How do Investments in R&D and Information Technology Interact on Firm Performance?

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Abstract

The impact of R&D investments cannot be evaluated separately from the investments made in information technologies in today's highly digitalized knowledge economy. Besides, there is a mixed evidence in the prior management literature on the impact of expensive R&D investments on either firm productivity or firm performance measures. This study explores the role of IT as a catalyst in enhancing the productivity of R&D processes using a unique multi-year firm level data of large global firms all over the world. The findings suggest that R&D and IT do not simply interact for better firm performance at all circumstances. The interaction effects are observed for industrial firms that spend more on R&D relative to their peers in the same industry; but not for firms that are in more knowledge-intensive industries. This study sheds light on the joint effects of R&D and IT making several other implications for companies and practitioners.

Keywords: R&D, Information technology, firm performance, interaction effects

JEL Codes: O30, M15

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Ar-Ge ve Bilgi Teknolojileri Yatırımları Firma Performansı üzerinde Nasıl Etkileşir?

Öz

Bugünün oldukça dijitalleşmiş bilgi ekonomisinde ARGE yatırımlarının etkileri bilgi teknolojilerine yapılan yatırımlardan ayrı olarak değerlendirilemez. Bunun yanı sıra, yönetim yazınında pahalı ARGE yatırımlarının firma performansı veya üretkenliği ölçütlerine etkisi ile ilgili karışık deliller mevcuttur. Bu çalışma kendine has çok yıllı firma seviyesinde dünya genelinde küresel ve büyük şirketlerin verilerini kullanarak Bilgi Teknolojilerinin ARGE süreçlerinin üretkenliğini arttırmadaki rolünü incelemektedir. Bulgular ARGE ve Bilgi Teknolojilerinin basit şekilde daha iyi firma performansı için tüm koşullarda etkileşmediğini göstermektedir. Etkileşme etkileri aynı endüstride yer alan diğer firmalardan göreceli olarak daha çok ARGE yatırımı yapan endüstriyel firmalarda görülürken daha bilgi-yoğun endüstrilerde gözlemlenmemektedir. Bu çalışma ARGE ve Bilgi Teknolojileri yatırımlarının ortak etkilerine ışık tutarken firmalar ve uygulamacılar için de diğer birçok öneriler sunmaktadır.

Anahtar Kelimeler: Ar-Ge, Bilgi Teknolojileri, firma performansı, etkileşme etkileri

JEL Kodları: O30, M15

Introduction

R&D is an expensive investment. Firms spend on the average 3.7% of their sales revenues on R&D investments where some firms invest more than 20% on R&D based on a recent data of the most innovative 1000 companies worldwide (Jaruzelski et al., 2015). Even small firms invest in R&D starting in the earlier years of their establishment. Do such spending in R&D reflect to greater innovation and firm performance? About half of the ten most innovative companies do also reside in the top twenty research and development (R&D) spenders of all companies in 2016 according to the Global Innovation 1000. But, the other half are not the most 20 R&D spenders. Thus, how R&D leads to greater innovation and firm performance remains a question that management scholars quest for more than 40 years now.

While R&D is crucial for firm performance for almost all firms regardless of the firms' industry, R&D alone is not a good indicator of the firm performance as the mixed evidence on the effects of R&D on firm performance suggests in the prior literature (Chan et al., 2001; Charusilawong, 2014; He & Wintoki, 2016; Lev & Sougiannis, 1996). R&D investments cannot be thought of separately from the Information Technology (IT) investments especially with the exponential growth of science and technology based firms in the last few decades. The execution of innovation intensive processes typically require high investments in IT. Thus, how IT plays a role on firm performance and more importantly whether these two investments (i.e., R&D and IT) jointly affect firm performance or not are questions that this study explores further.

Using a unique data set of firm-level and post-Internet R&D and IT, we test whether IT interacts with R&D for better firm performances. We use gross margin as a proxy for firm profitability. Because the intensities of R&D and IT spending differ significantly across different industries, the empirical analyses are conducted across groups of firms that invest in R&D and IT lower (or higher) than their peers in the same industry. The results suggest a positive interaction effect of R&D and IT investments on firm gross margin among industrial firms that are relatively high R&D spenders but spend less on IT relative to their peers in the same industry. The significant interaction effects are not observed at other groups of firms but the overall impact of R&D and IT investments differ significantly across different groups of firms within the industries that the firm belongs to. Thus, we discuss the implications of this study given the limitations of data and the unforeseen factors that might affect such relations.

This paper takes the following structure. We review the literature on relations of R&D and IT investments to various firm performance metrics in Section 2. The underlying conceptual model and the research hypotheses are developed in Section 3. Section 4 is devoted to the methodology. We discuss the findings of the empirical analyses and state the implications for future research in the last section 5.

Existing Research on the Relation between R&D and IT Investments and Firm Performance

There is an extensive amount of literature on the relations between expensive investments of R&D and firm performance or productivity measures

(Charusilawong, 2014; Chauvin & Hirschey, 1993; Z. Griliches & Mairesse, 1984; Zvi Griliches, 1994; Hall & Mairesse, 1995; He & Wintoki, 2016; Lee & Shim, 1995). However, the literature is limited in terms of the joint or the interaction effects of R&D and IT on firm performance. We first review the literature on the separate effects of these two crucial investments on firm performance. Then, the existing research on the relations with each other and the joint effect on productivity or firm performance is given in the following sections.

