\Delta TE = \partial(-u_{it}) / \partial t = \partial(-u_i\ e^{-\eta(t-T)}) / \partial t = u_i\, \eta e^{-\eta(t-T)}$

(41c)
$$
\begin{aligned}
\varepsilon_i &= \partial \ln y_{it} / \partial \ln x_{it} = \alpha_k + \beta_{kj} \ln x_{jit} + \beta_{kt}\, t \\
\varepsilon &= \sum[\alpha_k + \beta_{kj} \ln x_{jit} + \beta_{kt}\, t]
\end{aligned}
$$

(41d) $\Delta TE = \dfrac{\partial(-u_{it})}{\partial t} = u_i\, \eta e^{-\eta(t-T)}$

Thus, we can calculate the components of TFP growth from the estimated frontier translog production function.

V. Empirical Analysis

1. South Korea and the IT Revolution

We investigate the importance of information technology in productivity growth using the panel data for South Korean firms during the period from 1996 to 2000. The Korean economy during the second half of the 1990s (1996-2000) provides an interesting setting for the analysis of the role of information technology in productivity growth. The major motivation to choose South Korea is provided by its astonishing transformation into an Internet superpower during this period. As *The New York Times* (May 5, 2003) appropriately put it, South Korea has highlighted how far the United States has to go. Having seen how South Korea has turned itself into an Internet powerhouse, broadband advocates say that the United States risks losing out by not moving faster. America's uneven adoption of broadband has Silicon Valley executives looking at South Korea with env y.[7] We can draw some inference on the role of information technology in U.S. productivity growth from the South Korean experience.

Another merit of using Korean data includes the availability of vast panel data: We have observations on 4,022 Korean firms from 1996 to 2000. This magnitude of data has never been utilized for the analysis of the impact of

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7) For a detailed description of South Korea's achievement in IT, refer to the Appendix: South Korea as an Internet Leader.

information technology on productivity growth. The time period also adds some interesting ingredient to the analysis of the role of information technology in productivity growth. This period is characterized by the vicissitude of the IT revolution in South Korea. The IT boom flared up until early 2000, and it suddenly burst in the middle of 2000.8) The Korean economy also experienced a severe financial crisis in late 1997 and the aftermath of the crisis lasted until 1999.9) Thus, during the 1996-2000 period, the South Korean

8) Reflecting the IT bubble, the growth of the KOSDAQ market was truly explosive, reflecting phenomenal growth of the IT industry. The market value of the stocks listed on the KOSDAQ was W8 trillion on January 1999. The market value exceeded W10 trillion on April 12, 1999, W20 trillion on May 28, 1999, W30 trillion on July 9, 1999, W40 trillion on November 22, 1999, W60 trillion on December 1996, W70 trillion on December 16, and finally increased to more than W100 trillion on December 27, 1999. The KOSDAQ market was seven times larger just in one year. The size of the KOSDAQ was only 5 percent of that of the Korea Exchange in the beginning of 1999, but one sixth of that of the Korea Exchange at the end of 1999. In particular, the amount of daily trading volume of the KOSDAQ began to exceed that of Exchange on February 8, 2000, and it was 2.16 times larger than that of the Exchange by February 22, 2000. All of a sudden, the balloon began to shrink.

9) The financial crisis in South Korea was initially triggered by speculative attacks on the Korean currency (Won). By December 24, 1997, the South Korean Won lost almost 40 percent of its value. Many South Korean firms went on a borrowing spree in the 1990s, and as a consequence, they had a huge amount of foreign debt denominated mainly in the U.S. dollar, The sudden plunge in the value of the domestic currency resulted in increases in their indebtedness in domestic currency terms. The collapse of the Won also led to a sharp rise in inflation, and market interest rates rose sky-high. The resulting increase in interest payments led to deterioration in their profits and balance sheets. The collapse of the financial market and the sharp decline in foreign lending caused a recession.

economy experienced various layers of economic ups and downs: the beginning of the IT exuberance in 1996, the financial crisis from 1997 to 1998, the recovery from the financial crisis in 1999, and the peak of the IT boom in early 2000, and then the sudden bust of the IT bubble. In sum, South Korea during the 1996-2000 period is an ideal setting for the analysis of whether productivity growth driven by information technology could remain strong despite economic hardships. This is an important hypothesis recently raised for the U.S. economy for which many researchers want to have an answer.

