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THE IMPACT OF INFORMATION TECHNOLOGY ON LABOR PRODUCTIVITY GROWTH: EVIDENCE FROM FIVE OECD COUNTRIES, 1970-1990

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This paper examines the impact of information technology (IT) on labor productivity growth using industry-level data for five OECD countries (the United States, Canada, Japan, France, and the United Kingdom), from 1970 to 1990. Empirical findings show that IT investment has a positive effect on labor productivity growth, accounting for about 15 percent of this growth. The benefit of IT investment was on average lower than its cost over the 1970-1990 period, which implies that new IT investment had not been efficiently used in the early period of IT adoption. The benefit per dollar cost was almost two times greater in the 1980s than in the 1970s, which is mainly due to a rapid fall in IT prices.

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I. INTRODUCTION

During the last few decades, most developed countries have experienced a rapid increase in the use of information technology (IT), despite a slowdown in productivity growth rates. This is known as the IT productivity paradox, which is also captured by a famous quip by Robert

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Solow that "computers are everywhere but not in productivity statistics."[1] Although there have been a number of studies on the IT productivity paradox in the last decade, most studies have been restricted to examples in the United States.[2] It is therefore worthwhile to explore whether the IT productivity paradox has been an international phenomenon.

In this paper I explore the impact of IT investment on labor productivity growth using industry-level data from five OECD countries (the United States, Canada, Japan, France, and the United Kingdom). In particular, this study focuses on the early period of IT adoption, 1970-1990, while most cross-country studies have concentrated on more recent periods, since 1990.[3] Analyzing IT diffusion during the earlier period enables us to address a hypothesis raised by David (1990); Productivity gains from new technologies (e.g., dynamos and computers) can be delayed because the efficient use of new technologies can take a considerable amount of time. In a similar vein, general purpose technology (GPT) theories (e.g., Helpman and Trajtenberg, 1998) also propose a possible slowdown effect of a new GPT on the economy. Hobijn and Jovanovic (2001) also show that the IT revolution could contribute falls in stock prices in the 1970s, i.e., when IT first arrived. In this regard, exploring the impact of IT investment on labor productivity growth in the early period of IT adoption can explain whether IT adoption is associated with the productivity slowdown which occurred during the 1970s and 1980s.

The paper also uses both cross-country and cross-industry data.[4] In contrast to most recent cross-country studies which used aggregate

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[1] Allen (1997) provides several possible explanations for the IT productivity paradox that include time lags between IT investment and realized productivity gains and mismeasurement of inputs and outputs.

[2] The most important reason is the lack of data on IT investment at the international level. See Gera, Gu, and Lee (1999) for an industry-level analysis in Canada and the United States and Greenan and Mairesse (2000) and Crepon and Heckel (2002) for firm-level analyses in France. For the U.S. case, see Berndt and Morrison (1995), Morrison (1997), Stiroh (1998, 2002), Wolff (1999), and McGuckin and Stiroh (2002) for industry-level studies, and Lichtenberg (1995), Brynjolfsson and Hitt (1999, 2003), and Stolarick (1999) for firm- or plant-level studies.

[3] See Colecchia and Schreyer (2002), Jalava and Pohjola (2002), van Ark (2002), Daveri (2003), Inklaar, O'Mahony, and Timmer (2005).

[4] The dimensions of the data in this paper are very similar to those used by Gera, Gu, and Lee (1999). Since their data included only two countries, they estimated the split sample by country without pooling the data.

country-level data, I have used disaggregated industry-level data for the five OECD countries chosen. The effect of IT investment on productivity growth can be more clearly identified when using both cross-country and cross-industry data, because a common industry in different countries has a similar ratio of IT investment to output, but has not a similar productivity growth rate. Furthermore, the use of cross-country, cross-industry, and time-series data allows me to compare the productivity impact of IT investment by country, industry, and time period.

I have estimated the rate of return to IT investment using a production function that includes labor, non-IT investment, and IT investment.[5] My empirical results show that IT investment is positively associated with labor productivity growth. The estimated rate of return to IT investment is about 37 percent, which suggests that IT investment contributes about 15 percent to labor productivity growth over the 1970-1990 period.

In order to assess whether new IT investment was being efficiently used in the early period of IT adoption, I have measured the cost-effectiveness of IT investment, by comparing the rate of return to IT investment (the benefit) with the user cost of IT capital (the cost). The ratio of benefit to cost is on average about 0.60, which implies that IT investment was not cost-effective in the early period of IT adoption among the five OECD countries chosen. This result suggests that the IT productivity paradox is a common phenomenon in these countries, at least for the earlier period of IT adoption. However, a fall in the labor productivity growth rate, associated with the inefficient use of IT, is too small to explain the productivity slowdown which occurred in the 1970s and 1980s.

Using subsamples grouped by country, industry, and time period, results show some interesting variations in IT returns. The rate of return to IT investment is lower in the IT-intensive country sample, which consists of the U.S. and Canada, than it is in the less-IT-intensive sample consisting of France and the U.K. The rate of return estimate from IT investment in IT-intensive industries is positive, but in less-IT-intensive industries, it is not statistically significant. The rate of return to IT

[5] While most studies used a growth accounting framework, Dewan and Kraemer (2000) estimated a production function using aggregate cross-country data.

investment was lower in the 1970s than in the 1980s, but the ratio of benefit to cost was much lower in the 1970s than in the 1980s, due to a rapid fall in costs as well as a rise in benefits. These findings on variations in IT returns over certain time periods are consistent with the hypothesis that productivity gains from new information technologies can be delayed.

Section II describes the data used in this paper and discusses issues regarding the construction of the IT investment price deflator at the international level. Section III presents the empirical specifications. Section IV presents the empirical results, compares returns from IT investment among several subsamples according to industry, country, and time period, and measures the cost-effectiveness of IT investment. The conclusion is contained in Section V.

