View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Clute Institute: Journals

Information Technology Investments And Aggregate Productivity

Paul Moon Sub Choi, Ewha Womans University, Republic of Korea
Hakyoul Choe, Korea Advanced Institute of Science and Technology, Republic of Korea

ABSTRACT

Earlier studies have shown positive and large impacts of information technology (IT) investments on aggregate products in the nascent stage. However, this causal inference may not be applicable in the adult regime with a diminishing marginal productivity. We conduct a 52 cross-country analysis on a 15 year data of IT capital stocks, rather than flows as used in the literature. Controlling for country and time effects, the empirical implications of our study are as follows: First, the IT investment intensity positively affects aggregate productivity controlling for labor, assets, and financial markets. Second, the relative contribution has decreased as the law of diminishing returns predicts. Lastly, software and services have gained more capital allocation on relative terms in exchange for less on hardware. This finding contrasts with the existing argument that the hardware-software mix is time-constant due to substitution.

Keywords: Management Information System; Information Technology Investments; Aggregate Productivity

1. INTRODUCTION

The inconclusive association between information technology (IT) investments and productivity has attracted much debate in the last two decades. According to a World Bank (2009), IT investments account for 7.5 percent of the annual gross domestic products (GDP) and 40 percent of the total capital expenditure of the U.S. Yet, direct and visible impacts of IT investments on productivity have persistently been questioned. According to an Slye et al (2010) report, the U.S. federal government allocated $86 billion to IT purchases and services in the fiscal year of 2010 and possible deadweight losses of unproductive investments do moot a serious performance evaluation.

Loveman (1988) conducted an econometric analysis, for the first time in the literature, on a sample of 60 firms and argues that the IT investments yield insignificant productivity increases. On the contrary, Brynjolfsson (1993) and Brynjolfsson and Hitt (2003) show there are positive causalities based on their firm-level empirical studies. Their findings are also supported by Lee and Barua (1999) who use the same MPIT database as Loveman (1988) used. Autor et al. (2003) describe how introduction of computers reduced manual and routine tasks while increased demand for non-stylized expertise. This work-site pattern has been also documented in the U.K. and former West Germany, further confirming the effects of computers on the level of labor skills and demand for labor.

Two separate groups of studies have been developed in the literature: (1) What process the IT investments undergo while enhancing productivity; and (2) cross-industry and cross-country comparisons of the productivity impacts of IT investments. According to the 2009 annual report of Ministry of Internal Affairs and Communications of Japan, the productivity gap between the U.S. and Japan is explained by the cross-border difference in IT capital stocks. Also, in the cross-section of developed countries, the productivity increase is higher the higher the IT capital stocks.

Earlier studies have shown positive and large impacts of information technology (IT) investments on aggregate products in the nascent stage. However, this causal inference may not be applicable in the adult regime with a diminishing marginal productivity. We conduct a fifty two cross-country analysis on a fifteen year (1995—2009) data of IT capital stocks and real variables rather than flows and nominal, respectively, as used in the literature. Controlling for country and time effects, the empirical implications of our study are as follows: First, the IT investment intensity positively affects aggregate productivity controlling for labor, assets, and financial markets.

Copyright by author(s); CC-BY

Second, the relative contribution has decreased as the law of diminishing returns predicts. Lastly, software and services have gained more capital allocation on relative terms in exchange for less on hardware. This finding contrasts with the existing argument that the hardware-software mix is time-constant due to substitution.

The remainder of this paper is as follows: We compare an array of research analytics and empirics in the existing literature in Section 2. Section 3 proposes our model. We describe our data and conduct econometric analyses in Sections 4 and 5, respectively. Section 6 concludes.

2. LITERATURE REVIEW

2.1. Managerial Information Systems and Aggregate Productivity

Econometric methodologies are widely used in various areas within managerial information systems: Behavioral analysis, and country, industry and firm-level effects of IT. The IT productivity paradox in literature during the 1990's procreated a slew of research agenda on productivity effects of IT investments. The most stylized objective function during then augments an IT investment variable to the conventional Cobb-Douglas bivariate production function with labor and capital inputs (Cobb and Douglas, 1928). Regressions are conducted on a log-transformation of the trivariate production function:

$$Y = AL^{\alpha}K^{\beta}(IT)^{\gamma}$$

Park et al. (2007) show that the productivity of an IT developing country improves as the cumulative IT knowhow embedded in the imports from IT developed exporters is absorbed. Kudyba and Diwan (2002), based on their 500 firm-level database, conclude that IT investments increasingly enhances firm-level productivity over time. Mittal and Nault (2009) analyzed 19 industries and find that (1) IT investments yield positive externalities on labor and capital productivities in non-IT divisions within the sample companies; and (2) those marginal productivities vary in the cross-section of industry-level IT-intensity (Table 1).

Table 1
Recent references on productivity effects of IT investments.