2. Data

In order to investigate the relationship between information technology and TFP growth, we have constructed the panel data that include observations on 4,022 firms from 1996 to 2000. The variables included in the panel data set are gross output (y) measured by sales, labor input (L), capital input (K) measured by fixed assets, and material input (M) measured by the cost of sales. These data have been obtained from the Korea Information Service Co. (KISC). Sales, fixed assets and the cost of sales are deflated by the price indices of producers' fixed assets and intermediate goods, respectively.

We use the gross output measure as an output index for the estimation of the stochastic frontier production function and TFP growth. One important rationale for using gross output instead of value added output is that many previous studies have found that TFP analysis based on value added output has an upper bias for TFP growth compared with that based on gross output. Another reason to use gross output is that the data include IT venture firms and public firms. Although IT firms and public firms attempt to achieve a certain level of efficiency in the context of sales (gross output), they often fail to achieve efficiency in terms of profits or value added. Thus, we can better evaluate the performance of IT firms and non-IT firms more meaningfully by comparing technical efficiency in the achievement of gross output given specific levels of labor, capital, and materials. Besides these variables, we have also collected data such as profits, current business profits, and net income to look at accounting productivity.

The 4,022 firms that are included in the panel data set can be classified as follows:

(1) There are 3,696 private firms and 55 public firms. Among private firms, 271 firms (private) are affiliates of the 30 largest business groups (*chaebol*), and 3,696 firms (private) are non-*chaebol* firms.

(2) 284 firms are classified as IT firms, and 3,787 firms are non-IT firms.

(3) Private firms can also be broken down into large firms

and small firms according to the number of employees and the size of capital assets. Private firms are composed of 1,109 large firms and 2,587 small firms.

3. Analysis of Accounting Performance

When we compare accounting measures of firm performance between IT and non-IT firms, we immediately note that IT firms are financially more sound than non-IT firms and achieve higher net income per worker than non-IT firms in South Korea.

(1) The most dramatic consequence of the 1997 financial crisis was a sharp decline in the debt/equity ratio. The debt/equity ratio reached 310.0% in IT firms and 347.8% in non-IT firms before the 1997 financial crisis. But the ratio dropped to 246.9% in IT firms and 264.3% in non-IT firms in 1998 right after the crisis occurred, and the ratio was further lowered to 113.3% in IT firms and 170.3% in non-IT firms by 2000. The average debt/equity ratio of IT firms during the 1996-2000 period was 169.1% whereas the average debt/equity ratio of non-IT firms during the same period was 224.2%. Such a drastic fall in the debt/equity ratio was mainly due to the Korean government's drive to lower the debt/equity ratio. Many policymakers firmly believed that over-borrowing by firms in the 1990s was the direct cause of the financial crisis.

<Table 1> Debt/Equity Ratio

(%)

	IT Firms	Non-IT Firms	IT and G30	Non-IT and G30	IT and non-G30	Non-IT and non-G30	All Firms
1996	224.1	274.4	246.0	335.1	199.2	241.5	267.4
1997	310.0	347.8	359.8	433.3	253.1	300.0	342.2
1998	246.9	264.3	253.8	299.9	236.9	242.0	261.9
1999	113.4	166.1	113.7	155.7	113.0	174.4	156.6
2000	113.3	170.3	113.2	184.8	113.5	160.5	159.9
Average	169.1	224.2	217.3	281.7	183.1	223.7	237.6

(2) Sales per person were generally higher in non-IT firms than in IT firms. The average amount of sales per worker in IT firms during the 1996-2000 period was W407.0 million, but the average amount of sales per worker in non-IT firms during the same period was W465.6 million. (W represents the Korean Won. The current exchange rate between the U.S. dollar and the Korean Won is approximately W1, 150 = $1.00.) This difference was expected given the fact that IT firms in the late 1990s were in the early stage in developing profit-making business models.

However, we have a different story as far as net income per person (total amount of net income divided by the number of workers) is concerned. Net income per worker was much higher in IT firms than in non-IT firms. More specifically, the average net income per worker was W92.2 million during the

1996-2000 period, which is considerably higher than net income earned by a worker (W70.1 million) in non-IT firms. This indicates that IT firms maintained their production and operation costs at the lower level than those of non-IT firms, and IT firms earned more income by selling unit output.