II. DATA

To obtain IT investment data, I use the Input-Output (IO) Database published by the OECD. The IO database provides an internationally compatible industry classification for 33 sectors in ten OECD countries, using the International Standard Industry Classification (ISIC). Besides the transaction flows of intermediate goods, this database also includes investment flows for various types of assets (OECD, 1995).

IT investment is defined as the sum of the investments in office and computing machinery (OCM, ISIC 3825) and in communications equipment (CE, ISIC 3832). The definition of IT investment varies in the literature. Berndt and Morrison (1995) and Morrison (1997) defined IT as the sum of office, computing and accounting machinery, communications equipment and instruments, but Stiroh (1998, 2002) and Wolff (1999) equated IT with OCM. The Bureau of Economic Analysis (BEA) in the United States provides a broad definition of IT as information processing and related equipment, which includes OCM, CE, instruments, and photocopy and related equipment. Since the sum of OCM and CE accounts for more than 70 percent of information processing and related equipment, the definition of IT in this study is close to the BEA's broad definition of IT capital.[6]

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[6] Whether we use a narrow or broad definition of IT capital, these definitions exclude computer

Investment flows from the IT capital-producing industries to other industries are not available separately for some countries. After excluding these countries, five industrialized countries remain in the sample, namely the U.S., Canada, Japan, France, and the U.K. Since most countries publish IO tables every five-year, the IO database has five data points from 1970 to 1990.[7, 8]

The International Sectoral Database (ISDB) published by the OECD is used to construct output and input related variables. Real output is defined as the quantity of value-added. Since the ISDB does not provide gross output, value-added is used as output measure. Labor input is defined as the total number of hours of workers that is calculated by multiplying ave rage annual hours worked per person by total employment. In particular, both industry- and country-specific average annual hours per worker provided in ISDB (1998) are used. The ISDB covers 26 sectors in 14 OECD countries. To match the industry classification between the IO and ISDB data sets, I choose 20 industries using the ISIC. This industry classification has nine manufacturing and eleven non-manufacturing industries. All currency-denominated variables are converted to 1990 U.S. dollars using 1990 purchasing-power parities (PPP). GDP PPP is used for real output and gross fixed capital formation PPP is for IT and non-IT investments.

II.1 IT Investment Price

IT price indexes in the OECD IO database show a large difference between countries. Wyckoff (1995) examines the international compatibility of methods used for the IT price index, and concludes that

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software, since it is difficult to measure software investment using the OECD IO tables. For example, the U.S. BEA includes software as a part of IT after recent revision in the National Income and Product Accounts. However, the share of software investment in the total IT investment was relatively low before the mid-1980s, which implies that the results in this paper may not be sensitive to the inclusion of software. See Colecchia and Schreyer (2002) for the average share of software investment in the total IT investment at the aggregate level for nine OECD countries from 1980 to 2000.

[7] Publication year varies with country. For example, the U.S. BEA publishes the IO tables every five-year, when the last digit of the year is ‘2’ or ‘7’.

[8] Since the fixed capital formation tables of the OECD IO dataset are not available for the post-1990 period, the sample is limited to the 1970-1990 period.

the variation in the IT price index is largely due to differences in methodology. Two categories of methodology are used to capture any product quality changes in a price index: the matched-model and hedonic methods. The matched-model method records price changes in an identical product over time. Since the quality of IT products is constantly changing, it can be difficult to find an identical product over time. Therefore, the matched-model method may not reflect actual quality changes in IT products. In contrast, the hedonic method relates movements in a product's price to product characteristics, such as memory size, processor speed, and disk capacity. This method is based on the hypothesis that heterogeneous goods are the aggregation of product characteristics. As Triplett (1989) points out, the hedonic method is more appropriate for products experiencing large changes in quality. In fact, I find that patterns of IT prices in the OECD IO database are consistent with Wyckoff's finding that IT prices in most countries in which they are estimated by the hedonic method, decline more rapidly than those in some countries estimated by the conventional matched model method.[9]

To adjust cross-country differences in IT prices due to the different methods, I use the IT price index of the United States published by the BEA.[10] Although I use the U.S. IT price, there exists a possible bias due to cross-country difference in IT quality, product mix, and mark-up.[11] If the quality of IT products in the U.S. has improved faster than those in the other four countries, the use of the U.S. IT price for these countries overestimates their real stock of IT capital. However, Moch and Triplett (2002) find that hedonic IT prices of France and Germany are not significantly different from that of the U.S.

[9] Analyzing IT price data in the OECD IO database, the hedonic indexes of OCM for the United States and Canada declined by 9.49 and 4.26 percent per annum, respectively, whereas the pattern of changes in the matched-model indexes of OCM for Japan, France, and the United Kingdom were quite different: the annual rates of price change for OCM were -5.76, 4.14, and 6.65 percent, respectively. Some countries such as France now use the hedonic price method.

[10] Schreyer (2000) also uses the U.S. IT prices to examine the output contribution of IT investment among seven industrialized countries. However, the use of the U.S. hedonic prices for OCM may incur a possible measurement error because the asset composition within OCM is assumed to be the same across countries: OCM consists of several different assets (e.g., computers, terminals, storage devices, and printers) that have different hedonic prices. For example, the hedonic price has declined much faster for computers than the other OCM assets.

[11] I thank an anonymous referee for suggesting the potential bias due to the use of the U.S. IT price for the other countries.

I obtained nominal gross investments in OCM and CE from the OECD IO database. I constructed two real investment series of OCM and CE using the two U.S. price indexes of OCM and CE. The Törnqvist index method is used to aggregate the two assets. The price index of total IT investment varies according to different composition of the two IT assets. The OCM price index fell by 10.2 percent per year from 1970 to 1990, but the CE price increased by 3.9 percent per year.[12] Although the OCM and CE price indexes moved in opposite directions, the total IT investment price declined in the sample period. The total IT price index declined, not only because the OCM prices declined more rapidly than the CE prices rose, but also because the proportion of OCM to total IT increased during the sample period. The IT investment price decreased by 4.6 percent per year.