R&D Investments on Firm Performance

The economic growth has come to a point where the stagnation is inevitable as Ayres (2016) points out "The history until now has been the history of converting materials into things. The history of the future may be a history of wealth creation by knowledge accumulation, de-materialization, and institutional innovation". Knowledge economy that leads to evolutionary innovations is the key to future economic growth. Firms across different industries, even if they are not in knowledge-based industries, are obligated to invest in R&D. However, how and to what extent R&D reflects to productivity, growth or performance is still been questioned a lot finding place across a wide variety of research in the field of management.

There is an extensive stream of research studying the relationship between R&D and firm productivity or various firm performance measures. While most studies have focused on the impact of R&D spending on firm productivity growth, some others have explored the relationship between R&D and financial and accounting measures of firm performance, such as stock price/market value, and operating income.

Morbey (1988) finds a strong positive association between R&D and subsequent growth in firm sales tracking major US companies between the years between 1976 and 1985. R&D capital has a positive impact on operating income across a wide variety of industries based on a panel data of firms tracked between the years 1975 and 1991 (Lev & Sougiannis, 1996). Based on a study of 600 manufacturing firms, Ettlie (1998) reports that R&D intensity is significantly associated with improvement in market share, after controlling for firm size, industry and geographic region. His survey-based, study shows that R&D spending is also associated with greater computerization of manufacturing and increased agility as measured by qualitative indicators of manufacturing performance. In an empirical study of firm performance across US and Japanese firms, Lee and Shim (1995) observe that the impact of R&D on a firm's long run performance is significant and positive. The majority of such studies suggest R&D's positive contribution to firm productivity. However, these studies have limitations as in some the data belong to pre-Internet era or the variety of estimation methods and the data employed make it difficult to compare studies with each other.

There also exists some other research that cannot establish positive a link between R&D and firm productivity or performance. Thus, the evidence is mixed on the benefits of R&D. Chan et al. (2001) explore the relationship between R&D expenditures and the equity market value of firms between 1975 and 1995. Although their study does not support a direct link between R&D spending and future stock returns, their results suggest that R&D intensity is associated with greater volatility in stock returns after controlling for firm, size, age and industry effects. A study by Booz Allen Hamilton of 1000 publicly held, global firms, that spent the most on R&D in 2004, reports that there is no relationship between R&D spending and several measures of economic success including sales growth, profitability, market value, or total shareholder return (Kandybin & Kihn, 2004). Their study implies that there is a fundamental disconnect between R&D spending and performance wherein simply throwing greater amounts of money on new product innovation does not guarantee success.

The literature review also suggests that findings of the empirical analyses differ significantly with regards to the time-series method applied in empirical analyses. The strongest results, in terms of R&D impact, are reported in the cross-sectional studies, whereas time-series studies that link R&D to total factor productivity growth produce weaker results with some studies even showing statistically insignificant estimates (Arnold, Peterson, & Dennis, 2005). Other limitations in terms of developing accurate estimates of the impact of R&D can be summarized as: (a) possibility of spillovers where the benefits accrue to firms or nations other than the ones making these investments, and (b) a focus mostly on private R&D spending based on financial data reported by publicly traded firms, which reflects only a small fraction of true R&D spending in the economy.

IT Investments on Firm Performance

The effect of computerization on productivity and firm sales growth has been studied extensively since the late 1980's (Barua et al., 1991; Brynjolfsson, 1993; Brynjolfsson & Hitt, 1996; Dewan & Min, 1997; Hitt & Brynjolfsson, 1996). These studies were able to provide categorical evidence to refute earlier claims related to the "IT productivity paradox" which implied that the benefits of IT spending were not observable in aggregate output statistics. The study of Brynjolfsson and Hitt (1996) on measurement of IT-driven firm productivity showed that IT spending made a substantial and significant contribution to firm output (i.e. sales). Using firm-level data on a panel dataset of large firms from 1987-1991, they observed that the marginal product of computer capital was at least as large as the marginal product for other types of capital investments. Their results suggest that the IT productivity paradox disappeared by 1991, and that firm-level IT spending lead to significant improvements in product quality and variety, which in turn lead to greater firm output (Hitt & Brynjolfsson, 1996). Subsequent work also showed that IT investments are associated with significant returns on spending when they are accompanied by organizational process changes that are associated with improvements in human capital (Brynjolfsson & Hitt, 2000, 2003).

Although prior empirical studies confirm the productivity impact of IT, most studies show either a negative or no effect of IT investments on profitability (Aral & Weill, 2007; Hitt & Brynjolfsson, 1996; Rai et al., 1997). These findings appear to contradict other evidence showing that firms benefit from IT investment, prompting (Dedrick et al. 2003, p. 23) to call it "the profitability paradox" and others to question the strategic value of IT investments (Carr, 2004). Since there has been a significant shift in the nature of IT services in the Internet era, as compared to the pre-Internet era on which most of the earlier studies were based, it is imperative to develop a better understanding of the impact of IT on firm profitability. Newer types of IT systems that form the foundation of web-based computing are expected to have far greater transformational potential compared to their predecessors (Aral & Weill, 2007; Dos Santos et al., 1993).