	Park et al. (2007)	Kudyba and Diwan (2002)	Mittal and Nault (2009)
Research question	Do IT investments improve productivity?	Do IT investments improve productivity?	Do IT investments indirectly affect productivity?
Analysis level	Country level (IT-developed vs. developing)	Firm level Partly, industry level	Industry level (High IT-intensive industry indicated)
Method	Unit root test	OLS, Chow test	GLS, Autocorrelation (AR(1), heteroskedastcity
Model	Cobb-Douglas function $= A \;^{N} K \; L^{1}$ Log-transformation of TFP: $TFP \quad \frac{}{K \; L^{1}}$ $\log \; TFP \;=\; _{0} + \; F(S^{d}, S^{f}, z)$	Cobb-Douglas function $\ln Q_{ij} = \; 1\ln IL_{ij} + \; 2\ln Li_{j} + \; 3\ln IK_{ij} + \; 4\ln K_{ij}$	Cobb-Douglas function $= AK \quad L \; Z$ Log-transformation: $y = a + ak + \; l + \; z +$
Data	39 countries (4 groups) Period: 1992—2000	500 firms Period: 1994—1997	912firm-years (19 firms × 48 years) 19 SIC codes (industries) Period: 1953—2000
Independent var.	S^{d}: Domestic IT investments S^{f}: Foreign (exporters) IT investments Z: Controls (PC's, networks etc.)	L: labor K: capital IL: IT labor IK: IT capital	A: factor neutral technological change (embedded indirect effects of IT) K: quantity of non-IT capibal L: quantity of labor Z: quantity of IT capital
Dependent var.	TFP (Total factor productivity)	Q: Sales revenue Q: value added	γ: quantity of physical output
Findings	TFP (Total factor productivity)	IT capital proves productivity($\frac{dQ}{dIK} > 0$)	Difference between IT-intensive vs. non-IT-intensive industries.
	Cointegration test	Contribution IT capital to productivity (β) increases over time	Benefits from IT investments are indirect rather than direct.

2.2. Structure of Managerial Information Systems

Another strand of literature is on analyzing the long-run trends of IT investments. It has been generally accepted that the hardware-software mix is initially heavier on hardware in IT investments while the software proportion bulges with an “S”-curve. The reasoning is as follows: (1) The price of an iso-functional hardware decreases over time, according to Moore’s law (Larus 2009); while (2) hardware and software are assumed to be perfect substitutes like the labor and capital inputs in a typical production function; and (3) highly non-stylized tasks increasingly require software expenditure.

However, Gurbaxani and Mendelson (1992) conducted regressions and show that the hardware-software mix is statistically constant. They determine the value of an information service product (W) with respect to the quantities of hardware (s) and software (h) as follows:

$$W(s_t, h_t) = A s_t^{\alpha} h_t^{\beta}.$$

They defined the hardware-software budget ratio as

$$LRATIO_t \equiv log(H_t/S_t),$$

then regressed the ratio onto the gross domestic products (GDP) to find that the ratio remained statistically time-invariant. Specifically, (1) hardware investments outpaced those of software during economic booms; and (2) reversed during busts.

2.3. Econometric Analyses of IT Events and Investment Outcomes

Econometric analytics have been pervasively adopted in quantitative research of managerial information systems and, yet, the usage has been paid more caution and prudence. For example, ordinary (OLS) and/or generalized least squares (GLS) methods had been applied without autocorrelation tests on time series datasets. Acknowledging such procedural misconduct, Park et al. (2007) and Mittal and Nault (2009) conducted autocorrelation and cointegration tests before confirming model fitness. Also, Chow’s (1960) test has been used to verify statistically significant regime-shifts as the IT industry experienced major innovations: Incoming of PC-era (mid-1980’s), introduction of Windows OS (early 1990’s), mass-distribution of DBMS (1990’s), infiltration of the Internet (late 1990’s), and expansion of the high-speed Internet (early 2000’s).Econometric analytics of structural breaks are also employed in evaluating productivity impacts upon IT capital accumulation (Kudyba and Diwa, 2002).

Table 2
Major references, sample periods, and data sources.

Reference	Sample description	Sources
Brynjolfsson and Hitt (2002)	1987—1994	CII: capital stock of computers
	Balanced panel, 527 large US firms	Compustat II: public financial information
		BLS: computer rental prices for the capital factors
		IDG: computer HW and related expenses
Hitt et al. (2002)	1986—1998	SAP: ERP adoption using license agreement
	5603 firms	Compustat II: productivity, market value, firm performance
		CII: information technology use, firm level IT stocks, HW, capacity of
Hitt and Brynjolfsson (1996)	1988—1992	IDG: IT spending by large firms
	Panel, 370 largest firms	Compustat II: output, capital, labor, etc.
Kudyba and Diwan (2002)	1994—1997	Information Week:
		CII: IS budget, IT employees, revenue, etc.
		SEC: corporate disclosure reports, non-IT capital, costs of goods sold,
		Computer World: IT salary
Park et al. (2007)	1992—2000	OECD: capital shares, GDP, physical capital stock, labor
	39 countries	PWT 6.1: real GDP
		Worldbank: shares of ICT expenditures in GDP
		NBER-United Nations Trade: ISIC bilateral import flow data
Mittal and Nault (2009)	31 years	BLU: MFP data set of two-digit SIC, industry output, cost of energy,
	Manufacturing sector	materials, and service purchased, price deflators, IT capital stocks,
Gurbaxani and Mendelson (1992)	1976—1984 yearly data	IDC: IS spending in US (Computer Industry Report), IS budget
Mendelson (1987)	98 systems from 17 vendors	Computerworld: average cost per MIPS
Anderson (2003)	1999—2002	SEC: stock prices, Y2K spending, R&D spending, earnings.
	Fortune 1000 firms	