II.2 Descriptive Statistics

Table 1 illustrates the average ratios of IT investment to output for 20 industries from each country, during the period 1970-1990. The ratios are high in most non-manufacturing industries such as utilities, wholesale and retail trade, communications, financial institutions and insurance, and services. In particular, the ratios in the communications industry are extremely high because a large part of the investment in this industry consists of communications equipment.[13] Among the manufacturing industries, paper, paper products, printing and publishing, and fabricated metal products, machinery, and equipment industries have high ratios of IT investment to output. Table 1 shows that the IT ratio is relatively higher in the non-manufacturing sector (excluding the agriculture, mining, and construction industries) than in the manufacturing sector.

[12] The United States uses the hedonic price method for a very limited part of CE, but it is not enough to correct for quality improvements in CE.

[13] In particular, communications equipment is more unevenly distributed across industries than computers. The communications industry accounts for almost 60 percent of investment in communications equipment at the aggregate level.

[Table 1] Ratio of IT Investment to Output at the Industry-Level for Five OECD Countries, 1970-1990

No.	ISIC	Industry description	United States	Canada	Japan	France	United Kingdom
1	1	Agriculture, hunting, forestry, and fishing	0.190	0.025	0.287	0.010	0.035
2	2	Mining and quarrying	0.708	0.204	0.223	0.151	0.686
3	31	Food, beverages, and tobacco	0.229	0.135	0.201	0.149	0.227
4	32	Textiles, wearing apparel, and leather	0.347	0.100	0.428	0.192	0.070
5	33	Wood and wood products, including furniture	0.172	0.080	0.105	0.169	0.145
6	34	Paper, paper products, printing, and publishing	0.818	0.194	1.785	0.344	0.095
7	35	Chemicals and petroleum, coal, rubber, and plastic products	0.498	0.606	0.482	0.451	0.204
8	36	Non-metallic mineral products	0.383	0.150	0.301	0.479	0.063
9	37	Basic metal products	0.341	0.344	0.760	0.616	0.123
10	38	Fabricated metal products, machinery, and equipment	1.118	0.287	1.454	0.426	0.462
11	39	Other manufacturing industries	0.215	0.234	0.458	0.067	0.578
12	4	Electricity, gas, and water	1.394	1.365	0.768	0.762	1.348
13	5	Construction	0.096	0.043	0.187	0.101	0.032
14	61+62	Wholesale and retail trade	0.891	0.185	0.576	0.227	0.539
15	63	Restaurants and hotels	1.284	0.552	0.525	0.376	0.075
16	71	Transport and storage	2.982	0.314	0.366	0.378	0.191
17	72	Communications	11.671	21.738	8.127	17.377	6.462
18	81+82	Financial institutions and insurance	1.189	0.705	5.462	0.509	1.220
19	83	Real estate and business services	0.687	1.101	1.707	0.989	1.431
20	9	Community, social, and personal services	1.009	1.499	1.213	0.926	1.319
		Total industry					
		1970-1980	0.717	0.592	1.018	0.428	0.517
		1980-1990	1.618	1.503	2.557	1.123	1.170
		1970-1990	1.202	1.096	1.787	0.739	0.859

Notes: Ratios of IT investment to output for the total industry are weighted by the share of output of the industry. All ratios are in percentages.

Table 1 also compares the IT ratios in the 1970s with those in the 1980s, for each country, and suggests that the ratio increased very rapidly during this period in all five countries. For all five countries, the IT ratios in the 1980s were more than two times greater than those in the 1970s.

The average IT ratio between 1970 and 1990 was higher in the United States, Canada, and Japan than in France and the United Kingdom. Except for Japan, the IT ratio was the highest in the United States.

The upper-right portion of Table 2 presents industry cross-country correlations of labor productivity growth rates. For example, the correlation coefficient in the Canada column and the U.S. row shows correlations between the labor productivity growth rates of a common industry in the United States and Canada. Except for correlations with Japan, the industry cross-country correlations among the four countries are greater than 0.5 and are also statistically significant at the one percent level. However, correlation coefficients between Japan and the other four countries are low and are not statistically significant.[14]

[Table 2] Industry Cross-Country Correlations: Ratio of IT Investment to Output and Labor Productivity Growth Rate

	United States	Canada	Japan	France	United Kingdom	
United States		0.780 (0.000)	0.314 (0.155)	0.643 (0.000)	0.552 (0.003)	Labor productivity growth rate
Canada	0.969 (0.000)		0.300 (0.177)	0.640 (0.000)	0.528 (0.006)	
Japan	0.778 (0.000)	0.799 (0.000)		0.211 (0.359)	0.336 (0.124)	
France	0.968 (0.000)	0.998 (0.000)	0.790 (0.000)		0.549 (0.003)	
United Kingdom	0.916 (0.000)	0.954 (0.000)	0.854 (0.000)	0.944 (0.000)		
	Ratio of IT investment to output					

Notes: Industry cross-country correlation coefficients of IT investment per output are based on the average IT investment per output from 1970 to 1990 for 20 industries. Industry cross-country correlation coefficients of labor productivity growth rates IT are based on the average growth rates of labor productivity from 1970 to 1990 for 20 industries. Numbers in parentheses are *p*-values from two-tailed tests on a null hypothesis of independence.

[14] Similar patterns of low correlations between Japan and the other countries are also observed at the aggregate level such as GDP growth rates.

The lower-left portion of Table 2 reports industry cross-country correlation coefficients for IT investment-output ratios. All pairwise correlation coefficients are positive and significantly different from zero. The findings clearly show that the degree of computerization within an industry is very similar across all five countries. In contrast, labor productivity growth for a common industry is less likely to be correlated across any pair of countries. Therefore, Table 2 suggests that IT ratios are more similar for a common industry in different countries than labor productivity growth rates.

