Information Technology, Productivity, Value Added, and Inflation: An Empirical Study on the U.S. Economy, 1959-2008

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This paper is a macro study on the impact of information technology investment on three macroeconomic variables: labor productivity growth, business sector value added, and inflation in the US using quarterly data from 1959 to 2008. Using Vector Error Correction model, the paper investigates the extent to which IT investment shocks are responsible for the variation in the three macroeconomic variables in three periods: 1959-1980, 1981-2008, and 1994-2008. Empirical analysis shows that, during the period (1959-1980), shocks in investment in communication and computer equipments had a stronger positive impact on labor productivity growth and business value added compared to software investment. In the second period of investigation (1981-2008), shocks in investment in computer equipments are found to have the strongest effect on the three macroeconomic variables. The analysis of the Internet revolution (1994-2008) did not show a greater response of the macroeconomic variables of interest to IT investment.

INTRODUCTION

The impact of information technology investment on different economic variables in industrial countries has been targeted heavily by many economists in the last two decades with a special attention to studying the impact of IT investment on productivity growth in the 1990's. The general conclusion of these studies is that the revolution in information technology during the 1990's (the digital revolution), driven by the growth of the Internet, had positively contributed to productivity growth and to the stability of the macroeconomic environment.[1] A remarkable work in this matter is done by Kevin Stiroh (2001), (2002), (2004), Oliner and Sichel (2000) and (2002), Gust and Marquez (2004), James Everett (1998), Gera et al (1999), Amiti and Stiroh (2007), Jorgenson et al (2004), and Martin Feldstein (2003). In addition, the Economics and Statistics Administration of the Department of Commerce showed that, during 1996-2000, when the economy grew by an average 4 percent annually, IT producing sector grew by 21 percent a year on average (in real terms), and was responsible for 28 percent of overall real economic growth rate.[2]

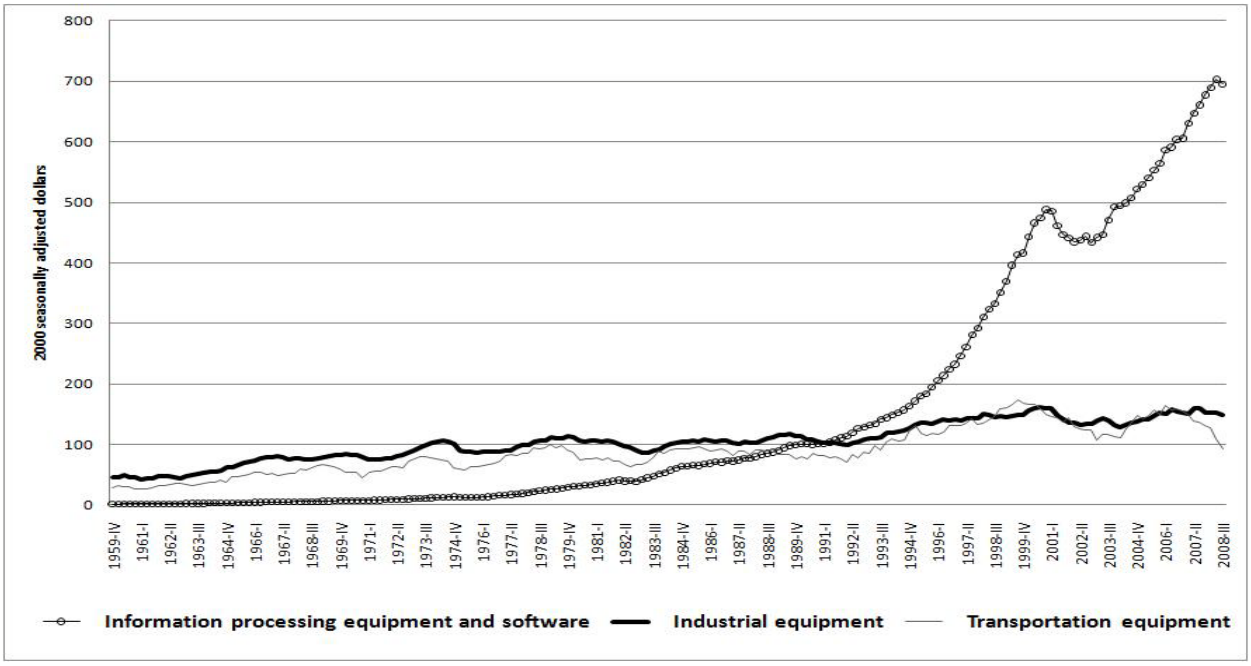
This paper is a macro study on the impact of information technology investment on three macroeconomic variables: productivity growth, nonfarm business sector value added, and inflation in the US using historical data from 1959 to 2008. My interest in incorporating the first two variables mentioned above indicates that this paper focuses on IT investment as an input into the production process of business firms and industries that use IT. In achieving this goal, I disaggregate IT investment into its three main categories: IT investment in communications equipments, computer equipments, and software. This disaggregation helps to determine the part of IT investment that plays the dominant role in affecting the three macroeconomic variables of interest. Using Vector Autoregression model, the paper aims at investigating the extent to which IT investment shocks are responsible for the variation in the three macroeconomic variables mentioned above in three historical periods: 1959-1980, 1981-2008, and 1994-2008.

The paper is organized as follows: section 2 describes the data and shows historical trends in private investment in information technology, section 3 explains the econometric framework, section 4 shows the empirical results, and section 5 provides concluding observation.

ECONOMIC TRENDS IN PRIVATE INVESTMENT IN INFORMATION TECHNOLOGY

The U.S. Department of Commerce indicators show that, in the late of 1990's, IT investment represented over 45 percent of all business equipment investment. In addition, one of the most notable economic developments in recent years has been the rapid increase in the IT sector's share of investment activity and of the gross domestic product. It grew from 4.9 percent of the