3. MODELS

3.1. Analytics

3.1.1. Investments in Managerial Information System and Productivity

A Cobb-Douglas production function is conveniently assumed to gauge the productivity effect of an IT investment: An IT variable is augmented to the conventional labor and capital inputs. A log-transformation is used for linear regressions:

$$\log Y_t = \mathrm{c} + \alpha \log L_t + \beta \log K_t + \gamma \log IT_t + \varepsilon_t,$$

where γ measures the percentage increase in productivity per every percentage additional IT capital expenditure. An IT investment may affect productivity directly; indirectly by labor and or capital productivity improvements via agents' learning experiences. As these propagations are time-varying, each variable is time-indexed. The IT-intensity has implications for the extent of IT growth: The marginal productivity of a later period may be weakened compared to that of an earlier stage due to the law of diminishing marginal return. The vintage classification of IT investments has to be considered accordingly.

3.1.2. Structure of Investments in Managerial Information Systems

The IT capital expenditures are on hardware, software, and services. In the literature, services branched out of software as corporate demand for services auxiliary to IT software diversified and complicated: Entrepreneurial resource planning (ERP), data warehouse, data mining, consumer relations management (CRM), supply chain management (SCM) etc. In addition, un-interrupted and un-resting utilization and maintenance features of software are unlike those of services.

Copyright by author(s); CC-BY

The dynamics of IT investments are determined by intertemporal and income factors: First, the natural increase of IT capital expenditure over time is due to the additional purchases of services and software to utilize, operate, and maintain the existing hardware assets. Also, short replacement periods of IT equipment and software prescribe timely retire of outdated IT purchases in exchange for newer ones. Second, firm and sovereign-level demand for capital goods increase when upon increments in sales revenue and GDP, respectively, and so do IT investments. In the following subsection, we embed hardware, software and services in the econometric model to examine their time and income-dependent effects on productivity.

3.2. Panel Data Econometrics

Our IT productivity data bears the desirable features of a typical panel dataset: Idiosyncratic heterogeneity, variability, and stationary measurement of changes (Baltagi, 2008).

3.2.1. Idiosyncratic Heterogeneity

IT investments vary country to country. Since IT capital goods are an infrastructure auxiliary to production, there are a number of concurrent factors that have to be aware of: Short or mid-run time-invariant Illiteracy, education level etc. In addition, politico-economic regime and structure, degree of market regulation, governance, colonial historical background, communication and network infrastructure, cultural aspects can affect infiltration and utilization of information systems that expand societal openness and mutual exchange. For example, a market-oriented country with a stringent transparency expectation will be relatively quick in adopting large scale information systems, and the ex post efficiency of capitalizing the investments will be relatively high thereby significantly improving the aggregate productivity. Also, a former colony or highly foreign-dependent country is highly likely to adopt the IT infrastructure from its previous political colonizer or dominant trading counterpart on contagion.

Deaton (1995) claims when statistically testing a hypothesis that a small farm is more productive than a lager lot, unobserved heterogeneity such as land quality has to be controlled for. Likewise, the timing and effect of IT investments can depend on the existing country-level conditions.

For example, Hong Kong, Singapore, and Korea took relatively short periods to reach high infiltration of internet and mobile telecommunication infiltration due to their relative narrow land masses and high population densities. On the contrary, this is unlikely the case in the U.S. and Canada where the clientele is geographically dispersed and, thus, the set-up costs and time to break-even can be high. According to an OECD (2008) report, 14% of South Korean population and an average OECD member had access to the high speed Internet by 2001 whereas an average OECD member country achieved it by 2006.

3.2.2 More Informative Data, More Variability

A cross-sectional data typically has a high variability. Data variability stems from variations due to group sizes, group characteristics, and inter-group interactions, where the size effect is the largest (Baltagi, 2008). In an IT investment effect analysis, GDPs, populations and capital sizes can contribute to data variability. For example, an IT capital investment equivalent to a change that amounts to 1% of labor force in Mainland China can result in a higher productivity change than that of the whole population in Hong Kong.

3.2.3. Identity and Measure Effects in Pure Cross-Section or Pure Time-Series Data

A stationary panel data may suffer an information loss in the cross-section. A panel of cross-sectional data “strings” can provide an array of factors that affect a time series of interest. For example, in order to explain the annual unemployment ratio of 10% that remained intact on a year-on-year basis one must designate the key explanatory and control variables for every cross-section of contemporaneous observations or estimates. Likewise, two separate observations of IT hardware investments in 1995 and 2000 that appear to be of the same numerical values are not statistically different unless other variables have been accounted for. Panel data analysis can overcome this impasse.

Known limitations of panel data analysis are the errors associated with model designing, data collection, and estimation. Research coverage, non-response, interview period, and recall failure may lead to data collection errors, while imprecise questionnaire, erroneous record, purposefully distorted responses to estimation errors. This research sources on macroeconomic data from literature-proven, systematic, and consistently maintained databases from IDC, World Bank, PWT etc., and we believe our panel econometric analytics are less prone to the aforementioned errors.