III. EMPIRICAL SPECIFICATION

Empirical specification used in this study is based on a Cobb-Douglas production function, which includes three inputs of labor, non-IT capital, and IT capital:

$$Y_{ijt} = A_{ijt} L_{jit}^{\alpha} KN_{ijt}^{\beta} KO_{ijt}^{\gamma} \tag{1}$$

where Y_{ijt} is the value-added output of industry i in country j at time period t, A is a technology index, L is labor input, KN is the non-IT capital stock, and KO is the IT capital stock.

Instead of estimating the output elasticity with respect to IT capital, I used an alternative approach that estimated the rate of return to IT investment. The output elasticity of IT capital (γ) can be re-parameterized into the rate of return to IT investment:

$$\gamma \frac{\Delta KO}{KO} = \left(\frac{\partial Y}{\partial KO}\right)\left(\frac{KO}{Y}\right)\left(\frac{\Delta KO}{KO}\right) = \rho \frac{\Delta KO}{Y} \tag{2}$$

where $\gamma = \left(\frac{\partial Y}{\partial KO}\right)\left(\frac{KO}{Y}\right)$ is the output elasticity with respect to IT capital, and $\rho = \frac{\partial Y}{\partial KO}$ is the rate of return to IT investment (or the marginal product of IT capital). ΔKO denotes the net IT investment that is equal to the gross IT investment minus the amount of depreciation.[15]

U.S. BEA depreciation rates are used for the two types IT assets (31 percent for OCM and 11 percent for CE). The average depreciation rate depends upon the composition of OCM and CE. Since the OECD IO tables do not provide capital stock, I capitalize the investment divided by the sum of the depreciation rate and the average growth rate of gross investment. Assuming the geometric depreciation scheme, I calculate the industry-specific depreciation rate for non-IT capital using the ISDB industry-specific average service life (OECD, 1998).

As shown in Table 1, IT investment-output ratios are much more heterogeneous across industries than over time periods.[16] When we assume a common output elasticity of IT capital, the returns to IT investment can be smaller in IT-intensive industries than in less-IT-intensive industries. If IT investment is related to technology adoption, it is not necessary to assume diminishing returns to IT investment. In fact, it is more reasonable to assume that each industry has a common return to IT investment when the industry has an industry-specific IT investment-output ratio. Hence, the output elasticity with respect to IT capital increases with the IT capital-output ratio. Constant elasticity also assumes the same technology across industry, country, or over time period, but the constant rate of return allows heterogeneity in technology.

After rewriting the production function in terms of growth rates, the labor productivity growth rate is expressed in terms of the growth rate of labor input, and non-IT and IT investment-output ratios as:

$$\Delta \ln\left(\frac{Y}{L}\right)_{ijt} = -(1-\alpha)\Delta \ln L_{ijt} + \phi\left(\frac{\Delta KN}{Y}\right)_{ijt}$$

[15] To avoid possible measurement errors in estimating the capital stock, I also estimate the model with the gross investment ratio. Results are not qualitatively different, but return estimates using the gross investment ratio make it difficult to calculate accurate benefit-cost ratios of IT investment. For example, Griliches and Lichtenberg (1984) and Hall and Mairesse (1995) use the gross R&D investment ratio and Gera, Gu, and Lee (1999) use the gross IT investment ratio to estimate returns to R&D and IT, respectively.

[16] This specification has been used in the R&D literature – such as Griliches and Lichtenberg (1986) and Hall and Mairesse (1995) – because of heterogeneous patterns of R&D intensity across industries. The specification is also found in the studies by De Long and Summers (1991) and Gera, Gu, and Lee (1999) that estimate the rate of return to equipment and IT investment, respectively.

$$+\left(\frac{\Delta KO}{Y}\right)_{ijt}+\xi_j+\psi_t+\varepsilon_{ijt} \qquad (3)$$

where $\Delta \ln\left(\frac{Y}{L}\right)$ is the growth rate of labor productivity, ΔKO is the net IT investment, and ρ is the rate of return to IT investment. ΔKN and ϕ are also similarly defined for non-IT investment. Since subperiods for some country are not five-year interval, all growth rates are annualized. $\Delta KO/Y$ is defined as an average ratio of beginning and end years for each subperiod. To avoid a possible endogeneity, I also use the beginning year IT ratio. However, results are qualitatively the same. Note that equation (3) does not impose the condition of constant returns to scale.

Equation (3) also allows heterogeneity in the growth rate of a technology index as $\Delta \ln A_{ijt}=\xi_j+\psi_t+\varepsilon_{ijt}$. $\Delta \ln A_{ijt}$ represents the growth rate of total factor productivity (TFP), ξ_j and ψ_t are country- and period-specific fixed effects in TFP growth, and ε_{ijt} is error terms.[17] In addition to period-specific variation of TFP growth rates, some studies point out the importance of cross-country differences in TFP growth rates. For example, Costello (1993) found that for major industrialized countries, a substantial portion of productivity growth is attributed to a country-specific factor that is common across industries within a country.

IV. EMPIRICAL RESULTS

IV.1 Main Results

Table 3 reports the regression results of equation (3) using panel data consisting of twenty industries, five countries, and four periods of five-year interval between 1970 and 1990. The sample has some missing observations that mostly appear to be in non-manufacturing industries in the 1970s. Although the maximum number of observations is 400 (5-country × 20-industry × 4-period), the sample size is 378 after omitting 22

[17] TFP growth rate is not necessarily to be the same as the rate of technical changes if there are scale economies and/or imperfect competition.

missing observations.[18]