There exists studies supporting this view. The study of Mithas et al. (2012), based on firm-level data from the Internet-computing era, suggests that the effect of IT investments on firm profitability is higher than other discretionary investments, such as advertising and R&D expenditures. Other studies that have explored the linkage between IT investments and their impact on firm profitability have shifted their focus from studying the aggregate impact of IT to an evaluation of the role of strategic and informational IT assets and their relationship with firm profitability measures (Aral & Weill, 2007). The results of these recent studies suggest a need to understand specific mechanisms through which IT can impact firm profitability through improvements in the effectiveness and efficiency of business processes. We argue that one such process that deserves closer investigation is the innovation or R&D process where IT investments have created a significant competitive advantage for firms in many industries.

The Joint Roles of R&D and IT on Firm Performance

Information technology plays a critical role in the success or failure of R&D projects. The knowledge-based view of the firm suggests that innovation processes are critical to generate new knowledge in the execution of R&D (Kogut & Zander, 1992; Nonaka & Takeuchi, 1995). In order to leverage the tacit and explicit knowledge that resides within and outside firms' boundaries, firms must build extensive capabilities in identifying and processing the information that resides within the workplace and can frequently involve external partners (Cohen & Levinthal, 1989; Sakakibara & Branstetter, 2001). IT can help firms build "high bandwidth" channels with their lead partners and customers to sense tacit and emerging customer/supplier information (Zeithaml & Bitner, 1996). The consumer packaged goods giant, Proctor and Gamble, has invested heavily in IT-driven innovation solutions as part of new product development efforts (Bloch & Lempres, 2008).

In a study by McKinsey, Marwaha et al. (2007) report that pharmaceutical companies which use IT in clinical trials processes increased their overall productivity by improving the speed, quality and costs associated with these processes. Estimated savings from such IT-driven initiatives that improve the overall efficiency of clinical trials is estimated to be in the range of $50 million to $100 million. Similarly, advances in the development of high-throughput screening and simulation software and development of unified IT systems have greatly improved the efficacy of drug discovery and development processes (Thouin, 2008).

The examples cited above provide anecdotal evidence on how IT can be used to improve the execution of R&D projects by increasing the consistency, alignment and relevance to customer needs. A review of the prior literature shows that the impact of R&D and IT on firm productivity and profitability has been treated separately in a vast majority of the studies. In other words, most studies have focused either on the impact of R&D on firm output and/or profitability, while others have studied the impact of IT on firm performance while treating R&D and other discretionary expenditures (such as advertising) as control variables. To the best of our knowledge, none of these studies have explored the complementary role of IT in enabling and moderating the impact of R&D investments on firm performance. We believe that, while the initial focus on measuring the direct impact of IT in the initial stages of industry-wide computerization in the 1990s was useful, it is more important to develop a better understanding of the impact of IT investments by virtue of their complementarities with other discretionary investments in firm-level processes.

An alternate pathway to measure the impact of IT is to focus on its role as a complementary resource for innovation-centric R&D processes. In other words, can IT make R&D investments more productive? An important issue in improving R&D productivity is the capability to facilitate seamless communication among virtual product design teams (Loch & Terwiesch, 1998; Nambisan, 2002). New types of IT, such as product lifecycle management (PLM) software and collaboration tools, can enable product design teams to collaborate across inter-organizational boundaries, gather and share design requirements, conduct design iterations, verify and test product designs, and facilitate final design hand-offs to other departments (Adler, 1995; McGrath & Iansiti, 1998). Such web-based tools provide an information rich medium that supports collaboration by facilitating synchronous communication within and across R&D teams (Banker et al., 2006; Bardhan, 2007). These tools also provide efficient data storage, electronic retrieval and reuse of product designs, and allow R&D teams to compress the overall product development time by reducing latency (Jana, 2009).

The Conceptual Model and the Research Hypotheses

Based on the discussions of the previous section, we posit three hypotheses. The first hypothesis is on the sole effect of R&D on firm performance and is stated as follows.

H1: R&D spending has a positive impact on firm performance.

Prior research on the impact of IT spending on firm performance has provided mixed evidence. Researchers have empirically linked IT investments to improvements in firm labor productivity, total factor productivity, output growth, and Tobin's q using cross-sectional and longitudinal data (Barua et al., 1991; Bharadwaj, 2000; Bresnahan et al., 2002; Brynjolfsson & Hitt, 1996, 2003). However, the evidence directly linking IT investments with improvements in firm profitability is less clear. Based on their analyses of firm panel data from the pre-Internet era, Hitt and Brynjolfsson (1996) and Rai et al. (1997) reported that IT did not have a significant impact on firm profitability. Recent studies have focused on the pathways through which IT investments can create value, using the resource-based view of the firm as the theoretical framework to study the impact of IT-enabled capabilities on firm performance (Aral & Weill, 2007; Banker et al., 2006; Bharadwaj, 2000). Dedrick et al. (2003, p. 23) coined the term "profitability paradox" to refer to the general failure to show a positive relationship between IT investments and other measures of firm financial performance. Kohli and Devaraj (2003) support this observation and state that the impact of IT investment on measures of profitability is mixed at best.