<Table 2> Accounting Productivity

(100 million Won)

		IT Firms	Non-IT Firms	IT and G30	Non-IT and G30	IT and non-G30	Non-IT and non-G30	All Firms
Sales per person	1996	1.749	2.661	4.220	2.138	1.357	1.915	2.506
	1997	2.076	3.214	5.415	2.571	1.586	2.214	3.015
	1998	2.775	3.875	6.822	3.588	2.071	2.525	3.684
	1999	3.564	4.139	6.836	4.884	2.445	2.794	4.044
	2000	4.070	4.656	7.823	5.151	2.920	3.071	4.552
	Average	2.847	3.709	6.223	3.666	2.076	2.504	3.560
Net income per person	1996	0.345	0.412	0.513	0.496	0.193	0.363	0.400
	1997	0.438	0.520	0.761	0.675	0.204	0.410	0.506
	1998	0.534	0.562	0.800	0.845	0.265	0.453	0.557
	1999	0.757	0.631	0.837	1.286	0.308	0.529	0.652
	2000	0.922	0.701	0.944	1.447	0.363	0.580	0.740
	Average	0.599	0.565	0.771	0.950	0.267	0.467	0.571
Sales per fixed assets	1996	1.230	1.500	1.840	1.379	1.050	1.255	1.462
	1997	1.029	1.391	1.731	1.078	0.959	1.142	1.335
	1998	1.081	1.257	1.611	1.069	1.100	0.988	1.231
	1999	1.021	1.186	1.456	1.033	1.001	0.968	1.159
	2000	1.280	1.327	1.667	1.344	1.175	1.052	1.319
	Average	1.128	1.332	1.661	1.181	1.057	1.081	1.301
Net income per fixed asset	1996	0.243	0.232	0.224	0.320	0.150	0.238	0.234
	1997	0.217	0.225	0.243	0.283	0.124	0.212	0.224
	1998	0.208	0.182	0.189	0.252	0.140	0.177	0.186
	1999	0.217	0.181	0.178	0.272	0.126	0.183	0.187
	2000	0.290	0.200	0.201	0.378	0.146	0.199	0.214
	Average	0.235	0.204	0.207	0.301	0.137	0.202	0.209

(3) A similar pattern is found in sales per fixed asset (i.e., capital) and net income per fixed asset. The average amount of sales per capital in IT firms during the 1996-2000 period was W128.0 million, whereas the average amount of sales per capital in non-IT firms was W132.7 million. In contrast, net income per capital was considerably larger in IT firms than in non-IT firms.

(4) Labor productivity increased rapidly in both IT firms and non-IT firms after the 1997 financial crisis. The rate of labor productivity growth was greater in IT firms than in non-IT firms. Such a sharp increase in labor productivity after the financial crisis was attributable mainly to a drastic reduction in employment during the restructuring process. The average of labor productivity in IT firms during the 1996-2000 period was W255.2 million whereas that of labor productivity in non-IT firms during the same period was W333.2 million. The average of capital productivity in IT firms was W120.8 million whereas that of capital productivity in non-IT firms during the same period was W141.9 million.

<Table 3> Factor Productivity

(100 million Won)

		IT Firms	Non-IT Firms	IT and G30	Non-IT and G30	IT and non-G30	Non-IT and non-G30	All Firms
Labor productivity (Y/L)	1996	1.688	2.567	2.063	4.072	1.309	1.847	2.418
	1997	1.896	2.935	2.348	4.945	1.448	2.022	2.754
	1998	2.403	3.355	3.106	5.907	1.794	2.186	3.190
	1999	3.157	3.664	4.324	6.053	2.166	2.474	3.581
	2000	3.167	4.137	4.576	6.950	2.596	2.729	4.045
	Average	2.552	3.332	3.283	5.585	1.863	2.252	3.197
Capital productivity (Y/K)	1996	1.207	1.470	1.352	1.805	1.030	1.230	1.433
	1997	1.013	1.370	1.062	1.705	0.945	1.125	1.314
	1998	1.250	1.456	1.236	1.863	1.271	1.147	1.425
	1999	1.099	1.279	1.111	1.566	1.078	1.045	1.249
	2000	1.473	1.522	1.544	1.915	1.355	1.206	1.514
	Average	1.208	1.419	1.261	1.771	1.136	1.150	1.387
Capital/Labor ratio (K/L)	1996	139.91	174.58	152.53	225.60	127.16	150.19	168.70
	1997	187.05	214.24	221.17	290.07	153.26	179.79	209.49
	1998	192.24	230.42	251.30	317.14	141.08	190.70	223.80
	1999	287.34	286.58	389.28	386.46	200.87	236.81	286.70
	2000	245.59	271.84	296.33	362.92	191.59	226.26	267.20
	Average	210.43	235.53	262.12	316.44	162.79	196.75	231.18