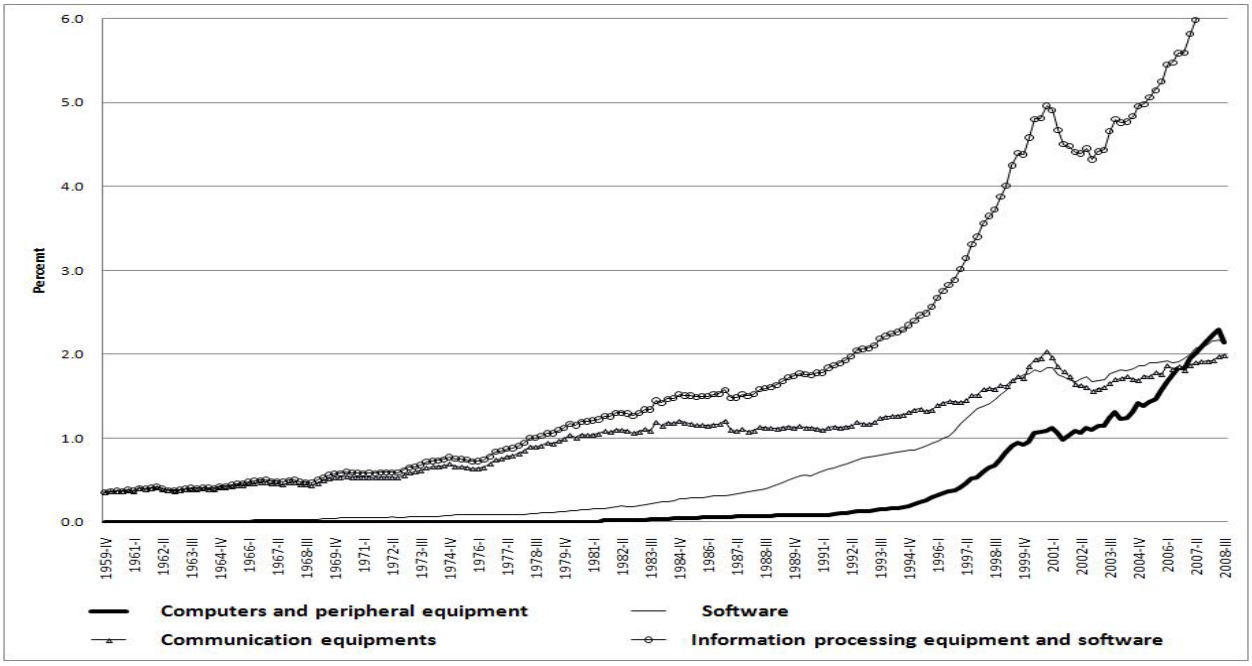
FIGURE 1
REAL PRIVATE NONRESIDENTIAL FIXED INVESTMENT BY TYPE



Source:the National Income and Product Accounts (NIPA) tables.

economy in 1985 to 6.1 percent by 1989 as personal computers started to penetrate homes and offices. The next boom started in 1994, with the burst of commercial activity driven by the Internet. In this period, 1994-2008, the IT share of nonresidential private fixed investment rose from 22% in 1994 to 48% in 2008. As shown in figure 1 below, recent National Income and Product Accounts (NIPA) tables show that real private investment in the three main components of IT continued to grow in stable pace during the first decade of the 21 century, with a notable rapid increase in computer and peripheral equipments investment, despite the temporary reduction in the beginning of this decade as a result of the 2001 recession.

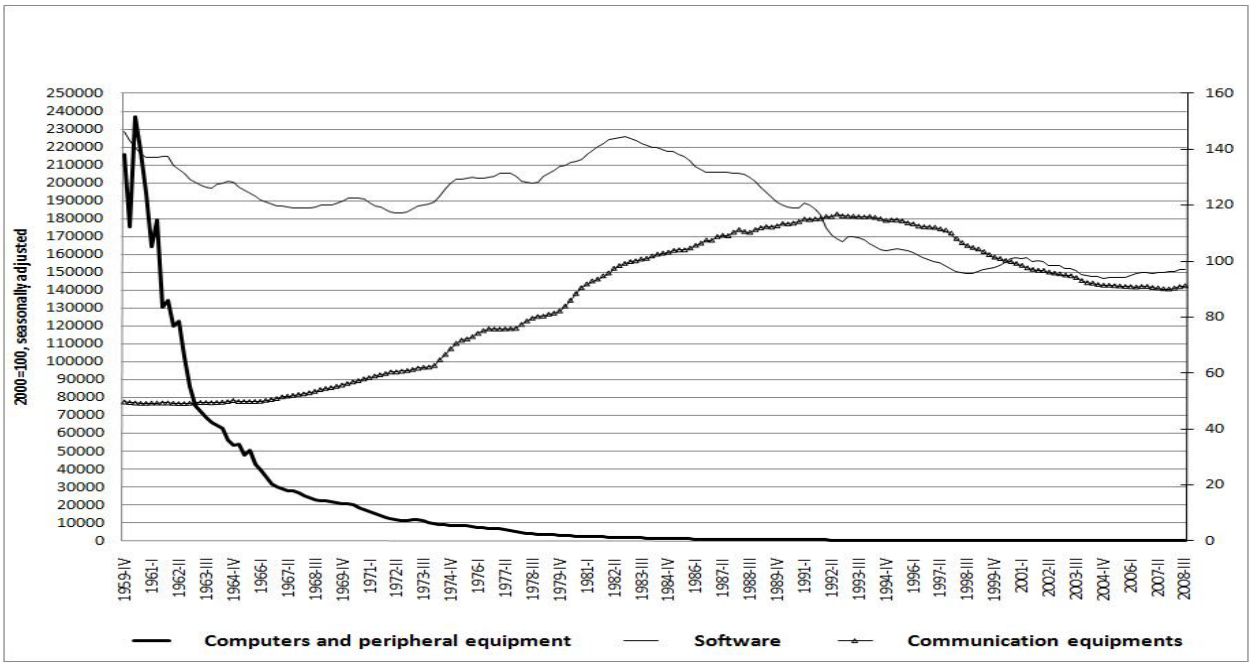
FIGURE 2
REAL PRIVATE FIXED INVESTMENT IN IT AS A PERCENT OF REAL GDP



Source: Author's calculations based on the National Income and Product Accounts (NIPA) tables and Federal Reserve Bank of St. Louis Economic Data (FRED).

Figure 2 shows that the percentage of information processing equipment and software to real GDP increased from 1% to 2% during the period 1980- 1994, and to 6 percent during the period 1994-2008. On the other hand, as indicated in the Emerging Digital Economy II report by Department of Commerce (1999), Microprocessor Prices dropped from $230 per million instructions per seconds (MIPS) to $3.42 per MIPS in 6 years. This huge reduction in the microprocessor price led to a huge reduction in IT products' prices (IT goods or equipments and services such as software) which lowered the overall inflation during the 1990's. Prices indexes of the three IT investment components during the full period of investigation (1959-2008) are shown in figure 3.

FIGURE 3
PRICE INDEXES FOR IT INVESTMENT BY TYPE



Source: the National Income and Product Accounts (NIPA) tables.
Note: the secondary Y-axis illustrates the scale of the price indexes of software and communication equipments.