Is IT alone a sufficient tool in itself to improve the firm performance? Or does it serve as a catalyst to improve the productivity of other business processes? Dos Santos et al. (1993) and Aral and Weill (2007) observe that while overall IT spending is not associated with firm market value, transformative IT investments that enable new types of business process capabilities are associated with improvements in firm margins and return on assets. Shah and Shin (2007) observe that IT spending contributes to growth in firm profitability through improvements in their inventory turnover ratio based on a large panel study of firms in the manufacturing sector. IT can also improve the rate of patent innovation by providing the appropriate communication infrastructure necessary to reduce time to market and product development time (Banker et al., 2006). Hence, we hypothesize that,

H2: IT spending has a positive impact on firm performance.

One of the most important challenges that innovation-intensive firms face is the greater technological complexity of the product development process. It is important to understand the major factors that improve the innovation process in these industries. For example, leading pharmaceutical companies have raised the productivity of their clinical trial processes by introducing several IT initiatives. These initiatives provide cross-trial transparency across the organization, enable physicians to use electronic data capture tools effectively, and manage workflows to eliminate the bottlenecks. Similarly, in other high-tech industries, IT investments play an important role by providing the organizational capabilities necessary to leverage R&D investments into significant reductions in product time to market and product quality which translate into higher gross margins (Banker et al. 2006).

In this study, we seek to investigate how IT impacts the relationship between R&D spending and firm performance. We argue that smart IT investments will help R&D managers improve the productivity of their product innovation processes by providing greater capabilities to harness the knowledge embedded across firm boundaries and enable easier (and faster) access to critical product design data that help to reduce product time to market and overall product development costs. Hence, we posit that the joint effect of R&D and IT will significantly improve the pace and quality of new product development, resulting in greater innovation especially in knowledge-intensive industries.

H3: The interaction effect of IT and R&D spending has a positive impact on firm performance.

Figure 1 describes our conceptual research model and our hypotheses in terms of the (a) direct effects of R&D and IT, and (b) interaction effect of R&D and IT investments on firm performance.

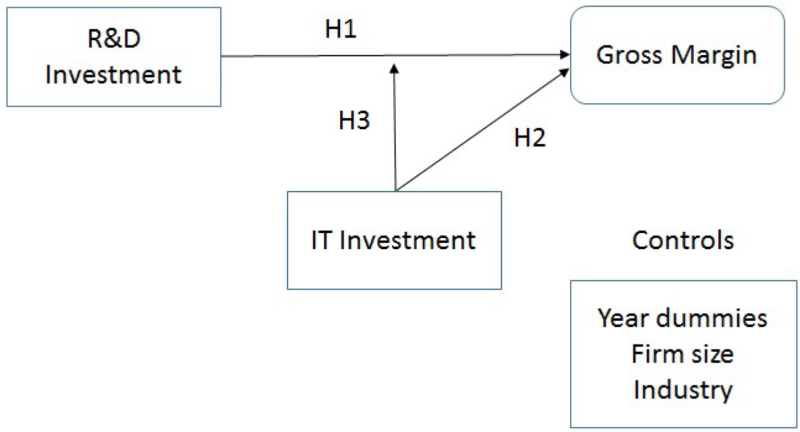

Figure 1. Conceptual Research Model

Methodology

Data and the Descriptive Statistics

We use data from two different sources in this study. We obtained multi-year, archival data on firm-level IT spending from an international research firm that is well-known for its IT data and research services. The data was obtained under a non-disclosure agreement that protects its confidentiality. The data was collected through an annual survey that is administered to chief information officers and other senior IT executives of large, global firms with the goal of collecting objective metrics on IT investments. This firm collects archival IT investment data, along with other IT investment-related information, as part of its annual, worldwide IT benchmarking survey. IT investments include all hardware, software, personnel, training, disaster recovery, facilities, and other costs associated with supporting the IT environment, including the data center, desktop/WAN/LAN server, voice and data network, help desk, application development and maintenance, and outsourcing. IT spending data for firms in this data set was available for the 1998 to 2004 period.

Data on financial and accounting metrics were constructed from the Standard & Poor's database, COMPUSTAT database. We collected firm-level data on gross margins, assets, sales, R&D, and advertising from the Compustat database. We note that the data on firm advertisement expenditures in Compustat is limited because advertising expenditures for several firms in our panel are not reported in Compustat. Hence, we supplement this data using data obtained from the TNS Media Intelligence (TNSMI) database which collects firm-level advertising data from 2002 onward. We note that this database provides a more accurate picture of new media advertising that is a fast-growing component of overall advertising expenditures, which includes internet-based advertising as well as traditional advertising spend such as network and cable TV, print media and radio. For firms on which advertising data was not available, we used the average advertising expenditures (as % of sales) of all firms in that 4-digit NAICS code as a proxy for the advertising intensity. This is a commonly used approach in empirical analyses when some portion of the data for a control variable is missing.