4. THEORY AND HYPOTHESES

4.1. Investments in Information Systems and Aggregate Productivity

Likewise, in labor and capital, an increase in IT investments brings a positive GDP growth. An IT utilization can forward some of the labor inputs from the existing manual and repetitive tasks to another higher value-added business lines. In South Korea, a daily average 100 issuances of export and import-related government permits are requested and granted on an electronic basis. This reportedly resulted in reduced in-person visits, paper documents, manual errors which collectively saved 6 trillion won-worth costs in 2009 according to Institute for International Trade (Choi 2010) in South Korea. An increase in IT investments can shore up aggregate revenues by efficiently re-allocating labor and capital into more productive usages.

H1: There is a positive association between an IT investment and aggregate productivity.

Countries vary in terms of the existing IT infrastructure, for example the infiltration ratios of high speed internet, PCs, wireless communication devices etc. An identical amount of IT investments will therefore yield differing productivity improvements in the cross-section of countries. Purchases of the same 100 units of PCs in both U.S. and Indian branches will imply significantly different productivity effects.

H2: Aggregate productivity effects of aggregate investments in information systems are not identical in the cross-section of countries.

When analyzing the productivity consequences of IT investments, one must consider both diminishing returns and network effects. An IT investment effect materializes upon building complementary assets, rather than directly, and when the number of users exceeds a certain threshold. The Internet which began as Advanced Research Projects Agency Network (ARPANET) in 1969 took 30 years to be widely adopted by the mass, and wireless communication with a phenomenal leap in the number of subscribers upon light-weighing and affordable mobile devices became available after mid-1990's.

These incremental momentums of productivity past thresholds of users or assets of IT investments can be considered as learning and network effects. An IT installation is a capital good that depreciates and whose returns diminish over time. During the 15 year sample period (1995—2009), we may observe both network and diminishing market product effects. Thus, we need control for the IT investment vintage of sample countries: Saturated IT installations in developed economies versus nascent IT investments in emerging or developing sovereignties.

H3: The productivity effects of IT system investments diminish over time.

4.2. Structure of Investments In Information Systems

Gurbaxani and Mendelson (1992) report that even as IT-driven services sophisticate and specialize hardware-software budget allocation ratio should remain constant due to substitution of the existing hardware to cost-saving and up-performing replacements, unlike the conventional wisdom in the literature that supporting software expenditures increase. We test their finding, which is based on data from 1980's, by using a 15 year (1995—2009) and 52 cross-country database.

H4a: Investment coefficients of hardware and software will remain intact even as aggregate products increase.

Maintenance and replacement costs of both hardware and software increase over time, and so do IT investments. Development and operation costs of software can be assumed to grow like an "S"-curve as the information system investments gain. The marginal cost of software diminishes as IT investments mature as technological innovations and steeping competition gravitate prices. When the investment cycle fully peaks there are replacement orders on information system goods and services. Unlike the software that faces wage hikes and employment rigidity, the hardware will continue save costs over time: The latter substitutes the former in terms of budget allocation.

H4b: As aggregate products increase, investments on hardware gain more than on software.

H4c: Investment coefficients of hardware and software will remain over time.

IT services include installation, customization, and maintenance of hardware equipment and software programs. Accordingly, demand for IT services move in tandem with those for IT investments in hardware and software. There is an upward climb in IT service expenditures over time as new and replacement investments in hardware and software accumulate.

H5a: There is a positive association between IT service investments and IT expenditures in hardware and software.

H5b: IT service investments rise over aggregate products.

H5c: IT service *investments rise over time.*

5. DATA

5.1. Databases

Analyzing country-level factor productivity effects requires time series data of GDP, labor, capital and IT investments. We sourced them from a variety of databases from World Bank, International Monetary Fund (IMF), Organization for Economic Co-operation and Development (OECD), and Penn World Trade (PWT). The OECD database only compiles those of member countries'. The World Bank database compiles nominal GDPs. The PWT database (Version 6.3, August 2009) keeps the records of all sovereign economies from 1950 until 2007 and reports real GDP estimates. We further extrapolated year 2008 real GDP estimates by extracting real GDP growth rates from GDP growth rates and deflators from the World Bank database. Factor composition ratios are estimated from total labor forces, employment ratios, and capital-GDP ratios available from the World Bank. Country-level IT investment-related variables since 2003 are also available from the World Bank. The IDC database is a compilation of firm-level survey responses and research findings pertaining to managerial information system investments in 52 countries with a sample period of 1995 through 2009. The database has three investment categories: Hardware, software, and services. We converted the nominal estimates from the IDC database to real variables by using the GDP deflators available from the World Bank.

5.2. Data Conversion and Missing Data Treatment

A variety of data sources imply unstandardized data frequencies, formats etc. We thus compiled the collected data per "stack-by-cross-section" to be readily analyzable on a statistical program. Accordingly, we constructed a balanced data by eliminating the United Arab Emirates (U.A.E.), whose data is available since 2001, from the 53 country-IDC database. As a result, we arrived at a 52 cross-country database over 15 years as the finalized sample.