(5) In sum, IT firms earn higher net income per worker and per capital, even though the amount of sales per worker and per capital, respectively, was smaller in IT firms

than in non-IT firms. Thus, IT firms during the 1996-2000 period was characterized by low average productivity of factor inputs (labor and capital) and high profits (or net income). These conflicting results suggest that on the basis of accounting performance and labor (or capital) productivity, it is difficult to fathom out how the IT revolution has affected productivity growth.

4. Empirical Results

A. Estimation of the Frontier Translog Production Function

As a first step in analyzing what happened to total factor productivity in South Korea during the IT frenzy period from 1996 to 2000, we have first estimated the frontier translog production function using the maximum likelihood method. The maximum likelihood estimation of the frontier translog production function yields the estimates of the production function parameters, the variance composition of the error term $(v_{it} - u_{it})$ specified in the frontier production function, and the statistical distribution of the error term representing technical efficiency. At the same time, the estimation of the parameters enables one to calculate the components of TFP.

<Table 4> The ML Estimation of the Frontier Translog Production Function

coefficient	Estimates	standard-error	t-ration
β_0	0.390	0.031	12.493
β_L	0.193	0.011	17.387
β_M	0.736	0.009	83.627
β_K	0.039	0.008	4.878
β_{LL}	0.034	0.003	10.047
β_{MN}	0.123	0.002	63.262
β_{KK}	0.015	0.002	6.686
β_{LM}	-0.073	0.002	-30.698
β_{LK}	0.024	0.002	12.389
β_{MK}	-0.036	0.002	-23.648
β_{Lt}	0.005	0.002	2.759
β_{Mt}	-0.005	0.001	-3.968
β_{Kt}	0.001	0.001	1.075
β_t	0.020	0.008	2.652
β_{tt}	0.003	0.002	1.520
δ_1	0.406	0.052	7.808
δ_2	-0.366	0.038	-9.734
δ_3	0.237	0.082	2.909
δ_{scale}	0.018	0.017	1.041
σ^2	0.075	0.002	38.932
γ	0.333	0.021	15.829

Table 4 shows that most of the estimated coefficients of the frontier translog production function are significant even at the 1 percent level of significance. Only β_{tt} and β_{kt} are not significant at the conventional level of significance. The sum (σ_S^2) of the variance of the random error (σ_v^2) and the variance of the technical inefficiency measure (σ_u^2) was 0.328, and the ratio of the two variances $(\gamma=\sigma_u^2/\sigma_v^2)$ was 0.876. Both the estimates are also statistically significant at the 1 percent level of significance. The estimated results indicate that approximately 12.4 percent of the variance of the composite error term in the stochastic frontier function is explained by the random error and 87.6 percent of the variance is explained by the technical inefficiency term.

B. Decomposition of TFP Growth

A sharp distinction must be drawn between what happened in the IT sector--the sector produces computers, computer software and software services, and communications equipment--and the rest of the economy--which uses this information technology. Table 5 presents statistics in the IT and non-IT sectors.

<Table 5> Decomposition of TFP growth

(%)

		IT Firms	Non-IT Firms	IT and G30	Non-IT and G30	IT and Non-G30	Non-IT and non-G30	All Firms
TFP growth rate ($\dot{TFP}$)	1997	2.794	2.780	2.435	2.396	2.832	2.807	2.781
	1998	2.371 (-15.1)	2.409 (-13.3)	2.122 (-12.8)	1.785 (-25.5)	2.397 (-15.4)	2.452 (-12.6)	2.406 (-13.5)
	1999	2.271 (-4.2)	2.301 (-4.5)	1.495 (-29.6)	1.596 (-10.6)	2.352 (-1.9)	2.350 (-4.2)	2.299 (-4.4)
	2000	1.895 (-16.6)	2.058 (-10.6)	1.084 (-27.5)	1.200 (-24.8)	1.981 (-15.8)	2.117 (-9.9)	2.046 (-11.0)
	Average	2.333	2.387	1.784	1.744	2.390	2.432	2.383