[Table 3] Estimation Results: IT Investment and Labor Productivity Growth

	(1) Time FE	(2) Time and country FE	(3) Time, country, industry FE	(4) 2SLS	(5) Semi-reduced	(6) WLS	(7) Excl. Japan	(8) Gross investment ratio
Δ Log of labor	-0.578 [a] (0.059)	-0.547 [a] (0.063)	-0.517 [a] (0.083)	-0.364 [b] (0.179)		-0.625 [a] (0.053)	-0.550 [a] (0.068)	-0.542 [a] (0.063)
Non-IT investment per output	0.139 [a] (0.037)	0.119 [a] (0.039)	0.171[b] (0.073)	0.113 [a] (0.043)	0.116 [a] (0.041)	0.060[c] (0.036)	0.111[b] (0.045)	0.028[a] (0.009)
IT investment per output	0.381 [a] (0.067)	0.374 [a] (0.065)	0.186[b] (0.089)	0.395 [a] (0.084)	0.366 [a] (0.063)	0.304 [a] (0.064)	0.401[a] (0.076)	0.202 [a] (0.032)
Adjusted R^2	0.365	0.384	0.400	0.361	0.169	0.368	0.402	0.390
Sample size	378	378	378	378	378	378	310	378

Notes: The dependent variable is the growth rate of labor productivity. All columns include both country and time period fixed effects (FE), except for column (1). Dependent variable in column (5) is the growth rate of output minus the product of the sample average of labor share and the growth rate of labor input. Δ indicates the change in the variable. Numbers in parentheses are heteroskedastic-consistent standard errors of estimates.

[a]: Significant at the 1 percent level.

[b]: Significant at the 5 percent level.

[c]: Significant at the 10 percent level.

Columns (1)-(3) of Table 3 presents panel regression results of the effect of IT investment on labor productivity growth according to different sets of fixed effects (FE). With both time and country fixed effects in column (2), the coefficient estimate of IT investment per output is about 0.37 and is statistically significant. The positive sign of the coefficient implies that the ratio of IT investment to output is positively associated with labor productivity growth. The estimate also suggests that the rate of return to IT investment (or the marginal product of IT capital) is about 37 percent. The IT return estimate in column (2) is close to the findings from Gera, Gu, and Lee (1999) who estimated the rates of return

[18] Missing observations are located in the 1970s, mainly for non-manufacturing industries in Canada and Japan.

to IT investment (about 35-50 percent) using the industry-level data for Canada and the United States.[19]

TFP growth rates also can vary across industries after correcting for both the period and country fixed effects. In column (3) of Table 3, the inclusion of industry fixed effects in addition to time and country fixed effects substantially reduces the IT return coefficient. As shown in Table 2, IT investment ratios are highly industry-specific and thus the three-way fixed effects can consume most of the variation in the IT variable. In fact, this is severe in the subsample analysis in Table 4. If industry fixed effects are correlated with IT investment rates, the coefficient of IT can be biased without industry fixed effects. However, Hausman's specification test results show that the null hypothesis of industry random effect cannot be rejected (*p*-value=0.19). Furthermore, the industry random effects with time and country fixed effects estimate on IT return is about 0.35 that is also close to the return estimate in column (2). Thus, I will use the regression with time and country fixed effects as a benchmark specification.

As shown in equation (2), the contribution of IT investment to output growth $(\gamma \frac{\Delta KO}{KO})$ can be obtained by multiplying the estimate of the return to IT investment $(\hat{\rho} = 0.374)$ by the average ratio of IT investment to output $(\overline{\frac{\Delta KO}{Y}} = 0.0084)$. Using the IT return estimate in column (2), I find that IT investment contributed approximately 0.31 percent to labor productivity growth or output growth during the period 1970-1990. Since labor productivity grew about 1.84 percent annually in the sample period, the result suggests that IT investment accounts for approximately 15 percent of labor productivity growth. In a similar vein, IT investment also contributes about 20 percent to the output growth of 3.00 percent. The output contribution of IT investment indicated by this research is slightly lower than that found by Oliner and Sichel (2000), who measured the output contribution of IT capital in the U.S. from 1974 to 1990 using a growth accounting framework instead of estimating the

[19] Column (1) of Table 4 reports IT return estimate for the subsample of the U.S. and Canada, which is also similar to findings of Gera, Gu, and Lee (1999).

production function. Using a growth accounting framework for seven industrialized countries from 1980 to 1996, Schreyer (2000) found that the output contribution from IT investment from 1980 to 1990 varied from 0.32 percent in the U.S. to 0.14 percent in Japan.[20]

Labor input and non-IT investment in total contribute almost 1.07 percent to output growth. Therefore, the growth of the three inputs in total accounts for almost half of the output growth in the five OECD countries over the 1970-1990 period.

IV.2 Robustness Tests

In columns (4)-(8) of Table 3, I examine the robustness of the rate of return to IT investment. The panel estimates of IT return in columns (1)-(3) may have a possible simultaneity problem. To correct for a possible simultaneity bias, I employ the two-stage least squares (2SLS) using the lagged variables as instruments. The return estimate for IT investment in column (4) of Table 3 is not materially different from the IT return estimate in column (2). Hence, the results suggest that simultaneity is not a serious problem in estimating returns from IT investment.21 However, the coefficient estimate of labor input (α) using the 2SLS estimation changes significantly from the estimate in column (2). This implies that labor input growth is strongly correlated with the productivity shock in the error terms. In fact, the estimate of labor share (α) in column (4) is 0.64, which is very close to the average share of labor input in the sample (i.e., 0.65).

To correct for a possible bias from an underestimated labor share, I have used a semi-reduced form of production function that uses the dependent variable equal to the output growth rate, minus the product of

[20] For G7 countries, there are some recent studies on how IT investment affects output growth using a growth accounting framework (Schreyer, 2000; Pilat and Lee, 2001; Colecchia and Schreyer, 2002; Jalava and Pohjola, 2002; van Ark, 2002; Daveri, 2003). A problem in the growth accounting framework is that IT investment can affect output growth only by way of capital deepening, because the marginal product of IT capital is assumed to be equal to its rental cost.