5.3. Conversion from Capital Flows to Capital Stocks

A majority of research in this area used IT capital flows, not stocks, due to difficulties in identifying and acquiring cumulative capital data sources and estimating the initial capital investments (Lee and Baura, 1997). In this study, we estimate the cumulative capital (K_{it}) in country i by year t as follows:

$$K_{it} = INV_{it} + (1 - r_t) \cdot K_{i,t-1},$$

where the existing value of capital $(K_{i,t-1})$ is depreciated at r_t and re-enforced by the fresh capital expenditure (INV_{it}). We assumed a 5% depreciation rate following Park et al. (2007).

In order to estimate the initial capital stocks in 1995, the first year in our sample period, we used the real GDP estimates from the PWT database and investments-GDP ratio from the World Bank database to arrive at the real investment amounts 1981 through 1995. We applied a 5% annual depreciation rate for the country-level capital stocks whereas 20% for the IT capital stocks due to the accelerated dilapidation nature of IT hardware equipment and software programs (Park et al., 2007). Since data compilation of IT capital stocks was neither consistent nor sufficient, we assumed the initial country-level capital stocks as four times the IT investments made in 1995.

Table 3
Description and sources of key variables.

Variable	Unit	Description	Definition	Remark
Gdp	$\times \$10^3$	Gross domestic products	PWT 8.0	
Inv	$\times \$10^3$	Aggregate investments	Annual total capital investments	GDP × capital ratio
Sum	$\times \$10^6$	Aggregate IT investments in flow	Sum of all IT investment sub-categories	IDC
Hw	$\times \$10^6$	Hardware investmetns	Computing and network equipment	IDC
Sw	$\times \$10^6$	Software purchases	Software packages, customization etc.	IDC
Svc	$\times \$10^6$	Services charges	Maintenance, operation, development etc.	IDC
K	$\times \$10^3$	Cumulative capital	PWT 8.0	
K2	$\times \$10^3$	Non-IT cumulative capital		K_t - ITS_t
Its	$\times \$10^6$	Aggregate IT capital		
Lab	1,000's	Labor	PWT 8.0	
Grp	Binary	1 for IT-developed country, 0 o.w.	1 for over 6% of IT investments-GDP ratio	
Time	Categorical	Year categorical variable	1995—2009	

Table 4
Representative statistics of key variables.

Variable	Description	Mean	Median	Maximum	Minimum	Std. Dev.
Gdp	Gross dosmestic products ($\times 10^6$)	927,489	287,809	13,149,344	33,378	1,823,060
Inv	Aggregate investments ($\times 10^6$)	224,871	68,426	4,521,596	2,959	473,551
Sum	Aggregate IT investments in flow	20,969	4,587	511,793	21	59,282
Hw	Hardware investments	9,225	2,441	192,291	16	23,471
Sw	Software purchases	3,846	614	134,872	3	13,559
Svc	Service charges	7,898	1,274	211,346	2	23,326
K	Cumulative capital ($\times 10^6$)	2,932,010	886,178	40,347,576	107,889	5,796,048
K2	Non-IT cumulative capital ($\times 10^6$)	2,846,253	857,112	38,350,057	106,876	5,577,348
Its	Aggregate IT capital	85,793	16,977	2,149,170	279	246,736
Lab	Labor inputs ($\times 10^6$)	41.0	9.6	777.4	0.9	114.2
StockReturn	Return of the representative stock market return (%)	-0.28	-0.85	494.00	-2.00	15.66
StockMarket	Ratio of the stock market capitalization over GDP (%)	65.92	46.71	606.00	0.02	66.91

5.4. Group and Time Dummies

In order to control for the growing versus mature status in terms of IT investments, we define the threshold as 5% annual IT investments out of the GDP: The IT-mature countries are assigned with ones as a dummy indicator. The trend effect is considered by applying year dummies 1996 through 2008.

6. RESULTS

6.1. Productivity Effects of IT Investments

We identified 4 models that explain the productivity effects of IT investments: Capital expenditure (LogInv) and concurrent yearly IT investments in flow (LogSum) affect GDPs (LogGdp) in Model 1. IT investments in stock

(LogIts) are used in Model 2 instead of flow (LogSum) as in Model 1 to seek a possibly different inference. We distinguish the non-IT capital stock (LogK2) from the IT capital stock (LogIts) in Model 3. Lastly, we estimate the coefficients of factors with autoregression in Model 4.

$$logGdp_t = \text{Intercept} + \alpha LogLab_t + \beta LogInv_t + \gamma LogSum_t + \varepsilon_t.$$

$$logGdp_t = \text{Intercept} + \alpha LogLab_t + \beta LogK_t + \gamma LogIts_t + \varepsilon_t.$$

$$logGdp_t = \text{Intercept} + \alpha LogLab_t + \beta LogK2_t + \gamma LogIts_t + \varepsilon_t.$$

$$DlogGdp_t = \text{Intercept} + \alpha DLogLab_t + \beta DLogK2_t + \gamma DLogIts_t + \varepsilon_t.$$

Table 5
Productivity effects of IT investments.
For the pooled OLS regression results herein, the dependent variables are LogGdp for Models 1, 2, and 3, and DLogGdp for Model 4. The numerical values below coefficient estimtes are their t-statistics. ***, **, and * stand for statistical significance based on two-sided tests at the 1%, 5%, and 10% level, respectively.