<Table 5>

		IT Firms	Non-IT Firms	IT and G30	Non-IT and G30	IT and Non-G30	Non-IT and non-G30	All Firms
Technological change	1997	2.279 (81.6)	2.255 (81.1)	1.844 (75.7)	1.705 (71.2)	2.325 (82.1)	2.293 (81.7)	2.257 (81.1)
	1998	2.034 (85.8)	2.081 (86.4)	1.688 (79.5)	1.469 (82.3)	2.071 (86.4)	2.124 (86.6)	2.078 (86.4)
	1999	1.732 (76.3)	1.822 (79.2)	1.104 (73.9)	1.187 (74.4)	1.798 (76.4)	1.865 (79.4)	1.815 (78.9)
	2000	0.922 (48.7)	1.496 (72.7)	0.640 (59.1)	0.837 (69.7)	1.427 (72.0)	1.542 (72.8)	1.486 (72.6)
	Average	1,850 (79.3)	1.914 (80.2)	1.319 (73.9)	1.300 (74.5)	1.905 (79.7)	1.956 (80.4)	1.909 (80.1)
Scale economies	1997	0.157 (5.6)	0.162 (5.8)	0.234 (9.6)	0.341 (14.2)	0.149 (5.3)	0.150 (5.3)	0.162 (5.8)
	1998	-0.020 (-0.8)	-0.034 (-1.4)	0.079 (3.7)	-0.031 (-1.8)	-0.030 (-1.2)	-0.034 (-1.4)	-0.033 (-1.4)
	1999	0.184 (8.1)	0.120 (5.2)	0.037 (2.5)	0.062 (3.9)	0.199 (8.5)	0.124 (5.3)	0.124 (5.4)
	2000	0.190 (10.0)	0.203 (9.9)	0.091 (8.4)	0.018 (1.5)	0.201 (10.1)	0.216 (10.2)	0.202 (9.9)
	Average	0.128 (5.5)	0.113 (4.7)	0.110 (6.2)	0.097 (5.6)	0.130 (5.4)	0.114 (4.7)	0.114 (4.8)
Efficiency improvement	1997	0.358 (12.8)	0.363 (13.1)	0.357 (14.7)	0.350 (14.6)	0.358 (12.6)	0.364 (13.0)	0.363 (13.0)
	1998	0.356 (15.0)	0.362 (15.0)	0.355 (16.7)	0.348 (19.5)	0.356 (14.9)	0.363 (14.8)	0.361 (15.0)
	1999	0.354 (15.6)	0.360 (15.6)	0.354 (23.7)	0.346 (21.7)	0.354 (15.1)	0.361 (15.4)	0.360 (15.6)
	2000	0.353 (18.6)	0.358 (17.4)	0.352 (32.5)	0.345 (28.7)	0.353 (17.8)	0.359 (17.0)	0.358 (17.5)
	Average	0.355 (15.2)	0.361 (15.1)	0.354 (19.9)	0.347 (19.9)	0.355 (14.9)	0.362 (14.9)	0.360 (15.1)

* The numbers in parenthesis besides TFP growth rate represent percentage proportions.

The growth rate of total factor productivity of both IT and non-IT firms reached a peak in 1997 when the impact of the IT boom began to be embodied into the economy. The annual TFP growth rate of IT firms was 2.79 percent, and that of non-IT firms was 2.78 percent. In the burgeoning stage of the IT boom in which many IT inventions and technologies were nascent, TFP growth in the IT sector was not proceeding at an extraordinary pace, although IT firms surpassed non-IT firms in TFP growth marginally. As the financial shock hit the Korean economy in late 1997, the stock and bond markets spun into a tailspin, and the KOSDAQ lost its value substantially.

The impacts of the financial crisis spread over the entire industries. It is no wonder that the shock had negative impacts on TFP in both IT and non-IT sectors. The TFP growth of IT firms slowed down from 2.79 percent in 1997 to 2.37 percent in 1998 by more than 15 percent. However, the decline in TFP growth of non-IT firms was less severe than IT firms. The TFP growth rate of non-IT firms decreased from 2.78 percent in 1997 to 2.41 percent in 1998. This finding suggests that the TFP of the IT sector is more susceptible to a financial crisis. This finding is, however, not surprising. The major financing of IT firms comes from the KOSDAQ market and venture capital firms whose financial position is more sensitive to financial uncertainty. Thus, a well-functioning financial system is crucial for the health of the IT industry.