[21] In a similar vein, De Long and Summers (1991) raised the issue of simultaneity with respect to the equipment investment-output ratio in the labor productivity growth equation, and compared a coefficient from the high productivity subsample with that from the total sample. If the coefficient in the high productivity sample is the same as that in the total sample, the IT investment per output variable may not be correlated with unobservable factors.

the sample average of labor share and the growth rate of labor input, $\Delta \ln Y_{ijt} - \hat{S}_L \Delta \ln L_{ijt}$, where $\hat{S}_L$ is the average labor share in the sample (Griliches and Mairesse, 1995; Hall and Mairesse, 1995).[22] The estimation results using the semi-reduced form in column (5) yields a very similar IT return compared to that in column (2). The results suggest that the underestimated coefficient of labor input is not likely to affect the estimates of IT returns.

Although the size of the non-manufacturing sector in terms of output is greater than that of the manufacturing sector, the sample is more disaggregated for the manufacturing sector than the non-manufacturing sector. To correct for the disproportionate sample size relative to the share of industry, I employ the weighted panel estimation method, using weights equal to the share of industry output within a country. In column (6), the weighted panel estimate of IT return is about 0.30 that is lower than the estimate in column (2), but is not significantly different from the benchmark estimate.

In column (7), I exclude Japan from the sample because of possible measurement errors in the IT investment data, which may be associated with the difference in industry classifications. Note that the IT ratio of Japan in Table 1 is significantly higher than those of any other countries. Despite excluding Japan from the sample, the return estimate for IT investment changes little.

Finally, I estimate IT return for all the models in Table 3, using gross IT investment ratio. Results on IT return are not qualitatively different. In fact, IT return estimates vary from 0.13 to 0.20 depending upon fixed-effects used in Table 3.

IV.3 Benefit-Cost Analysis

Throughout Table 3, I found that IT investment has a higher return than non-IT investment, and contributes significantly to both output and labor productivity growth, in spite of a small share of IT investment. However,

[22] Instead of using the average share of labor in the sample, I also use the labor share ($S_{L,ijt}$) without averaging the sample share; but the IT return estimate is about 0.32, which is also close to the estimate in column (2) of Table 3.

the findings do not indicate whether IT capital was efficiently used or not in the early period of IT adoption. To measure the cost-effectiveness of IT investment, I compare the benefit of IT investment with its cost. To measure the cost associated with IT capital, I construct the user cost of IT capital.[23]

The user cost of capital (W_{KO}) is defined as:

$$W_{KO} = \frac{P_{IO}(1-\zeta - uz)(\delta_{KO} + r - \dot{P}_{IO})}{1-u} \tag{4}$$

where P_{IO} is the IT investment price deflator, ζ is the rate of investment tax credit, u is the corporate income tax rate, δ_{KO} is the depreciation rate of IT capital, z is the present value of capital consumption allowances, r is the nominal interest rate, and $\dot{P}_{IO,t} = (P^e_{IO,t+1} - P_{IO,t})/P_{IO,t}$ is the expected capital gain or loss.[24]

We may expect that the user cost of IT capital is greater than that of non-IT capital because of a high rate of depreciation for IT capital (16.2 percent) as well as the capital loss (4.8 percent) associated with a rapid fall in the IT investment price. While a fall in IT investment prices reduced the user cost of IT capital, the rate of decline itself added to the cost of using this capital, because of the opportunity cost of waiting for cheaper IT capital.

Using the static profit maximization condition with respect to IT capital, I constructed the benefit-cost (BC) ratio as:

$$BC = \frac{P_Y \hat{\rho}}{W_{KO}} \tag{5}$$

where P_Y is the output price deflator, $\hat{\rho}$ is an estimate of the return to IT investment (or marginal product of IT capital) in equation (3), and $P_Y \hat{\rho}$

[23] Besides conventional productivity measures, Brynjolfsson and Hitt (1998) argue that the economic value of IT investment depends increasingly on product quality, timeliness, customization, convenience, variety, and other intangibles. Although they argue that cost saving is one of several reasons for IT investment, the assessment of these other benefits is beyond the scope of this study.

[24] Tax variables such as corporate income tax rates and investment tax credit rates were obtained from Jorgenson and Landau (1993) and Cummins, Hasset, and Hubbard (1996).

is the nominal value of benefits associated with IT investment. Since the BC ratio of IT investment is defined as the ratio of the value of marginal product of IT capital to the before-tax user cost of IT capital, a BC ratio that is greater than one, implies that the benefit from IT investment is greater than its cost.[25]

In spite of the high rate of return to IT investment reported in column (2) of Table 3, the BC ratio is about 0.61 after correcting for costs associated with the use of IT capital.[26] Such a value of BC ratio less than one implies that the user cost of IT investment exceeded its return during the sample period. The finding also suggests that IT investment was not efficiently used during the early period of IT adoption in the 1970s and 1980s. But, the results do not imply that all the firms used IT inefficiently. Some firms succeeded with IT, and others failed. On average, IT benefits were less than its costs.

The results in this paper are consistent with the finding of Berndt and Morrison (1995) that increases in the proportion of high-technology capital were negatively correlated with multifactor productivity growth for twenty U.S. manufacturing sectors. The finding is also consistent with the prediction of David (1990), suggesting that productivity gains from new technologies (e.g., dynamos and computers) can be delayed because the efficient use of new technologies takes time.

A few theoretical studies argue that the arrival of a new technology can cause an initial slowdown in productivity growth that is associated with the cost of developing complementary inputs (Helpman and Trajtenberg, 1998), or with a loss of experience with the old technology and inexperience with the new technology (Greenwood and Yorukoglu, 1996; Hornstein and Krusell, 1996).[27] These studies hypothesize that a rapid adoption of new technologies, including IT, could have resulted in the productivity slowdown since the 1970s. Kiley (2001) and Bessen (2002) show that adoption or adjustment costs associated with IT investment could have lowered U.S. productivity growth from the 1970s to the early

[25] To evaluate the cost-effectiveness of IT investment based on the BC ratio, the condition of the perfect capital market should be assumed.