	Model 1	Model 2	Model 3	Model 4
Intercept	4.378 ***	2.956 ***	3.079 ***	0.003
	32.582	15.889	16.702	0.368
LogLab	0.236 ***	0.245 ***	0.249 ***	
	20.757	19.356	19.642	
DLogLab				0.388 ***
				4.678
LogInv	0.588 ***			
	29.410			
LogK		0.565 ***		
		26.546		
LogK2			0.546 ***	
			26.144	
DLogK2				0.369 ***
				4.748
LogSum	0.142 ***			
	13.705			
LogIts		0.145 ***	0.159 ***	
		13.582	15.411	
DLogIts				0.092 ***
				3.544
No. of Obs.	780	780	780	780
R^2	0.971	0.967	0.967	0.111

In Table 5, all coefficient estimates are shown to be statistically and economically significant. In Models 1, 2, and 3, the coefficient estimates of labor factor (LogLab) are in the range of 0.236 and 0.249: A 1 percent increase in labor input gives rise to a GDP growth of roughly 20 basis points. The productivity effect of capital factor has a higher magnitude as the range of coefficient estimates are 0.369 and 0.588: A 1 percent increase in capital expenditure yields a GDP growth of up to circa 60 basis points. In Models 1 through 4, although all models show high fitness with R^2's in the range of 11.1% and 97.1%, we choose Model 3 as our inference toolkit since it employs the capital input in stock while separating the non-IT portion from the IT capital stock.

Table 6
Productivity effects of IT capital stocks.

The dependent variable is LogGdp. Fixed effects follow the feasesible geralized least squares (FGLS) method. The numerical values below coefficient estimtes are their t-statistics. ***, **, and * stand for statistical significance based on two-sided tests at the 1%, 5%, and 10% level, respectively.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Intercept	4.765 ***	6.496 ***	4.542 ***	4.574 ***	4.568 ***	4.070 ***	4.088 ***	4.105 ***
	14.686	14.946	13.044	13.099	13.097	11.282	11.370	11.378
LogLab	0.196 ***	0.089	0.270 ***	0.263 ***	0.267 ***	0.271 ***	0.268 ***	0.269 ***
	3.509	1.540	4.517	4.404	4.476	9.172	9.173	9.137
LogK2	0.474 ***	0.396 ***	0.519 ***	0.516 ***	0.517 ***	0.550 ***	0.547 ***	0.547 ***
	14.153	11.180	14.407	14.283	14.328	16.503	16.443	16.405
LogIts	0.104 ***	0.058 **	0.050 ***	0.053 ***	0.052 ***	0.053 ***	0.057 ***	0.055 ***
	8.394	4.061	3.669	3.921	3.780	3.850	4.152	3.994
StockReturn			0.000		0.000	0.000		0.000
			-1.623		-1.608	-1.598		-1.581
StockMarket				-25.427	-24.976		-31.686	-31.194
				-1.202	-1.182		-1.532	-1.510
Trend		0.010 ***				-0.001	-0.001	-0.001
		5.828				-0.478	-0.552	-0.460
Fixed Effect	Yes	Yes	Yes	Yes	Yes			
Random Effect						Yes	Yes	Yes
No. of Obs.	780	780	630	630	630	630	630	630
R^2	0.995	0.995	0.996	0.996	0.996	0.956	0.836	0.835

Panel regression results are reported in Table 6. All model specifications, Models 1 through 5, show positive productivity effects of labor (LogLab), capital (LogK2) and IT investment (LogIts) factors. The fixed-effect model (Model 3) shows a lower IT investment intensity than the pooled regression model (Model 1) with coefficient estimates of 0.050 and 0.104, respectively.

We augment the IT-developed countries group dummy (ItDev) and trend term (Time) into Model 3 to settle with the finalize model identification:

$$logGdp_t = \text{Intercept} + \alpha LogLab_t + \beta LogK2_t + \gamma LogIts_t + \delta Time + \varepsilon_t.$$

Copyright by author(s); CC-BY

Table 7
Fixed-effect panel regressions of productivity effects.

The dependent variable is LogGdp. Fixed effects follow the feasesible geralized least squares (FGLS) method. The numerical values below coefficient estimtes are their t-statistics. ***, **, and * stand for statistical significance based on two-sided tests at the 1%, 5%, and 10% level, respectively. The regresssion model is as follows: $LogGdp_t$ = Intercept + α $LogLab_t$ + β $LogK2_t$ + γ $LogIts_t$ + δ Time + ε_t.

Variable	Estimate
Intercept	6.496 ***
	14.946
LogLab	0.089
	1.540
LogK2	0.396 ***
	11.180
LogIts	0.058 ***
	4.061
Time	0.010 ***
	5.828
Durbin-Watson	0.373
No. of Obs.	780
R^2	0.995

In Table 7, we report fixed-effect panel regressions of the productivity effects of IT investments with year and country effects of categorical variables. The coefficient estimates of the year categorical variable (Time) show decreasing GDP growth rates over time due to the law of diminishing returns of labor, capital and IT investment factors alike. The regression results reported in Table 7 appears to be robust to autocorrelation as the Durbin and Watson's (1950, 1951) statistic is insignificant. Overall, the results shown in Tables 6 and 7 are in favor of hypotheses *H1*, *H2*, and *H3*.