THE ECONOMETRIC FRAMEWORK

Data Sources

Data is collected quarterly; it begins in the first quarter in 1959 and ends at the third quarter in 2008 (196 observations for each series). To study the intertemporal impact of IT variables on the three macroeconomic variables of interest, data is disaggregated into 3 data sets: 1959-1980, 1981-2008, and 1994-2008. The two chosen break points in separating the data (1981 and 1994) reflect two major booms in the IT history: the introduction of IBM personal computers and the MS-DOS computer operating system by Microsoft (1981), and the Internet revolution (1994). Data on GDP, labor force, and GDP deflator are collected from the Federal Reserve Bank of St. Louis Economic Data (FRED). Data on IT investment, IT price indexes, and the nonfarm business value added are collected from the National Income and Product Accounts Tables, Bureau of Economic Analysis. Inflation is calculated as the first difference of the log of GDP deflator and real output per worker growth is calculated as the first difference of the log of real output per worker. All other variables are in log form.

Methodology

It is well known that the endogeneity problem usually arises whenever we investigate the relationship between macroeconomic variables. One way to solve for this problem is treat all the variables of concern as endogenous using Vector Autoregression technique (VAR). The VAR model representation can be written as follows:

$$Y_t = v + A_1\, Y_{t-1} + \ldots\ldots + A_p\, Y_{t-p} + u_t \; ; \; u_t \sim i.i.d.(0, \sum)$$

where Y is a $K \times 1$ vector of endogenous variables, v is a $K \times 1$ vector of intercept terms, $A_1,\ldots..,A_p$ are matrices of coefficients to be estimated, p is the number of lags, $t = 1,2,\ldots.,T$, and u_t is i.i.d. vector of innovations that may be contemporaneously correlated but are uncorrelated with their own lagged values and uncorrelated with all of the right-hand side variables. The use of VAR model requires that series must be stationary; otherwise, a Vector Error Correction model (VEC) is generally applied. To test for stationarity, I used the unit root Augmented Dickey-Fuller test (ADF) and found that all series, except of private investment in computer equipments and labor productivity growth, have unit root and are first difference stationary. The optimal lag length in each specification is determined using Sim's (1980) likelihood ratio:

$$LR=(T-K)*log\ (\Omega_0/\Omega_1)\sim\chi^2$$

Where T is the number of observations=196, $K=1+P_1N$, (P_1 is the order under the alternative hypothesis and N is the number of variables), Ω_0 and Ω_1 are the determinant residual covariance under the null and the alternative hypothesis. The determination of the optimal lag length using the LR test in most of the model specifications (7 out of 9 different specifications) is supported by the lowest value of AIC test. Finally, the Johansen Cointegration test is used to test for cointeration under 2 different assumptions: linear deterministic trend and no deterministic trend (restricted constant). The trace and the max-eigenvalue tests both indicate that there are 3 cointegrating vectors at both 5% and 1% levels in all different specifications.

Since most of the variables are found to be non-stationary, I apply a VEC model since the simple VAR of the first differenced variables is misspecified and contains only information on short-run relationships between the variables. The VEC model could be written as follows:

$$\Delta Y_t = v + \Pi Y_{t-1} + + \sum_{i=1}^{p-1} \Gamma \Delta\, Y_{t-i} \ + u_t$$

where Δ is the difference operator, Π denotes an $(n \times n)$ matrix of coefficients and contains information regarding the short-run relationships among the variables. Γ is an $(n \times n)$ coefficient matrix decomposed as $\Pi = \alpha \beta'$, where α and β are $(n \times r)$ adjustment and co-integration matrices, respectively.

Finally, I performed the LM test for autocorrelation in order to test for misspecification. The results of the LM test for the residual serial correlation in all different specifications of the VEC model show no obvious residual autocorrelation problem since all p-values are larger than 0.05 level of significance.

EMPIRICAL RESULTS

Impulse Response Functions

A useful way to trace the effect of one time shock in each IT investment variables on current and future values of the three macroeconomic variables of concern is by estimating the impulse response functions. In all of the model specifications, I use generalized impulse response functions (GIRFs) developed by Pesaran and Shin (1998) since they are not sensitive to the ordering of the variables. GIRFs tables are shown in Appendix A.

Empirical analysis of the accumulated generalized impulse response functions shows that, during the first period of investigation (1959-1980), shocks in investment in communication and computer equipments have a positive impact on productivity growth and nonfarm business value

added while the accumulated response (over 12 quarters) of the two macroeconomic variables to software investment is also positive but much weaker than their response to the other two IT variables (computer and communication equipments). The accumulated response of nonfarm business value added to innovations in investment in communication equipments, computer equipments, and software is found to be 0.08%, 0.03%, and 0.003%, respectively, while the accumulated response of labor productivity growth is found to be greater than that of nonfarm business value added with a point estimate of 0.37% (computer equipments), 0.32% (communication equipments), and 0.05% (software). On the other hand, inflation responded negatively to shocks in all of the IT variables as its accumulated response is estimated to be -0.12%, -0.14%, and -0.1% to computer equipments, software, and communication equipments, respectively. These results show that, even before the introduction of IBM personal computers and the MS-DOS computer operating system by Microsoft in 1981, information technology investment is found to have a significant impact on some macroeconomic variables, in particular, labor productivity growth.

In the second period of investigation (1981-2008), shocks in investment in computer equipments are found to have the strongest impact on the three macroeconomic variables among all IT investment variables. During this period, inflation responded more significantly to computer and software investment but not to communication equipments. This is expected since there is a continuous decrease in the price indexes of both computer and software investment in most of the quarters under investigation, while the price index of communication investment shows an upward trend during the period (1981-1994) and then a downward trend in the period (1995-2008). The accumulated response of inflation to investment in computer equipments, software, and communication equipments over 12 periods is negative and estimated to be -0.3%, -0.22%, and- 0.1%, respectively. The accumulated response of labor productivity growth to both computer equipment and software investment is positive with a point estimate of 0.43% and 0.31%, respectively, while it was 0.22% to investment in communication equipment. The accumulated responses of nonfarm business value added are found to be positive to all types of IT investment with a point estimate of 0.08% (computer equipments), 0.06% (software), and 0.04% (communication). The analysis of the Internet revolution subset (1994-2008) did not show a greater response of the macro variables to IT investment. In fact, the three macro variables responded less to all types of IT investment compared to the full period (1981-2008). This result conflicts with some studies, such as Kevin Stiroh (2001) and (2002), and Oliner and Sichel (2000), as their findings support the assumption that IT investment contribution to productivity growth was the highest in the 1990's. But we must note that these studies focus on the second half of the 1990's only, while the Internet revolution subset under investigation in this study includes the second half of the 1990's and the first 8 years of the 21st century. The later period includes the recessionary period (2001-2003), at which the percentage of investment in information processing equipments and software to real GDP dropped from 5% in the fourth quarter of 2000 to 4.3% in the first quarter of 2003, before it booms again and reach 6% in the third quarter of 2008.