[26] The estimate of the BC ratio is also highly significant (*t*-value = 5.02). Standard errors for BC ratios are calculated using the delta method.

[27] However, productivity drops associated with technology switching can occur only if experience with old technology is not (or only partially) transferable to new technology.

1980s.[28]

The inefficient use of IT capital in the 1970s and 1980s can give us an interesting insight into the productivity slowdown experienced by most OECD countries. In the previous section I showed that IT capital contributed about 0.31 percent to labor productivity or output growth for the period 1970-1990. The BC ratio of less than one suggests that IT capital could have a greater contribution to output growth if IT capital was efficiently used. To measure the labor productivity slowdown effect due to the inefficient use of IT, I calculate the potential productivity contribution from IT capital multiplying IT investment ratio by potential IT return assuming the BC ratio equal to one. Thus, the productivity slowdown effect due to inefficient use of IT is defined as the potential contribution (0.52 percent) minus the actual contribution (0.31 percent). Therefore, the inefficient use of IT capital could lower labor productivity growth rate by 0.21 percent.[29] This finding supports the hypothesis that the adoption of IT could contribute to the productivity slowdown which occurred in the 1970s and 1980s. However, the size of the slowdown effect associated with IT adoption is too small to explain the actual productivity slowdown which occurred in this period. As Sichel (1997) suggests this small slowdown effect is mainly due to the existence of a small share of IT capital.

IV.4 Results from Split Samples

In Table 4, I compare estimates of IT returns for various subsamples, grouped by country, industry, and time period. Columns (1)-(3) of Table 4 compare IT returns for three groups of countries according to the ratio of IT investment to output. The first group in Table 4, comprising the United States and Canada, has a higher IT investment ratio than that of France and the United Kingdom. However, I exclude Japan from the two groups to avoid possible measurement errors, and estimate the Japanese

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[28] Using plant-level data in the Columbian manufacturing sector, Huggett and Ospina (2001) show that total factor productivity growth initially falls after large purchases of new equipment.

[29] This productivity slowdown effect associated with the inefficient use of IT cannot be explained by the conventional growth accounting framework, in which IT return is assumed to be equal to the ex-ante user cost of IT capital relative to output price.

sample separately.

[Table 4] Estimation Results: Split Samples by Country, Industry, and Time Period

	Country			Industry		Time period	
	(1) United States and Canada	(2) Japan	(3) France and United Kingdom	(4) IT-intensive industries	(5) Less-IT-intensive industry	(6) 1970 -1980	(7) 1980 -1990
Δ Log of labor	-0.632 [a]	-0.510 [a]	-0.504 [a]	-0.670 [a]	-0.465 [a]	-0.488 [a]	-0.676 [a]
	(0.077)	(0.138)	(0.114)	(0.111)	(0.076)	(0.071)	(0.091)
Non-IT investment per output	0.025	0.152 [b]	0.206 [a]	0.114 [b]	0.038	0.132 [b]	0.088
	(0.054)	(0.065)	(0.068)	(0.049)	(0.078)	(0.055)	(0.058)
IT investment per output	0.380 [a]	0.251 [a]	0.456 [a]	0.364 [a]	-0.239	0.372 [a]	0.410 [a]
	(0.080)	(0.098)	(0.167)	(0.065)	(1.387)	(0.095)	(0.093)
Adjusted R^2	0.504	0.181	0.312	0.459	0.312	0.429	0.402
Sample size	156	68	154	196	182	178	200
Benefit-cost ratio of IT investment	0.563 [a]	0.643 [a]	0.665 [a]	0.604 [a]	-0.361	0.363 [a]	0.725 [a]
	(0.108)	(0.237)	(0.207)	(0.101)	(1.995)	(0.087)	(0.152)

Notes: The dependent variable is the growth rate of labor productivity. Numbers in parentheses are heteroskedastic-consistent standard errors of estimates. Δ indicates the change in the variable. Except for column (2), all columns include the period and country fixed effects. Column (2) includes only the period fixed effects. Standard errors for benefit-cost ratios of IT investment are calculated using the delta method.

[a]: Significant at the 1 percent level.

[b]: Significant at the 5 percent level.

[c]: Significant at the 10 percent level.

The IT return for the country subsample with a high IT ratio is slightly lower than that of the subsample with a low IT ratio. The IT return of Japan, with the highest IT ratio, is the lowest among the three groups. The results suggest that the marginal product of IT capital may decrease with the accumulation of IT capital. However, cross-country variation in IT returns is also associated with the asset composition of IT investment such as OCM and CE. For example, although the IT return is lower in Japan than in the sample of the United States and Canada, the BC ratio is higher in Japan than in the sample of the United States and Canada. In fact, Japan has the highest proportion of CE in total IT investment, and subsequently has the lowest user cost, due to low depreciation rates and smaller capital losses. Since I use only five developed countries with relatively high ratios of IT investment, it is unreasonable to expect a strong cross-country variation in IT returns.

Columns (4) and (5) of Table 4 compare IT returns for industry subsamples according to the ratio of IT investment to output. The IT return in the sample of IT-intensive industries is 0.36, which is close to the IT return in the whole sample. However, the estimate of the IT return is statistically insignificant in industries that are using IT less intensively. Using plant-level data in the U.S. manufacturing sector, Stolarick (1999) estimates the output elasticity of IT spending, industry by industry. In his study, positive elasticities are found in manufacturing industries more associated with consumer goods or finished products (e.g., furniture, publishing, industrial machinery, and electronics), while the probability of no positive relationship is greater for those manufacturing industries associated with raw materials (e.g., lumber, paper, petroleum, rubber and plastics, stone and clay, leather, and primary metals). As shown in Table 1, the publishing, industrial machinery, and electronics industries have relatively higher IT ratios than other manufacturing industries, so his finding is somewhat similar to the result indicated in this paper.