Since the focus of our study is on the interaction impact of IT on R&D investments, we intentionally restrict our focus to firms that have non-zero R&D and IT expenditures. In other words, we remove from consideration firms that report zero expenditure on either R&D or IT categories since the interaction effect of such investments would be zero by definition. This is an important distinction between our dataset and others who have studied the profitability impact of R&D and IT in the prior literature (Mithas et al., 2012). Furthermore, we restrict our attention to a balanced panel which comprises of seventy firms for which we have complete firm-level data on our variables of interest, namely gross margins, R&D spend, IT spend, advertising expenditures, assets, and sales. Overall, we have 490 firm-year observations for 70 firms over 7 years.

The firms in our data set belong to two primary industries: Industrials, and Computers & Electronics (C&E). The Industrials category is comprised of 44 firms in sectors such as manufacturing, energy, consumer packaged goods, and metals and natural resources. The firms in this category range from process manufacturers (two-digit NAICS 31 and 32) to discrete manufacturers of machinery, metal products, electrical equipment, and motor vehicle manufacturing (three-digit NAICS 331, 332, 333, 335 and 336). The C&E category is comprised of 26 firms that belong to the high-tech computer hardware, software development, and electronics manufacturing sectors. The firms in this category range from computer and semiconductor manufacturers, to electro-medical and control instruments manufacturers and software and data processing services (three-digit NAICS 334, 511, 518, 541, and 561).

Table 1. Variable Definitions and Sources

Variable	Definition	Source
GM	Difference between sales and cost of goods sold (COGS) divided by sales.	Sales & COGS correspond to Compustat data items 12 and 41, respectively.
R&D	R&D spending divided by sales.	*R&D* is obtained from Compustat as research and development expense (data 46) divided by sales (data 12).
IT	IT spending (all hardware, software, personnel, and other costs associated with supporting the IT environment) to sales.	Firm-level IT spending obtained from an international research firm that is well known for its IT data and research services.
Assets	Total assets divided by sales.	*Assets* is obtained from Compustat as total assets (data6) divided by sales (data12).
Advert	Advertising expenses divided by sales.	*Adv* is obtained from Compustat as advertising expense (data45) divided by sales (data12). Missing values are supplemented from TNMSI database from 2002 onward.
IndConc	Industry concentration ratio calculated using Herfindahl-Hirschman Index (HHI).	HHI equals the squared sum of the market shares of each firm in that industry. Market share is the net sales (data12) divided by the total sales in that industry.

We use Gross Margin (GM) to measure firm performance. The predictor variables that we use in our econometric models are research and development (R&D), information technology (IT), and advertising (Advertising) expenditures. We control for firm size using firm assets (Assets), and industry concentration using the Herfindahl index as a proxy for market share (Dewan et al. 2007). We also control for time trends by using year dummies for our panel data. IT spending is defined as the dollar value of capital and operational expenses to support the IT environment. Consistent with the prior literature on IT and R&D productivity, all independent and dependent variables are measured as a ratio relative to firm sales (Chao & Kavadias, 2013; Mithas et al., 2012). Further details on variable definitions and data sources are provided in Table 1.

Table 2 provides descriptive statistics on the model variables in our data set. During the time period 1998 to 2004, the average R&D intensity was 5.8% while IT spending and advertising intensity ratios were 3.7% and 2.8%, respectively. The average gross margin was 40%, while average annual sales for firms in our sample were $18.77 billion. We note that average R&D spending among industrial firms is only 2.4%, while it is almost four times higher at 8.6% for firms in the C&E sector. However, average IT spending seems to be fairly uniform across firms and varies between a low of 3.4% among industrials to a high of 4.1% among C&E firms.

Table 2. Descriptive Statistics of the Model Variables

		R&D	IT	Sales ($M)	Assets	Advertising	Gross Margin
Industrials	Mean	0.024	0.034	22,279	1.088	0.028	0.321
	Median	0.021	0.026	5,319	1.013	0.017	0.282
	Std Dev	0.018	0.050	51,223	0.378	0.036	0.131
	Min	0.001	0.001	83	0.322	0.000	0.067
	Max	0.104	0.384	335,086	2.797	0.200	0.693
	75%ile	0.032	0.0328	10,242	1.293	0.026	0.387
	25%ile	0.010	0.020	2,407	0.845	0.007	0.238
Computers & Electronics	Mean	0.086	0.041	13,335	1.185	0.021	0.411
	Median	0.066	0.033	4,142	1.006	0.014	0.418
	Std. Dev.	0.070	0.033	23,201	0.594	0.021	0.213
	Min	0.001	0.004	519	0.275	0.000	0.063
	Max	0.380	0.262	110,789	3.249	0.100	0.954
	75%ile	0.140	0.051	10,560	1.474	0.028	0.548
	25%ile	0.028	0.023	1,559	0.797	0.005	0.267
Overall Sample	Mean	0.058	0.037	18,771	1.172	0.028	0.400
	Median	0.032	0.030	5,526	1.069	0.018	0.345
	Std. Dev.	0.066	0.042	40,750	0.496	0.033	0.208

We report the Pearson correlation matrix in Table 3. The correlation coefficients indicate that R&D is positively correlated with gross margin (α =0.689; $p < 0.001$). We note that R&D and IT spending are not significantly correlated (α=0.062; $p<0.145$) which suggests that firms' investment decisions related to IT and R&D spending are independently made as one would expect, since such decisions are typically made by different functional owners.