It is worth noting that even though the Korean economy was hit hard by the 1997 financial crisis, both IT and non-IT firms maintained quite robust TFP growth, especially despite the recession in 1998. This robustness is in parallel with the U.S. productivity surge during the 2001 recession. It would not be possible for the economy to achieve such robust productivity growth under the Old Economy in the face of economic hardships.

The slowdown trend of TFP growth almost halted in 1999 when the aftermath of the financial crisis was considerably subdued, and the economy began to recover. The TFP growth rate of IT firms decreased from 2.37 percent in 1998 to 2.27 percent in 1999 only by 4.2 percent, and that of non-IT firms decreased from 2.41 percent to 2.30 percent by 4.5 percent.

The IT boom reached a peak in early 2000, and then the IT bubble began to burst in the middle of 2000. The collapse of the IT bubble that originated in the United States rapidly spread to other countries including South Korea. The burst of the IT bubble had ripple effects on both the IT and non-IT sectors of the economy. As expected, IT firms experienced a larger decline in TFP growth than non-IT firms. Non-IT firms' TFP growth rate fell from 2.30 percent in 1999 to 2.06 percent in 2000 by 10.6 percent, but IT firms' TFP growth rate fell from 2.27 percent in 1999 to 1.90 percent in 2000 by 16.6 percent.

However, one caveat is in order. The TFP growth rate of 1.9 percent still represents a remarkable performance in light of the fact that the Korean economy suffered from two external shocks: the 1997 financial crisis and the collapse of the IT bubble. This magnitude of TFP growth adds to economic growth by 1.9 percentage point. Furthermore, TFP growth remained quite robust to economic ups and downs during the 1996-2000 period of economic turbulence. The annual TFP growth rate of IT firms ranges from 1.9 percent (2000) to 2.79 percent (1997), and that of non-IT firms ranges 2.06 percent to 2.78 percent. Thus, our finding supports our Hypothesis 1.

Hypothesis 1: Productivity growth under the New Economy is more robust to business cycles than under the Old Economy.

Next, we have examined the sources of TFP growth focusing on how the composition of TFP growth changed with different phases of IT developments. The dominant source of TFP growth came from technological progress, and this feature holds up in both IT and non-IT firms. During the 1996-2000 period, technological progress accounts for 79.3 percent of TFP growth of IT firms and 80.2 percent of TFP growth of non-IT firms. However, the proportion of technological progress in TFP growth tended to decline over time. For example, this proportion in the IT sector dropped from 81. 6 percent in 1997 to 71.4 percent in 2000, and the proportion in the non-IT sector fell from 81.1 percent to 72.7 percent.

The second largest component of TFP growth is technical efficiency improvement. Efficiency improvement accounts for 15.2 percent of TFP growth of IT firms and 15.1 percent of TFP growth of non-IT firms on average during the 1996-2000 period. On the surface, the average figures suggest no substantial difference in the behavior of efficiency improvement between IT and non-IT firms. However, a careful perusal of the trend reveals quite different patterns between IT and non-IT firms. Efficiency improvement was more conspicuous in the IT sector than in the non-IT sector. The proportion of efficiency improvement in IT firms increased from 12.8 percent in 1997 to 18.6 percent in 2000, whereas the proportion in non-IT firms increased from 13.1 percent in 1997 to 17.4 percent in 2000.

Another noticeable feature is that the proportion of efficiency improvement in TFP growth tended to increase continually in both the IT and non-IT sectors. As we discussed, this source (efficiency improvement) primarily represents improved management and organizational productivity. Here, we argue that non-IT firms as well as IT firms reaped greater managerial and organizational advantages under the New Economy than under the Old Economy. Thus, this finding corroborates our Hypothesis 2.

Hypothesis 2: Improvement in business efficiency plays a greater role in enhancing productivity growth under the New Economy than under the Old Economy.

Finally, scale economies had the smallest contribution to TFP growth. However, this source of TFP growth presents interesting features. We have discovered that the contribution of scale economies to TFP growth widely fluctuates. The proportion of scale economies in TFP growth fluctuated from -0.8 percent (1998) to 10.0 percent (2000) in the IT sector and from -1.4 percent (1998) to 9.9 percent (2000) in the non-IT sector. Another interesting finding is that the proportion of scale economies in TFP growth was larger in IT firms than in non-IT firms. This implies that IT firms enjoyed greater economies of scale than non-IT firms on average. All IT and non-IT firms experienced diseconomies of scale in 1998 right after the 1997 financial crisis, indicating that scale economies contributed negatively to TFP growth, but they gradually recuperated from this setback in 1999.