Furthermore, the results of columns (4) and (5) confirm that the assumption of constant returns to scale does not hold for IT capital. For example, the IT return in the IT-intensive industry is not necessarily lower than that in the less-IT intensive industry if the network effect of IT capital exists within an industry.

Columns (6) and (7) of Table 4 report interesting time-series patterns for IT returns. Despite a smaller increase in IT return from the 1970s to the 1980s, the BC ratio is almost two times greater in the 1980s than in the 1970s because of a lower user cost of IT capital (W_{KO}) in the 1980s. The user cost of IT capital has a strong decreasing trend mainly due to rapid declines in the IT investment price. The IT investment price has declined at an annual rate of approximately 5 percent, while all other components determining the user cost of IT capital, such as the depreciation rate, nominal interest rate, and tax-related variables, have changed little over the sample period. Therefore, the findings suggest that

IT capital was more efficiently used in the 1980s than in the 1970s.

However, we should be careful about relating the finding on the rising BC ratio to the argument of David (1990) that the efficient use of new technologies can take a considerable amount of time. From the 1970s to 1980s, the benefit of IT capital *given quality* changed little while the benefit *given dollar cost* rose significantly.[30] The findings cast doubt on the argument that the contribution of computers given quality could increase due to more efficient use or network effects. IT became more efficiently used only in terms of its cost-effectiveness.

In fact, there is a large literature showing a variation in IT impacts on productivity growth or IT returns over different time periods. For example, evidence for the IT impact on productivity in several U.S. industry-level studies varies depending upon the choice of sample periods. While the studies by Berndt and Morrison (1995) and Stiroh (1999) using the pre-1990 sample for U.S. industries fail to find a positive contribution of IT capital to productivity growth, the studies by McGuckin and Stiroh (2002) and Stiroh (2002) using data from the 1980s and 1990s, find a positive productivity contribution associated with IT capital. For example, using data from 55 industries over the period 1980-1996, McGuckin and Stiroh (2002) show that computers have a larger elasticity in the range 0.15-0.20, and appear more productive than other forms of capital.[31] Furthermore, Wolff (1999) uses data for 68 U.S. industries during three periods from 1958 to 1987 to estimate the effect of computerization on total factor productivity growth. He finds that computerization did not appear to exert positive effects on productivity growth using the whole sample period, but find a positive and significant coefficient for computerization using a sample restricted to the goods industries for the period 1977-1987. Along with these industry-level analyses, several firm- and plant-level studies, using data from the late 1980s and the 1990s (Lichtenberg, 1995; Brynjolfsson and Hitt, 1999, 2003; Stolarick, 1999) strongly support

[30] I thank an anonymous referee for suggesting me to clarify the interpretation of the rising BC ratio.

[31] McGuckin and Stiroh (2002) argue that using aggregate data may not be appropriate for analyzing the effects of IT on productivity growth. In their study, estimation results for IT capital elasticities in different types of production functions have huge variations according to the level of aggregation. In particular, elasticity estimates of IT capital using disaggregated data, such as sector- or industry-level data, are more stable than those using aggregate data.

excess returns from IT investment.

In a similar vein, IT return estimates in this study are smaller than those in a recent cross-country study by Dewan and Kraemer (2000). Using aggregate data for 17 OECD countries for the recent period of 1985-1995, they estimate the rate of return from the output elasticity with respect to IT capital, and their estimate for IT return is about 70 percent. Their estimate is similar to that of Brynjolfsson and Hitt (1999, 2003) who use firm-level data from the late 1980s to the early 1990s, but is larger than my estimate. This comparison suggests that a difference in IT return estimates can result from the choice of sample time period, rather than from the choice of country.

Furthermore, the findings in Table 4 give mixed results for diminishing returns to IT investment: IT return is not necessarily low in subsamples with higher IT output ratio. This suggests that IT investment may not be considered as a conventional input, but instead should be attributed to technology adoption.

V. CONCLUSION

In this paper I examine the relationship between IT investment and labor productivity growth using industry-level data for five OECD countries from 1970 to 1990. I find that the rate of return to IT investment is about 37 percent, and that IT investment is positively related to labor productivity growth.

The return to IT investment was lower than its user cost in the 1970-1990 period, which implies that IT investment on average was not cost-effective. This confirms the IT productivity paradox was an international phenomenon. From the 1970s to the 1980s, the user cost of IT capital rapidly declined, while the return to IT investment slightly increased.[32] These two findings support the hypothesis that the efficient use of new technologies can take a considerable amount of time. However, the rising BC ratio (measured by benefit per dollar cost) is mainly because computers with higher quality became available with the same or lower

[32] In this intertemporal aspect of IT investment, the firms' choice of IT investment in the 1970s can be rationalized if IT investment in the first period gives higher profitability of IT investment in the second period.

price. The findings also cast doubt that computers given quality became more productive.

Since the data is not available for the post-1990 period, I only compare the two early periods of IT adoption. If the hypothesis of delayed efficient use of new technologies holds, the higher return or even excess return might be observed in the mature period of post-1990 period. Analyzing U.S. industry- and firm-level data, Stiroh (2002) and Brynjolfsson and Hitt (2003) confirm the excess return to IT investment.

I also find both cross-country and cross-industry variations in IT returns and BC ratios. The rate of return to IT investment was lower in the IT-intensive country sample than in the less-IT-intensive country sample, but the BC ratios of IT investment were not proportional to the size of IT returns due to different costs between countries. Although I found a cross-country variation in IT returns, it could be worthwhile to investigate which factors are important determinants of IT returns between countries. In this sprit, Cette, Lopez, and Noual (2005) find Europe's lag in ICT diffusion compared to the U.S. is not due to cross-country differences in the price elasticity of IT demand, but is attributed to more structural cross-country differences. As suggested by Bresnahan and Greenstein (2001), different IT benefits among countries may depend on the availability of coinvention and on differences in spillover and network effects.

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