Econometric Estimation

We estimate the effects of the primary variables of interest, R&D and IT spending, through the interaction effects model which is expressed as follows.

$$GM_{i,t} = \alpha_0 + \alpha_1 R\&D_{i,t} + \alpha_2 IT_{i,t} + \alpha_3 R\&D_{i,t} xIT_{i,t} + \alpha_4 Assets_{i,t} + \alpha_5 Advert_{i,t} + \alpha_6 IndConc_{i,t} + \alpha_{5,k} Year_k + \varepsilon_{i,t} \quad (1)$$

The index *i* represents the firm, while index *t* represents the year, and the variable $\varepsilon_{i,t}$ denotes the error term. The variables $R\&D_{i,t}$, $IT_{i,t}$, and $Advert_{i,t}$, represent R&D, IT and advertising intensity, respectively, while $Assets_{i,t}$ and $IndConc_{i,t}$ measure the firm assets and market share of firm *i* in year *t*. $GM_{i,t}$ represents the gross margin of firm *i* in year *t*. Year *k* represents a time dummy for each year in our sample. We estimate the models specified in (1) using the current year values of the independent variables, as well as 1-year and 2-year lagged values of the explanatory variables. We use current year values of Assets in the lagged models since the relationship between firm assets and profitability does not involve a lagged impact. Although IT spending data was available only from 1998-2004, we are able to use the 2005 and 2006 data for the dependent variable (gross margin) when we incorporate 1-year and 2-year lags on the independent variables.

Table 3. Pearson Correlation Matrix of the Model Variables

	R&D	**IT**	**Sales**	**Assets**	**Advertising**	**GM**
R&D	1					
IT	0.062 (0.145)	1				
Sales	-0.089 (0.018)	-0.050 (0.239)	1			
Assets	0.540 (<.0001)	-0.011 (0.798)	0.029 (0.437)	1		
Advertising	0.070 (0.063)	-0.028 (0.515)	-0.046 (0.219)	0.005 (0.890)	1	
GM	0.689 (<.0001)	0.036 (0.389)	-0.114 (0.002)	0.432 (<.0001)	0.390 (<.0001)	1

p-values are shown in parentheses.

We estimate the model shown in equation (1) using pooled, ordinary least squares (OLS) regression analysis. In order to control for time-series correlation of our variables, we compute the *z*-statistic to report the statistical significance of coefficient estimates in our regression models. The *z*-statistic is computed using year-by-year regression estimations as in Equation (2).

$$z - stat = \frac{1}{\sqrt{N}} \sum_{j=1}^{N} \frac{t_j}{\sqrt{k_j / k_{j-2}}} \qquad (2)$$

Here, *t* is t-stat, *k*j is the degrees of freedom for year *j*, and *N* is the number of years. Our use of the *z*-statistic to calculate the *p*-values of coefficient estimates of our pooled regression models is a well-validated approach for estimation models that involves within-firm, correlation of error terms across time (Ali et al. 2007). We also use the Huber White procedure to correct for heteroscedasticity.

Another important concern in our estimation deals with simultaneity issues. Specifically, when an exogenous shock affects the dependent and one or more independent variables, the latter will be correlated with the residual term and lead to inconsistent regression estimates (Lev & Sougiannis, 1996). We account for endogeneity by estimating our regression models in a simultaneous equation model using two-stage least squares (2SLS) estimation. In this procedure, we use the instrumental variable method, where the instrument is chosen to substitute for the explanatory variable that may be correlated with the residual. A good instrument is one that is correlated with the substituted explanatory variable but is not correlated with the residual. In our study, we choose the lagged values of R&D and IT as instruments. We argue that, since the lagged values of R&D and IT spending represent investments in a prior period, they will be unaffected (or only mildly correlated) with firm idiosyncratic shocks in the current period. Such shocks could include a change in managerial strategy or corporate control that affect future investments but not the ones made in a prior period. Hence, we argue for the use of lagged values of explanatory variables as suitable instruments in the 2SLS estimation (Brynjolfsson & Hitt, 1996; Villas-Boas & Winer, 1999). We first regress R&D and IT on their respective instruments, and then use the predicted values (from the first stage) and explanatory variables in the original model shown in (1).

We report our standardized regression coefficient estimates for "Industrials" and "C&E" firms, separately in Table 4, since R&D and IT investment trends and their usage differ significantly across these industries. The column "Current year" reports the estimates for regressions using current year values of the dependent and independent variables, while the "1-yr" and "2-yr" columns reflect the regression estimates for one- and two-year-lagged models, respectively. All regressions are statistically significant and explain a significant portion of the variance in gross margin. We observe that R&D has a weak but positive impact (p-value < 0.10) on GM among Industrials for the current year and one-year lagged models, while it has a significant, positive impact on GM for C&E firms for all model specifications. We also observe that IT has a positive, significant impact on GM among Industrials and C&E firms for all models. Hence, our initial results suggest support for hypotheses H1 and H2, in terms of the direct impact of R&D and IT, respectively, on gross margin.