Variance Decomposition

It is well known that variance decomposition shows how much of the variations in the considered variable could be explained by the other variables. To estimate the variance decomposition of the three macroeconomic variables of interest, I use the following Cholesky

Ordering of the variables: IT investment, labor productivity growth, nonfarm business value added, and inflation. In each time period mentioned above, I use the three different IT variables: computer equipments, software, and communication equipments. Variance decomposition analysis is shown in Appendix B.

When analyzing the decomposition of variance of nonfarm business value added in the first period (1959-1980), I found that most of its variation in the short run and the long run is explained by shocks in real GDP growth per worker, with no significant role played by any of the IT variables. The picture changed dramatically in the second period (1981-2008) as investment in computer equipments started to play a crucial role in explaining the variation in nonfarm business value added in both the short and long run, in particular, 23.3% of variation in nonfarm business value added in the 4^{th} quarter and 45.8% of its variation in the 12^{th} quarter is explained by shocks in computer equipment investment. The largest impact appears in the 10^{th} to 12^{th} quarter. The other two IT investment variables are found to explain small variation in nonfarm business value added in the short and long run. The period of Internet revolution (1994-2008) shows a significant role of both investment in communication equipments (in the long run) and investment in software (in the short and long run), and a sharp decline in the impact of computer equipments investment. This result matches with the previous analysis of the generalized impulse response functions, but contradicts with Oliner and Sichel (2000) calculations (using a neoclassical growth accounting framework) as they estimated the contribution of computer hardware to growth of real nonfarm business output to be the highest among all other IT capital variables during the period 1996-1999[3].

On the other hand, all IT variables are found to explain a small variation in labor productivity growth in the short run during the period (1959-1980). Investment in computer and communication equipments started to play a more important role in the long run, in particular, the 10^{th} to 12^{th} quarter, as they explain 7% and 6%, approximately, of the variation in labor productivity growth, respectively. The second period (1981-2008) did not show a significant change in the impact of computer equipment and communication equipment investment, since the two IT variables explain 8.5% and 7.1% of the variation in real output growth per worker in the 12^{th} quarter, while we can see a meaningful change in the role played by software investment, as it explains 5.9% of the variation in labor productivity growth (versus 1% in the 12^{th} quarter of the first period of investigation).

The Internet revolution period (1994-2008) demonstrates an important change in the role of the three IT variables as investment in software took the lead among IT variables in explaining variations in labor productivity growth in the long run, since the percentages of variance of labor productivity growth in the 12^{th} quarter explained by computer equipments, software, and communication equipments are 10.8%, 13.6%, and 12.3%, respectively.

Finally, the decomposition of variance of inflation shows that IT variables explain a small variation in inflation during the first period (1959-1980) and that investment in communication equipments has the greatest short run and long run impact among IT variables, as it explains 7.2% and 8% of the variation in inflation in the 4^{th} and 12^{th} quarters, respectively, (while the other two IT variables together explain 2.3% and 2.7 of the variation in inflation in the same quarters). A noticeable change is found in the second period (1981-2008) and the Internet period (1994-2008). That is, due to the significant reduction in the microprocessor price as explained previously, investment in computer equipments is found to play a dominant role in explaining variation in inflation among all IT variables in the short run only (the first four quarters). For

example, the percentage of variance of inflation explained by computer investment in the 4th quarter in the period (1981-2008) is 8.4%, versus 3.3% and 1.9% for communication equipment and software investment, respectively. The same rank of the IT variables is found in the Internet revolution period with a slight increase in the importance of communication and software investment in explaining the variance in inflation. The long run analysis of the variance decomposition of inflation in the second period (1981-2008) shows a significant increase in the importance of software investment in explaining the variation in inflation followed by communication and computer equipment investment. The percentages of variance in inflation in the 12th quarter explained by software, communication, and computer investment are 16.4%, 10.1%, and 6.6%, respectively. When we focus on the period of Internet revolution subset, we find that 10.2% of the variance in inflation is explained by communication investment followed by computer investment (7.7%) and software investment (4.5%) in the 12th quarter.

CONCLUDING OBSERVATIONS

The impact of IT investment on the macroeconomic performance is investigated in this paper during the second half of the twentieth century and the first decade of the twenty first century. Using a vector error correction model, I examine the impact of computer equipments, software, and communication equipment on three macroeconomic variables: nonfarm business value added, labor productivity growth, and inflation in three data sets: (1959-1980), (1981-2008), and (1994-2008). The study of the accumulated generalized impulse response functions shows that the relative importance of each IT variable in affecting the three macroeconomic variables under investigation changes over time. In addition, the study found that, even before the introduction of IBM personal computers and the MS-DOS computer operating system by Microsoft in 1981, information technology investment played an important role in affecting labor productivity growth. To be more specific, during the period (1959-1980), shocks in investment in communication and computer equipments had a stronger positive impact on labor productivity growth and business value added compared to software investment. Also, inflation responded negatively to shocks in all of the IT variables with a relatively greater response to software investment.

In the second period of investigation (1981-2008), shocks in investment in computer equipments are found to have the strongest effect on the three macroeconomic variables among all other IT investment variables, while the analysis of the Internet revolution subset (1994-2008) did not show a greater response of the macro variables to IT investment.

The variance decomposition analysis of the three macroeconomic variables supports the results of the generalized impulse response functions, particularly in the second period (1981-2008), as computer equipments is found to play a dominant role among all other IT variables in explaining the variation in labor productivity growth in the long run, the variation in inflation in the short run, and the variation in nonfarm business value added in both the short and long run. Investment in software is found to play a crucial role among other IT variables in explaining the variation in inflation in the long run in the same period. The Internet revolution subset shows a noticeable change in the importance of software investment as it was the strongest among other IT variables in explaining variation of nonfarm business value added in the short run, while communication investment took the lead in the long run.