One final remark is in order. As discussed previously, IT impacts on productivity growth can only be felt strongly at the firm level. Moreover, investments in technology do not have a direct effect on productivity in many situations. Their impact is indirect, and the channel through which IT affects productivity is mostly related to changes in other aspects of the production process. For example, in retailers such as Wal-Mart and Kmart, IT helps improve logistics and inventory management such as warehouse automation, cross-docking and inventory tracking, which in turn improve operational effectiveness, thereby reducing costs. In the banking industry, IT applications are associated with the lending systems, checking imaging and the creation of ATMs and voice response unit. With the invention of credit scoring and underwriting software, the number and quality of loans being processed are increased. The use of voice response unit (VRU) lowers call center costs in handling inquiries. In 1998, VRUs handled nearly four times the call volume they had in 1993 while the cost per call handled by VRU decreased 44 percent from 1993 to 1998 (Mckinsey Global Institute, 2002). Checking imaging lowers some labor and storage costs. ATMs together with online banking allow customers to access to banking services 24 hours a day. Although the investment in ATMs and online banking is much lower than that in physical bank branches, the volume of customers they service and the amount of transactions they perform outweigh those that can be done through physical bank branches. Thus, the most significant aspect of the value of IT is its ability to enable complimentary organizational investments such as business processes and work practices. This, in turn, results in productivity increases by reducing production costs and more importantly by improving product quality, variety and convenience (Brynjolfsson, 2000).

VI. Concluding Remarks and Policy Implications

The purpose of this study has been to investigate the effect of information technology (IT) on productivity growth in an information economy. The 1990s was a period during which the hope for a new economy was heightened. The New Economy is an economy with rapid technological change and increasing use of information technology, an economy in which productivity growth continues strong, and in which substantial premiums are paid, both to individuals and firms, for advanced skills and adaptability to change.[10] This study has explored whether the hope was reality or hype.

Consensus has prevailed that information technology is the most powerful force in enhancing productivity, and steady productivity growth is a sure road to the coexistence of low inflation with low unemployment. A substantial number of studies have found significant and positive relationships between information technology and U.S. productivity growth. In particular, the recent literature on the productivity spurt during the 1995-2000 period has confirmed that a considerable portion of the 1995-2000 productivity growth in the United States was attributable to information technology. However, many questions surrounding the role of information technology in productivity growth remain unresolved. In particular, a surprising amount of disagreement exists concerning the

10) See Rivlin (2003)

mechanism through which information technology affects productivity growth. Another important issue is concerned with whether productivity growth in the New Economy is subject to different phases of the business cycle as in the Old Economy.

This study has extended the existing literature in several important respects. First, this paper has attempted to disentangle the source of IT-driven productivity growth that has remained unexplained in the previous literature. This decomposition is extremely useful in investigating whether productivity growth in the New Economy exhibits different patterns from those under the Old Economy. This study is further distinguished from the existing studies in its methodology. We have employed a frontier production function to examine the source of productivity growth and used a vast set of panel data to enhance the power of test. Our panel data set includes observations on 4,022 Korean firms. This magnitude of data has never been utilized for the analysis of the importance of information technology in productivity growth.

The time period covered in this study corresponds to the period of the IT frenzy in South Korea. South Korea has been in the forefront of the IT revolution that occurred in the late 1990s. There has been astronomical spending on broadband and other high-tech innovations in South Korea during this period, which has helped transform the country into an IT powerhouse. The overall IT sector accounts for about 13 percent of economic activity, bringing about seismic changes in the life style of Korean people. Thus, the South Korean experience offers a litmus test for evaluating the role of IT in productivity growth. This period also roughly matches the period (1995-2000) during which the U.S. economy achieved an impressive growth in productivity. This allows us to compare the impact of IT on productivity growth in a small, but most digitalized society with the impact of IT on productivity growth in a large, but less digitalized society.

By introducing a stochastic frontier production function and utilizing the latest developments in computer algorithms, this study has successfully unraveled the source of TFP growth and decomposed it into three parts; (1) technological change, (2) efficiency improvement, and (3) scale economies. First, we have found a strong relationship between information technology and productivity growth.