Table 4. Pooled Regression Results of the Main and Interaction Effects on Gross Margin

	Industrials			C&E		
	Current year	1-year Lag	2-year Lag	Current year	1-year Lag	2-year Lag
R&D	0.336*	0.087*	0.098	1.178***	0.644***	0.614***
IT	0.688***	0.481***	0.441***	0.608***	0.265***	0.215***
R&D x IT	-0.502**	-0.11	-0.112	-0.754***	-0.11	-0.088
Assets	-0.051	-0.072*	-0.063*	0.214***	0.212***	0.254***
Advertising	0.458***	0.487***	0.520***	0.295***	0.335***	0.329***
Ind. Conc.	0.061	0.065	0.056	-0.005	-0.035	-0.029
Adj. R^2	0.47 (0.85, 0.69)	0.45	0.45	0.63 (0.85, 0.72)	0.72	0.72
F value	20.52 (<.0001)	19.78 (<.0001)	19.33 (<.0001)	27.40 (<.0001)	34.27 (<.0001)	34.17 (<.0001)
No. of firm-year obs.	308			182		

- $*p<0.1$, $**p<0.05$, $***p<0.01$. *p*-values are calculated based on the z-statistic to account for the possibility of within firm correlation of error terms over time.
- Adjusted R^2 values for instrumental variable regressions in the first stage of 2SLS are shown in parentheses for R&D and IT, respectively, in the row titled "Adj. R^2."
- Standardized coefficients are provided.

Furthermore, firm assets has a positive association with gross margin for C&E firms, while the association is negative among Industrials. Advertising, on the other hand, has a positive and significant impact on gross margins for both types of firms across all model specifications. We also observe that *IndConc* does not have a significant impact on firm gross margin.

However, contrary to our expectations, our results indicate that the interaction term "R&D x IT" has a negative or statistically insignificant coefficient for both industry categories. It turns out that simply adding the cross-product terms to the main effects model does not reveal the real impact of the interaction of the key explanatory variables on financial performance. A better way of investigating the interaction impact is explained in the next section.

Interaction Effect Models: Clustering Firms into Quadrants

Kandybin & Kihn (2004) argue that there is some evidence of diminishing returns of R&D "beyond a saturation point" based on their analyses of firm R&D data collected at Booz Allen. In a similar vein, Rubin notes that "… beyond a certain point, extra IT spending does no good…" based on his research on IT spending pattern in the financial services industry. He refers to this sweet spot as the "optimal IT intensity" (Gruman, 2007). To test this effect, we create a scatter plot in Figure 2 where the combined R&D and IT spending is plot against gross margin for C&E firms over the 1998 to 2004 period. We observe that there is a peak saturation point when combined "R&D plus IT spending" is approximately 20% of sales. Beyond this peak, gross margins decline rapidly.

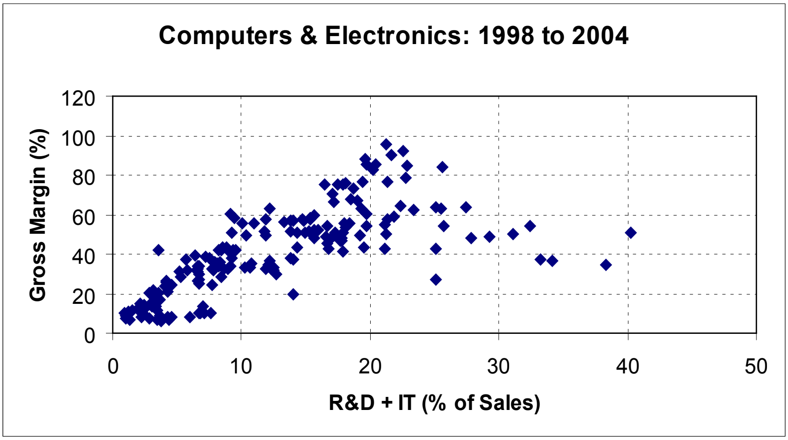

Figure 2. Diminishing Returns to IT and R&D Spending

To study this effect within the framework of our empirical model, we split our sample data into four quadrants based on the median values of IT and R&D spending as shown in Figure 3. Here, Q1 represents firms in the first quadrant where R&D and IT spending are less than their corresponding industry median levels in time *t*, i.e., *R&D*i,t < *R&D*Med(t) and *IT*i,t < *IT*Med(t), respectively. Similarly, Q2 represents firms in the second quadrant where *R&D*i,t > *R&D*Med(t) and *IT*i,t < *IT*Med(t). Q3 and Q4 represent firms in the third and fourth quadrant, respectively.