APPENDIX A: ACCUMULATED IMPULSE RESPONSE FUNCTIONS

TABLE 1
ACCUMULATED RESPONSE OF BUSINESS VALUUE ADDED, PRODUCTIVITY GROWTH, AND INFLATION TO SHOCKS IN IT INVESTMENT IN COMPUTER EQUIPMENTS (1959-1980)

Period	Value added	Productivity	Inflation
1	0.001	0.017	-0.041
2	0.003	0.076	-0.107
3	0.006	0.202	-0.149
4	0.012	0.279	-0.179
5	0.019	0.348	-0.199
6	0.027	0.389	-0.207
7	0.036	0.409	-0.206
8	0.045	0.415	-0.198
9	0.055	0.411	-0.184
10	0.065	0.401	-0.166
11	0.075	0.389	-0.145
12	0.085	0.376	-0.123

TABLE 2
ACCUMULATED RESPONSE OF BUSINESS VALUUE ADDED, PRODUCTIVITY GROWTH, AND INFLATION TO SHOCKS IN IT INVESTMENT IN COMPUTER EQUIPMENTS (1981-2008)

Period	Value added	Productivity	Inflation
1	0.001	0.004	-0.059
2	0.004	0.135	-0.089
3	0.009	0.228	-0.105
4	0.015	0.218	-0.089
5	0.021	0.247	-0.131
6	0.028	0.310	-0.173
7	0.036	0.324	-0.195
8	0.045	0.335	-0.208
9	0.053	0.333	-0.240
10	0.062	0.377	-0.263
11	0.072	0.402	-0.284
12	0.083	0.436	-0.308

TABLE 3
ACCUMULATED RESPONSE OF BUSINESS VALUUE ADDED, PRODUCTIVITY GROWTH, AND INFLATION TO SHOCKS IN IT INVESTMENT IN COMPUTER EQUIPMENTS (1994-2008)

Period	Value added	Productivity	Inflation
1	0.001	0.027	-0.054
2	0.003	0.145	-0.075
3	0.005	0.134	-0.088
4	0.007	0.136	-0.098
5	0.008	0.138	-0.113
6	0.010	0.147	-0.128
7	0.011	0.152	-0.142
8	0.013	0.158	-0.156
9	0.014	0.163	-0.169
10	0.015	0.168	-0.182
11	0.015	0.173	-0.194
12	0.016	0.178	-0.206

TABLE 4
ACCUMULATED RESPONSE OF BUSINESS VALUUE ADDED, PRODUCTIVITY GROWTH, AND INFLATION TO SHOCKS IN IT INVESTMENT IN SOFTWARE (1959-1980)

Period	Value added	Productivity	Inflation
1	-0.002	-0.111	-0.040
2	-0.004	-0.090	-0.075
3	-0.007	-0.143	-0.123
4	-0.006	0.059	-0.124
5	-0.007	-0.038	-0.157
6	-0.007	-0.029	-0.200
7	-0.007	-0.064	-0.209
8	-0.006	-0.046	-0.215
9	-0.006	-0.090	-0.211
10	-0.005	-0.081	-0.185
11	-0.004	-0.087	-0.163
12	-0.003	-0.056	-0.145

TABLE 5
ACCUMULATED RESPONSE OF BUSINESS VALUUE ADDED, PRODUCTIVITY GROWTH, AND INFLATION TO SHOCKS IN IT INVESTMENT IN SOFTWARE (1981-2008)

Period	Value added	Productivity	Inflation
1	0.001	0.039	-0.041
2	0.005	0.231	-0.059
3	0.012	0.274	-0.063
4	0.018	0.213	-0.056
5	0.025	0.292	-0.097
6	0.032	0.260	-0.097
7	0.038	0.199	-0.111
8	0.044	0.198	-0.108
9	0.050	0.258	-0.150
10	0.055	0.180	-0.172
11	0.060	0.264	-0.211
12	0.067	0.310	-0.225

TABLE 6
ACCUMULATED RESPONSE OF BUSINESS VALUUE ADDED, PRODUCTIVITY GROWTH, AND INFLATION TO SHOCKS IN IT INVESTMENT IN SOFTWARE (1994-2008)

Period	Value added	Productivity	Inflation
1	0.002	0.095	-0.067
2	0.005	0.219	-0.053
3	0.009	0.263	-0.032
4	0.012	0.026	-0.037
5	0.015	0.118	-0.077
6	0.018	0.127	-0.094
7	0.021	0.128	-0.097
8	0.024	0.138	-0.097
9	0.026	0.149	-0.115
10	0.028	0.069	-0.113
11	0.029	0.100	-0.133
12	0.030	0.120	-0.143

TABLE 7
ACCUMULATED RESPONSE OF BUSINESS VALUUE ADDED, PRODUCTIVITY GROWTH, AND INFLATION TO SHOCKS IN IT INVESTMENT IN COMMUNICATION EQUIPMENTS (1959-1980)

Period	Value added	Productivity	Inflation
1	0.002	0.011	0.030
2	0.004	0.049	0.041
3	0.006	0.087	0.049
4	0.008	0.122	0.054
5	0.011	0.154	0.058
6	0.014	0.185	0.062
7	0.018	0.213	0.067
8	0.021	0.239	0.072
9	0.026	0.263	0.078
10	0.030	0.284	0.085
11	0.034	0.304	0.093
12	0.039	0.321	0.102

TABLE 8
ACCUMULATED RESPONSE OF BUSINESS VALUUE ADDED, PRODUCTIVITY GROWTH, AND INFLATION TO SHOCKS IN IT INVESTMENT IN COMMUNICATION EQUIPMENTS (1981-2008)

Period	Value added	Productivity	Inflation
1	0.001	0.038	-0.010
2	0.005	0.155	-0.011
3	0.008	0.142	-0.008
4	0.011	0.049	-0.002
5	0.014	0.100	-0.010
6	0.018	0.086	-0.022
7	0.021	0.105	-0.031
8	0.025	0.125	-0.045
9	0.029	0.149	-0.061
10	0.034	0.179	-0.077
11	0.039	0.206	-0.092
12	0.045	0.228	-0.108

TABLE 9
ACCUMULATED RESPONSE OF BUSINESS VALUUE ADDED, PRODUCTIVITY GROWTH, AND INFLATION TO SHOCKS IN IT INVESTMENT IN COMMUNICATION EQUIPMENTS (1994-2008)

Period	Value added	Productivity	Inflation
1	0.001	0.003	-0.055
2	0.004	0.096	-0.033
3	0.005	0.005	-0.036
4	0.006	0.022	-0.040
5	0.005	0.052	-0.059
6	0.004	0.067	-0.080
7	0.001	0.080	-0.103
8	0.002	0.089	-0.125
9	0.006	0.097	-0.147
10	0.010	0.103	-0.168
11	0.015	0.109	-0.187
12	0.021	0.115	-0.206

APPENDIX B: VARIANCE DECOMPOSITION[4]

TABLE 1
DECOMPOSITION OF VARIANCE OF NONFARM BUSINESS VALUE ADDED (1959-1980)