6.2. Structure of IT Investments

In order to identify factors that affect investments in IT hardware, software and services, Gurbaxani and Mendelson's (1992) model that identifies GDP as a causal factor turned out statistically insignificant in our undocumented empirical analysis using the data described in Section 5. Instead, we extend from our specification (Model 3, Table 5) presented in Subsection 6.1.

In Panel A of Table 8, we verify seek determinants of IT hardware investments with (Models 2, 4) and without (Models 1, 3) the trend term with pooled (Models 1 and 2), fixed (Model 3) and random effect (Model 4) model specifications. The GDP (LogGdp) is shown to be increasing budget allocations in IT hardware investments with statistically and economically meaningful coefficient estimates in the range of 0.977 and 1.688: A 1 percent growth in aggregate income can roughly upsize capital expenditures in IT hardware equipment by more than 1 percent. The time effect (Trend) appears to shown intuitively positive signs.

$$logHw_t = \text{Intercept} + Trend + \alpha LogGdp_t + \varepsilon_t.$$

$$logHw_t = \text{Intercept} + \alpha LogGdp_t + \varepsilon_t.$$

$$logSw_t = \text{Intercept} + Trend + \alpha LogGdp_t + \varepsilon_t.$$

Copyright by author(s); CC-BY

$$logSw_t = \text{Intercept} + \alpha LogGdp_t + \varepsilon_t.$$

$$logSvc_t = \text{Intercept} + Trend + \alpha LogGdp_t + \varepsilon_t.$$

$$logSvc_t = \text{Intercept} + \alpha LogGdp_t + \varepsilon_t.$$

Table 8
Structure of IT investments: Hardward, software, and services.

Fixed effects follow the feasesible geralized least squares (FGLS) method. The numerical values below coefficient estimtes are their t-statistics. ***, **, and * stand for statistical significance based on two-sided tests at the 1%, 5%, and 10% level, respectively.

Panel A: Hardware.

	Model 1	Model 2	Model 3	Model 4
Intercept	-4.789 ***	-4.839 ***	-13.793 ***	-5.502 ***
	-16.761	-17.180	-14.518	-6.501
Trend		0.030 ***		0.028 ***
		4.944		8.129
LogGdp	0.989 ***	0.977 ***	1.688 ***	1.029 ***
	44.810	44.618	22.898	15.498
	0.000	0.000	0.000	0.000
Pooled Effect	Yes	Yes		
Fixed Effect			Yes	
Random Effect				Yes
No. of Obs.	780	780	780	780
R^2	0.721	0.729	0.944	0.481

Panel B: Software.

	Model 1	Model 2	Model 3	Model 4
Intercept	-6.388 ***	-6.500 ***	-23.755 ***	-5.022 ***
	-13.709	-14.343	-25.035	-4.587
Trend		0.067 ***		0.070 ***
		6.821		19.509
LogGdp	1.005 ***	0.978 ***	2.353 ***	0.861 ***
	27.928	27.766	31.962	10.075
Pooled Effect	Yes	Yes		
Fixed Effect			Yes	
Random Effect				Yes
No. of Obs.	780	780	780	780
R^2	0.501	0.529	0.963	0.697

Panel C: Services.

	Model 1	Model 2	Model 3	Model 4
Intercept	-6.166 ***	-6.287 ***	-26.331 ***	-7.315 ***
	-11.448	-11.958	-26.000	-5.883
Trend		0.072 ***		0.069 ***
		6.353		17.078
LogGdp	1.040 ***	1.010 ***	2.605 ***	1.092 ***
	24.997	24.728	33.150	11.248
Pooled Effect	Yes	Yes		
Fixed Effect			Yes	
Random Effect				Yes
No. of Obs.	780	780	780	780
R^2	0.445	0.421	0.965	0.681

Although economic growth spurs investments in hardware (Panel A), software (Panel B) and services (Panel C) alike, the coefficient estimates are not the same as hypothesis *H4a* claims. Although not all coefficient estimates of the hardware models (Panel A) are statistically significant (the time effect, Trend, terms), since their economic magnitudes are larger than those of the software models (Panel B), respectively, these results are in favor of hypothesis *H4b*. Panel C witnesses that investments in IT services rise over time (Trend) and income (LogGdp).

6.3. Comparison with Existing Studies

As we compare our results listed in Tables 5, 6 and 7, positive productivity effects of IT investments remain robust beyond 1990s into the first decade of the 21st century.

Table 9
Comparable articles in the literature.

Reference	Sample Period	Factor	Coefficient	Income (Y)
Brynjolfsson (1993)	1987—1991	IT capital flow	0.017	Gross revenue
Brynjolfsson and Hitt (2003)	1988—1992	IT capital stock	0.088	Value added
Lichenberg (1995)	1988—1992	IT capital flow	0.106	Gross revenue
Lee and Baura (1997)	1978—1984	IT capital flow	0.040	Gross revenue
Choe and Choi (2015)	1995—2009	IT capital stock	0.056	Gross domestic products

7. CONCLUSION

Earlier studies have shown positive and large impacts of information technology (IT) investments on aggregate products in the nascent stage. However, this causal inference may not be applicable in the adult regime with a diminishing marginal productivity. We conduct a fifty cross-country analysis on a fifteen year (1995—2009) data of IT capital stocks and real variables rather than flows and nominal, respectively, as used in the literature. Controlling for country and time effects, the empirical implications of our study are as follows: First, the IT investment intensity positively affects aggregate productivity controlling for labor, assets, and financial markets. Second, the relative contribution has decreased as the law of diminishing returns predicts. Lastly, software and services have gained more capital allocation on relative terms in exchange for less on hardware. This finding contrasts with the existing argument that the hardware-software mix is time-constant due to substitution.