The most fruitful results obtained from our study are statistics on the source of total factor productivity (TFP) growth. We have found that approximately 80 percent of TFP growth comes from technological change, 15 percent of TFP growth comes from efficiency improvement, and the rest comes from scale economies. Thus, the dominant source of TFP growth is technological progress. This indicates that knowledge discovery and invention are the major driver of productivity growth, and this trend is likely to continue at least over the next five to 10 years.

Our empirical results also support the two proposed hypotheses: (1) Productivity growth under the New Economy is more robust to business cycles than under the Old Economy, and (2) improvement in business efficiency plays a greater role in enhancing productivity growth under the New Economy than under the Old Economy.

Our findings suggest several important policy implications. First, the New Economy has changed the way that policymakers deal with economic problems. In the Old Economy where a tradeoff between inflation and unemployment is a norm, the focus of economic policy tends to tilt toward monetary policy rather than fiscal policy because in an inflation-prone economy, monetary policy is more flexible and effective in curbing inflation. In an information economy that may be less prone to inflation, however, the importance of monetary policy will dwindle, and fiscal policy will be equally important.

Second, we raise the question of what role traditional aggregate demand (AD) policy could play in the New Economy. Should policymakers (the government and the central bank) encourage competition and leave uncompetitive firms to exit from the market or boost AD using the traditional fiscal-monetary stimulus as in Japan? It has been increasingly apparent that the Japanese formula failed because it relied on public spending, not market forces. In Japan, there were two economic upturns in the 1990s, but they fizzled soon, because the two recoveries were driven not by the private sector, but by the public sector. U.S. policymakers took a different path. The U.S. government took several actions including tax cuts which targeted mainly aggregate supply rather than aggregate demand during the period of the recent economic downturn. In an information economy, traditional AD policy should be used to maintain the health of the financial market to control excessive investment and irrational exuberance.

Third, the health of the financial system becomes more important. Investors are no less susceptible to exuberance and hype. Indeed, irrational exuberance could lead to the collapse of the financial market as we experienced. Thus, the task of the central bank should shift from controlling inflation toward maintaining the health of the financial markets. This conclusion is echoed by Rivlin (2003) and others.

Finally, the perception on the role of the government is changing in an information economy. Academic economists have tended to disdain government intervention, but many high-tech business leaders in the United States have begun to pay attention to the role of the Korean government in actively promoting IT investment. The Korean government built a nationwide fiber network to get almost every urban home hooked on the high-speed Internet. The Korean government invested $850 million in broadband infrastructure and is planning to spend another $850 million over the next four years (2004-2007). The Korean government even provided loans to IT venture firms at very low interest rates, and this kind of policy has begun to pay off in South Korea. It goes without saying that an efficient financial system to allocate funds efficiently is crucial for IT firms to grow.

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Abstract

This study investigates the effect of information technology (IT) on productivity growth in an information economy. A substantial number of studies have found significant and positive relationships between IT and U.S. productivity growth. The recent literature on the productivity surge during the second half of the 1990s has confirmed that almost all of the productivity improvement in the United States was attributable to IT. However, the existing studies have one important missing element in the analysis of the importance of IT in productivity growth. They have failed to unravel where productivity growth comes from. This study has extended the existing literature in several important ways. First, we have successfully decomposed the sources of productivity growth into technological progress, efficiency improvement, and scale economies using a stochastic frontier production function. We have applied our model to Korea which has emerged as an Internet paradise in the late 1990s. Another merit of using Korean data is provided by the availability of vast panel data that include observations on 4,022 firms from 1996 to 2000.

We have found a strong relationship between IT and productivity growth. Surprisingly, productivity growth

remained quite strong despite the 1997 financial crisis and the subsequent recession, and the bust of the IT bubble in 2000. Our empirical results also show that approximately 80% of TFP growth comes from technological progress, 15% of TFP growth comes from efficiency improvement, and the rest comes from scale economies. Thus, the dominant source of TFP growth is technological progress, but the proportion of efficiency improvement in TFP growth has continually increased. Efficiency improvement primarily represents improved management and organizational productivity. Thus our study supports two proposed hypotheses: (1) productivity growth under the New Economy is more robust to business cycles than under the Old Economy, and (2) improvement in business efficiency plays a greater role in enhancing productivity under the New Economy than under the Old Economy. We conclude that information technology has already made a quantum difference in productivity growth.