Period	S.E.	Computer	Software	Communication	Labor productivity	Business value added	Inflation
1	0.013710	0.194416	3.212834	2.646468	71.91527	22.03102	0.000000
2	0.022527	0.080028	3.402929	2.896918	64.23025	29.08310	0.306775
3	0.030038	0.084271	2.901440	2.177027	66.52976	27.93709	0.370412
4	0.036018	0.065878	2.469347	1.833645	67.39895	27.58011	0.652070
5	0.041186	0.086029	2.321371	1.513669	68.01727	27.28484	0.776827
6	0.045598	0.091259	2.204863	1.288676	68.13666	27.47251	0.806034
7	0.049590	0.104744	2.156540	1.123142	68.14634	27.65068	0.818552
8	0.053151	0.110753	2.126350	1.006014	68.08726	27.83482	0.834803
9	0.056432	0.115010	2.107054	0.917649	68.03162	27.99044	0.838223
10	0.059490	0.117553	2.093416	0.850711	67.96208	28.13745	0.838789
11	0.062385	0.119840	2.084156	0.797922	67.91502	28.24361	0.839452
12	0.065147	0.121127	2.075487	0.755639	67.87923	28.32783	0.840684

TABLE 2
DECOMPOSITION OF VARIANCE OF NONFARM BUSINESS VALUE ADDED
(1981-2008)

Period	S.E.	Computer	Software	Communication	Labor productivity	Business value added	Inflation
1	0.006758	1.025370	0.000806	0.089897	56.35185	42.53207	0.000000
2	0.010505	7.500698	0.197993	0.441422	40.61877	51.01390	0.227218
3	0.014691	16.24478	0.661687	0.242001	33.14024	49.59063	0.120665
4	0.018491	23.35607	0.488361	0.760211	28.50760	46.75963	0.128122
5	0.021903	28.19036	0.348046	1.347811	24.45709	45.25551	0.401189
6	0.024734	33.90138	0.585169	2.086473	20.37523	41.79778	1.253977
7	0.027811	38.80725	1.067844	3.647317	16.88596	37.74908	1.842546
8	0.031089	42.32029	1.527272	5.301400	13.92465	34.16048	2.765898
9	0.034164	44.09582	1.993925	6.912406	11.88663	31.39386	3.717360
10	0.037338	45.06586	2.592185	8.312085	10.52459	29.05257	4.452706
11	0.040445	45.61004	3.074430	9.051878	9.544476	27.72820	4.990978
12	0.043413	45.88263	3.393736	9.540591	8.915388	26.93643	5.331224

TABLE 3
DECOMPOSITION OF VARIANCE OF NONFARM BUSINESS VALUE ADDED
(1994-2008)

Period	S.E.	Computer	Software	Communication	Labor productivity	Business value added	Inflation
1	0.005604	3.627492	15.72128	7.413413	34.89606	38.34176	0.000000
2	0.008135	7.931210	34.70797	3.572977	24.62495	28.93974	0.223145
3	0.011654	7.424282	38.90585	2.019078	26.65997	20.12285	4.867969
4	0.014182	7.416192	34.98478	3.684221	26.22162	20.55236	7.140823
5	0.017368	6.136348	35.78375	10.03737	24.71528	18.19290	5.134348
6	0.020529	5.018762	34.63197	16.16792	22.48569	17.87922	3.816436
7	0.023956	3.736519	30.47744	22.28330	22.35241	18.34517	2.805163
8	0.027683	2.806417	27.60110	28.66009	21.47447	17.30875	2.149166
9	0.031520	2.169011	24.84990	33.72852	21.11872	16.46846	1.665379
10	0.035619	1.716018	21.39344	39.32106	20.01427	16.24937	1.305839
11	0.039843	1.371499	18.72855	43.50943	18.94778	16.19093	1.251812
12	0.044065	1.130261	16.88361	46.18962	18.06602	16.47345	1.257048

TABLE 4
DECOMPOSITION OF VARIANCE OF NONFARM BUSINESS VALUE ADDED (1994-2001)

Period	S.E.	Computer	Software	Communication	Labor productivity	Business value added	Inflation
1	0.016056	17.59244	5.899930	2.012316	64.40418	10.09113	0.000000
2	0.029524	17.00696	8.216502	1.847582	62.92322	4.989837	5.015903
3	0.046515	16.86473	12.62642	3.538155	61.45691	2.647950	2.865838
4	0.061997	10.90770	10.65904	3.498909	62.38159	2.475503	4.077251
5	0.077293	6.428806	20.14898	6.445309	60.74339	1.753768	4.479752
6	0.091798	4.370383	21.24534	9.662282	58.59328	1.313741	4.814971
7	0.105387	3.044529	20.62463	12.91768	57.49930	1.000838	4.913015
8	0.117232	2.352456	18.75988	14.86451	57.10135	0.728774	6.193031
9	0.128030	1.987441	17.16719	17.02271	56.33326	0.542550	6.946847
10	0.137647	1.697590	15.11590	18.95980	56.11935	0.412157	7.695210
11	0.146727	1.469954	13.16948	20.17950	56.30192	0.332786	8.546364
12	0.155291	1.309634	11.34333	20.97016	56.51909	0.305390	9.552387

TABLE 5
DECOMPOSITION OF VARIANCE OF PRODUCTIVITY GROWTH (1959-1980)

Period	S.E.	Computer	Software	Communication	Labor productivity	Business value added	Inflation
1	0.860162	0.059123	0.566311	3.093186	96.28138	0.000000	0.000000
2	0.884877	0.322107	0.647110	5.139058	91.48315	2.161302	0.247273
3	0.934523	2.623365	0.682636	4.643408	82.86735	3.468180	5.715058
4	0.969630	2.974962	1.445721	4.678901	78.44502	6.092390	6.363006
5	1.010704	4.569331	1.356108	4.586617	72.63364	9.564415	7.289892
6	1.049573	4.851716	1.489740	4.797992	68.44602	11.30705	9.107490
7	1.084122	5.670372	1.455376	5.128289	64.45587	12.62821	10.66188
8	1.116255	6.137897	1.480155	5.592574	61.12566	14.18528	11.47843
9	1.146874	6.614198	1.500352	5.996997	58.05635	15.53066	12.30144
10	1.175590	7.038006	1.526247	6.367964	55.39050	16.56889	13.10839
11	1.203241	7.490970	1.540117	6.673654	52.96333	17.52306	13.80886
12	1.229834	7.883387	1.560685	6.950645	50.78348	18.40995	14.41185

TABLE 6
DECOMPOSITION OF VARIANCE OF PRODUCTIVITY GROWTH (1981-2008)