In order to leverage our results shown herein up to a feasible set of policy implications, we plan to buttress our research agenda with demystifying the propagation processes and time lags of the productivity effects of IT investments. Addressing these issues, prerequisites may be to augment control variables to minimize autoregressions and endogeneities of IT investments vis-à-vis aggregate products. Also, the binary dummy variable defined as IT-developed versus developing economy can be rendered as a country-specific categorical variable to control for a variety of sovereign-level conditions of IT development.

ACKNOWLEDGEMENTS

Special thanks are due to Seong Kook Kim, Songchun Moon, and Hee-Dong Yang. Standard disclaimer rules apply and all errors are of our own. This work was supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2015S1A5A2A01010876).

AUTHOR'S NOTE

Standard disclaimer rules apply and all errors are of our own.

AUTHOR BIOGRAPHIES

Paul Moon Sub Choi is an assistant professor of finance at the College of Business Administration, Ewha Womans University. Before he joined Ewha in 2010, he had taught at the State University of New York at Binghamton. He received his degrees from Yonsei (B.A.), Harvard (A.M.), and Cornell University (Ph.D). (first author)

Hakyoul Choe is a Ph.D. candidate in managerial information systems at the KAIST Business School. He received his degrees from Yonsei (B.A.) and the KAIST (M.S.). (corresponding author)

REFERENCES

Anderson, M. C., Banker, R. D., Ravindran, S., 2003. The New Productivity Paradox. Communications of the ACM 46(3), 91-94.
Autor, D. H., Levy, F., Murnane, R. J., 2003. The Skill Content of Recent Technological Change: An Empirical Exploration. Quarterly Journal of Economics 118(4), 1279-1334.
Baltagi, B. H., 2008. *Econometric Analysis of Panel Data*, 4th edition, Wiley.
Brynjolfsson, E., 1993. The Productivity Paradox of Information Technology. Communications of the ACM, 36(12), 66-77.
Brynjolfsson, E., Hitt, L. M., 2003. Computing Productivity: Firm-Level Evidence. The Review of Economics and Statistics 85(4), 793-808 .
Chow, G. C., 1960. Tests of Equality between Sets of Coefficients in Two Linear Regressions. Econometrica 28(3), 591–605.
Choi, Y., 2009. Analyzing Economic Impact of Paperless Trade on International Trade. Trade Focus 9(64) of Institute for International Trade. (in Korean).
Cobb, C. W., Douglas, P. H., 1928. A Theory of Production. American Economic Review 18 (Supplement), 139–165.
Durbin, J., Watson, G. S., 1950. Testing for Serial Correlation in Least Squares Regression: I. Biometrika 37, 409–428.
Durbin, J., Watson, G. S., 1951. Testing for Serial Correlation in Least Squares Regression, II. Biometrika 38, 159–179.
Gurbaxani, V., Mendelson, H., 1992. An Empirical Analysis of Software and Hardware Spending. Decision Support Systems 8(1), 1-16.
Hitt, L. M., Wu, D. J., Zhou, X., 2002. ERP Investments: Business Impact and Productivity Measures. Journal of Management Information Systems 19(1), 71-98.
Kudyba, S., Diwan, R., 2002. Research Report: Increasing Returns to Information Technology. Information Systems Research 13(1), 104-111.
Larus, J., 2009. Spending Moore's Dividend. Communications of the ACM 52(5), 62-69.
Lee, B., Barua, A., 1999. An Integrated Assessment of Productivity and Efficiency Impacts of Information Technology Investments: Old Data, New Analysis and Evidence. Journal of Productivity Analysis 12(1), 21-43.
Loveman, G. W., 1988. An Assessment of the Productivity Impact on Information Technologies. MIT Management in the l990s Working Paper #88-054.
Mendelson, H., 1987. Economies of Scale in Computing: Grosch's Law Revisited. Communications of the ACM 30(12), 1066-1072.
Mittal, N., Nault, B. R., 2009. Investments in Information Technology: Indirect Effects and Information Technology Intensity. Information Systems Research 20(1), 140-154.
OECD, 2008. Broadband Growth and Policies in OECD Countries. (downloaded on 2 May 2012 from http://www.oecd.org/dataoecd/32/57/40629067.pdf).
Park, J., Shin, S., Sanders, G. L., 2007. Impact of International Information Technology Transfer on National Productivity, Information Systems Research, 18(1), 86-102.
Slye, J., Peterson, D., Petty, A., 2010. Federal Information Technology Market 2010-2015. INPUT's Annual Forecast (downloaded on 12 November 2011 from http://iq.govwin.com/corp/library/detail.cfm?ItemID=12801&bt2&cmp=EMC-2feditfc070110).
World Bank, 2009. World Bank Development Indicators 2009. (downloaded on 2 February 2015 from http://data.World Bank.org/products/data-books/WDI-2009).