Period	S.E.	Computer	Software	Communication	Labor productivity	Business value added	Inflation
1	0.488848	0.251388	0.035625	0.831860	98.88113	0.000000	0.000000
2	0.530686	6.976402	0.428911	2.681973	85.93495	1.572245	2.405518
3	0.553729	10.14359	1.605033	4.350361	79.91414	1.509174	2.477703
4	0.581913	9.189259	3.999300	7.345109	72.46278	4.353636	2.649916
5	0.594662	9.448551	4.981777	7.126016	69.38917	5.280318	3.774167
6	0.639051	8.896535	6.218102	6.201119	61.39234	13.31993	3.971975
7	0.663675	8.987703	5.972364	7.219092	60.47200	13.65739	3.691446
8	0.670130	8.863043	5.882755	7.235733	59.59194	13.89979	4.526732
9	0.675005	8.925345	5.825313	7.169799	58.96424	14.63920	4.476104
10	0.688312	8.661215	6.177978	7.127314	58.47614	15.20078	4.356572
11	0.693036	8.668452	6.107553	7.288603	58.35659	15.27813	4.300670
12	0.700047	8.507908	5.990561	7.169406	57.77442	16.32541	4.232302

TABLE 7
DECOMPOSITION OF VARIANCE OF PRODUCTIVITY GROWTH (1994-2008)

Period	S.E.	Computer	Software	Communication	Labor productivity	Business value added	Inflation
1	0.441760	5.745687	9.648493	13.92557	70.68025	0.000000	0.000000
2	0.539552	7.688538	10.82055	17.06998	54.23868	10.11683	0.065423
3	0.585568	7.932621	10.74861	14.56251	48.21245	8.995026	9.548787
4	0.616192	7.896841	14.51745	14.91727	45.76140	8.275055	8.631977
5	0.663529	8.576925	14.45395	13.51250	39.48192	11.19515	12.77955
6	0.697155	8.633779	13.15975	12.61923	39.80262	10.17369	15.61094
7	0.718814	10.85117	12.37963	12.33731	38.92175	10.24282	15.26731
8	0.732799	10.69856	12.33361	11.92948	37.72965	12.42800	14.88070
9	0.740405	11.34050	12.18306	11.71628	37.03016	12.61865	15.11134
10	0.757350	10.83872	13.95859	12.47046	36.10273	12.18659	14.44291
11	0.775462	10.98934	13.38071	11.89538	34.65213	11.65770	17.42475
12	0.780160	10.87278	13.62022	12.30732	34.36471	11.57429	17.26068

TABLE 8
DECOMPOSITION OF VARIANCE OF PRODUCTIVITY GROWTH (1994-2001)

Period	S.E.	Computer	Software	Communication	Labor productivity	Business value added	Inflation
1	0.031534	14.77695	2.670124	22.22553	60.32739	0.000000	0.000000
2	0.059833	20.11182	1.643324	27.51168	37.56947	1.881554	11.28214
3	0.081383	21.02790	2.204250	34.64832	30.51821	1.959665	9.641649
4	0.095106	22.82640	2.920851	33.09232	28.90897	2.282080	9.969388
5	0.110111	21.90847	2.790657	33.94746	27.88839	3.785087	9.679937
6	0.128255	22.27523	4.466450	32.82843	26.98217	3.696926	9.750802
7	0.144785	28.33704	4.109345	30.16021	24.79180	3.443835	9.157768
8	0.159520	28.03262	4.779981	29.85115	24.67551	3.567510	9.093234
9	0.175373	27.49556	5.031172	29.28905	24.84665	3.519673	9.817890
10	0.192841	26.88806	7.175625	28.87991	24.08099	3.482326	9.493087
11	0.211533	26.91667	7.339711	28.83845	24.36760	3.372052	9.165517
12	0.230111	25.99179	7.503691	28.07547	26.02522	3.222985	9.180846

TABLE 9
DECOMPOSITION OF VARIANCE OF INFLATION (1959-1980)

Period	S.E.	Computer	Software	Communication	Labor productivity	Business value added	Inflation
1	0.329416	0.174208	0.403344	1.883361	0.303932	4.387859	92.84730
2	0.381118	0.491375	0.671564	2.938439	1.193953	4.353921	90.35075
3	0.427841	0.688475	0.657413	5.978799	4.877813	8.352979	79.44452
4	0.476688	1.693881	0.631943	7.218062	9.034114	7.949239	73.47276
5	0.521606	1.756609	0.622392	7.653164	11.99660	6.995178	70.97605
6	0.562095	1.814458	0.638783	7.837387	15.47690	6.614678	67.61779
7	0.596588	1.924668	0.625955	8.045557	17.70835	6.443747	65.25173
8	0.631170	1.993229	0.625696	8.012566	19.48861	6.160024	63.71988
9	0.662701	2.039438	0.624393	8.004967	20.67988	5.924830	62.72650
10	0.692674	2.072064	0.629549	7.992119	21.71186	5.795175	61.79923
11	0.721008	2.121695	0.627700	8.005501	22.45336	5.697145	61.09460
12	0.748597	2.155559	0.629156	8.006465	23.07755	5.601858	60.52941

TABLE 10
DECOMPOSITION OF VARIANCE OF INFLATION (1981-2008)

Period	S.E.	Computer	Software	Communication	Labor productivity	Business value added	Inflation
1	0.192150	8.092129	0.019178	0.025852	0.123266	1.360683	90.37889
2	0.198288	8.828128	0.018681	0.142326	2.355920	1.649186	87.00576
3	0.206149	8.307289	0.097705	2.266313	2.298932	1.574262	85.45550
4	0.221744	8.407264	1.928111	3.389307	2.035068	2.635815	81.60444
5	0.246038	8.354586	2.471917	3.094501	1.685417	4.425501	79.96808
6	0.253678	9.374526	2.831371	4.563894	2.435567	4.917931	75.87671
7	0.267885	8.629012	4.940873	4.411063	3.430605	4.852871	73.73558
8	0.283180	7.723485	7.602744	5.198245	4.235058	4.892335	70.34813
9	0.294282	7.456937	9.325151	7.343166	4.524372	4.667007	66.68337
10	0.304518	7.060763	11.69850	8.681773	4.863792	4.556742	63.13843
11	0.320999	6.732039	14.63044	9.196450	5.023263	4.861046	59.55676
12	0.334995	6.627468	16.47159	10.19587	5.229060	5.299889	56.17613

TABLE 11
DECOMPOSITION OF VARIANCE OF INFLATION (1994-2008)

Period	S.E.	Computer	Software	Communication	Labor productivity	Business value added	Inflation
1	0.201097	6.707505	4.468452	0.035189	6.449054	5.311860	77.02794
2	0.207690	6.468706	5.350189	2.423808	7.697727	5.244314	72.81526
3	0.229391	7.871269	6.208003	6.907747	8.992326	4.714596	64.30606
4	0.252718	7.035185	5.249672	6.986711	8.971374	4.396822	61.36024
5	0.296044	5.456575	4.953657	11.21143	11.38420	3.618611	63.37553
6	0.317085	8.755917	4.674306	9.815784	14.60368	4.091739	58.05858
7	0.337914	7.788570	4.263878	10.11416	14.02240	4.707132	59.10386
8	0.344876	8.943517	4.171471	10.11944	13.69201	4.627419	58.44614
9	0.351305	8.744200	4.512435	10.06676	14.27433	4.596852	57.80542
10	0.363490	8.256384	4.305814	10.81356	14.33537	6.267815	56.02106
11	0.382322	7.544192	4.678197	10.57840	13.72600	5.892201	57.58100
12	0.389322	7.745773	4.512075	10.24756	14.13013	6.020513	57.34395

TABLE 12
DECOMPOSITION OF VARIANCE OF INFLATION (1994-2001)

Period	S.E.	Computer	Software	Communication	Labor productivity	Business value added	Inflation
1	0.024156	10.56735	0.027096	25.40617	0.239244	14.00223	49.75790
2	0.031805	10.25920	2.741264	21.28397	2.504448	11.99526	51.21585
3	0.037976	13.61509	4.617326	18.77153	2.606855	10.10656	50.28264
4	0.043985	12.00413	4.266567	14.94516	11.78005	10.81958	46.18452
5	0.048682	9.539944	3.467535	14.07263	12.60208	10.91904	49.39877
6	0.053020	11.38444	3.542776	11.16706	16.62341	8.830122	48.45219
7	0.056110	9.960895	4.107712	9.169474	19.77496	7.436556	49.55040
8	0.059056	8.551558	4.643385	8.662207	22.94824	7.443698	47.75092
9	0.061723	7.157154	3.932454	7.586750	27.52188	6.850788	46.95098
10	0.064220	7.196605	3.606993	6.300169	30.08383	5.989895	46.82251
11	0.066580	6.590115	3.422161	6.372163	31.85951	5.538178	46.21787
12	0.068652	5.670864	3.273680	7.208705	34.75709	5.055855	44.03380

ENDNOTES

1. The term “digital revolution” is referred to the ability to use microscopic circuits to process and store huge amounts of information. For more details see: The Emerging Digital Economy II, Economics and Statistics Administration, U.S. Department of Commerce, June 1999.
2. For more details about the formulas used to calculate the contribution of IT investment to economic growth and inflation see: Digital Economy 2002 Appendices, U.S. Department of Commerce, March 2002, pp. 10-38.
3. I studied the impact of IT investment variables on the three macroeconomic variables of interest during the second half of the 1990’s, as most of the studies on IT investment did, and found that during the period (1994-2001), investment in computer equipments takes the lead among all IT investment variables in explaining the variation in nonfarm business value added but only in the short run (up to the fourth quarter) while investment in communication equipments and software was a major player in the long run as shown in table 4, appendix B. Investment in communication equipments is found to be the highest among all other IT variables in explaining variations in labor productivity growth and inflation in both the short run and long run as indicated in tables 8 and 12, appendix B.
4. The Cholesky Ordering of the variables is as follows: IT investment, real GDP growth per worker, nonfarm business value added, and inflation. In each time period mentioned above, I use the three IT variables: computer equipments, software, and communication equipments.

REFERENCES

Baily, M.N. (2002). The New Economy: Post Mortem or Second Wind?. Journal of Economic Perspectives, 16 (Spring), 3–22.

Basu, S., Fernald, J.G., & Shapiro M.D. (2001). Productivity Growth in the 1990s: Technology, Utilization, or Adjustment?. Carnegie-Rochester Conference Series on Public Policy, 55 (December), 117–65.

Brynjolfsson, E., Hitt, L.M. (2000). Beyond Computation: Information Technology, Organizational Transformation, and Business Performance, Journal of Economic Perspectives, 14 (Fall), 23–48.

Engle, R.F., Granger, C.W.J. (1987). Co-integration and Error Correction: Representation, Estimation, and Testing, Econometrica, 55, 251-276.

Gordon, R.J, (2000). Does the new economy measure up to the great inventions of the past?. Journal of Economic Perspectives, 14 (Fall), 49–74.

Helpman, E. (1998). General Purpose Technologies and Economic Growth, Cambridge, MA. MIT Press.

James, E.E. (1998). Annual Review of Information Technology Developments for Economic and Social Historians, The Economic History Review, New Series, Vol. 51, No. 2 (May), 382-397

Johansen, S. (1988). Statistical Analysis of Cointegrating Vectors, Journal of Economic Dynamics and Control. 12. 231-254.

Jorgenson, D.W. (2001). Information technology and the U.S. economy. American Economic Review, 91 (March), 1–32.

Jorgenson, D.W., Ho, M.S. & Stiroh, K.J. (2002). Projecting productivity growth: Lessons from the U.S. growth resurgence. Federal Reserve Bank of Atlanta Economic Review, 87, (Third Quarter), 1–13.

Jorgenson, D.W., Stiroh, K.. (1999). Information technology and growth, American Economic Review Papers and Proceedings, 89, 109–115.

Jorgenson, D.W., Stiroh, K., (2000). Raising the Speed Limit: US Economic Growth in the Information Age. Brooking Papers on Economic Activity, 1, 125–211.

Oliner, S.D., and Sichel, D.E. (2002). Information Technology and Productivity: Where Are We Now and Where Are We Going?. Federal Reserve Bank of Atlanta Economic Review, Third Quarter. 15-44.

Oliner, S.D., and Sichel, D.E. (2000a). The Resurgence of Growth in the Late 1990s: Is Information Technology the Story? Journal of Economic Perspectives, 14 (Fall), 3–22.

Pesaran, H.H. and Shin, Y. (1998). Generalized Impulse Response Analysis in Linear Multivariate Models. Economic Letters, 58, 17-29.

Sims, C.A. (1980). Macroeconomics and Reality. Econometrica. 48, 1-48.

Stiroh, K.J. (2002). Information Technology and the U.S. Productivity Revival: What Do the Industry Data Say?. American Economic Review, 92, 5, 1559-76.

Stiroh, K.J. (2001). Investing in Information Technology: Productivity Payoffs for U.S. Industries, Federal Reserve Bank of New York Current Issues in Economic and Finance, Volume 7, No. 6, 1-6.

Taylor, T. (2001). Thinking about a 'New Economy'. The Public Interest, Summer, 143, 1-7.

U.S. Department of commerce. (2002). Digital Economy, Economics and Statistics Administration.

U.S. Department of commerce. (1999). The Emerging digital Economy I and II, Economics and Statistics Administration.