We run the interaction effects model for firms in each quadrant by introducing a dummy variable, *D*i,j,t, where *D*i,j,t = 1 if firm *i* belongs to quadrant *j* in year *t*, and zero otherwise. Our model is specified as:

$$\begin{aligned} GM_{i,t} &= \alpha_0 + \alpha_1 R\&D_{i,t} + \alpha_2 IT_{i,t} + \alpha_3 R\&D_{i,t} xIT_{i,t} + \alpha_4 Assets_{i,t} \\ &+ \alpha_5 Advert_{i,t} + \alpha_6 IndConc_{i,t} + \alpha_7 R\&D_{i,t} xIT_{i,t} xD_{i,1,t} \\ &+ \alpha_8 R\&D_{i,t} xIT_{i,t} xD_{i,2,t} + \alpha_9 R\&D_{i,t} xIT_{i,t} xD_{i,4,t} + \alpha_{10,k} Year + \varepsilon_{i,t} \end{aligned} \quad (3)$$

We note that the dummy variable *D*i,1,t =1 for firm *i* in Q1 in year *t*, and zero for other firms in quadrants Q2, Q3, and Q4. We observe that the interaction term “R&D x IT” represents the baseline, interaction effect of R&D and IT, while the other interaction terms “R&D x IT x *D*j” represent interaction effects relative to the baseline quadrant, i.e., Q3.

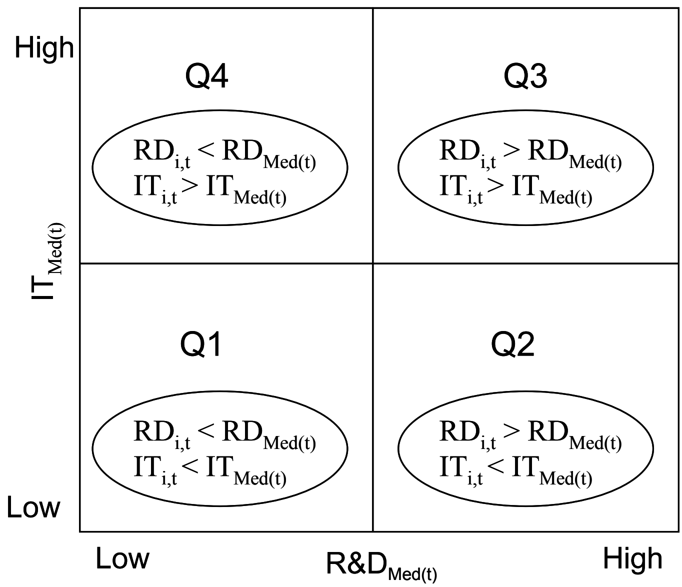

Figure 3. Quadrants based on Firm-level R&D and relative to Industry Median

Similar to our earlier estimation, we report the parameter estimates for the current year and one- and two-year lagged specifications of equation (3) in Table 5. Our results indicate that the main effects of R&D, IT and *Advertising* are generally similar to the earlier results described in Table 4, with the one exception being that the main effect of R&D among Industrials is no longer statistically significant. However, there are significant differences in the coefficient estimates of the "R&D x IT" interaction term across industries. Focusing first on *Industrials*, we observe that the interaction term in Q1 (i.e. R&D x IT x D1) is statistically significant (coeff.=0.07, $p < 0.05$) for the current- and one-year lagged models. Similarly, the interaction term is significant for Q2 firms with estimates of 0.074 and 0.068 ($p < 0.05$) for the one- and two-year lagged models, respectively. However, the interaction term is not significant for *Industrial* firms in quadrants Q3 and Q4. We also note that the interaction effect of R&D and IT is not statistically significant among *C&E* firms.

Our results suggest that firms in Q2, which spend more on R&D compared to their industry peers, exhibit a positive interaction impact between

R&D and IT investments. In other words, firms which spend more on R&D but less on IT (compared to their industry peers) realize greater, marginal returns compared to firms in Q3 and Q4 that make relatively larger investments in R&D and IT, respectively. On the contrary, Q3 firms that outspend their peers on both R&D and IT dimensions exhibit statistically insignificant, interaction effects. Our results provide evidence of a "tipping point" beyond which spending on R&D or IT does not yield significantly greater marginal returns.

To summarize, the interaction effect of R&D and IT is positive among Industrials when firm R&D spending is greater than the industry median and IT spending is lower than its corresponding industry median. When firms outspend their peers on both R&D and IT, the interaction impact between R&D and IT is not significant and any incremental spending does not have a significant, marginal impact on firm profitability. Hence, we argue that support for hypothesis H3 with respect to the interaction effect of R&D and IT is more nuanced, i.e. the interaction impact of IT is observed only among *Industrial* firms which fall in the lower, left or right quadrant of their peer group based on relative R&D and IT spend levels. Furthermore, among *C&E* firms, our results support the direct impact of R&D and IT but do not provide supporting evidence of a significant interaction effect.

Table 5. Interaction Effects Model of Firm Performance across Different Quadrants

	Industrials			C&E		
	Current year	1-year Lag	2-year Lag	Current year	1-year Lag	2-year Lag
R&D	0.384	0.016	-0.015	2.201***	0.775***	0.740***
IT	0.803***	0.499***	0.468***	0.907***	0.249***	0.159***
R&D x IT	-0.607	-0.104	-0.073	-1.545	-0.220	-0.161
Assets	-0.042	-0.045	-0.033	0.144***	0.244***	0.292***
Advertising	0.458***	0.489***	0.505***	0.246***	0.337***	0.337***
Ind. Conc.	0.091	0.085	0.082	0.000	-0.041	-0.038
R&D x IT x D1	0.071**	0.053*	0.022	-0.091	-0.006	-0.004
R&D x IT x D2	-0.001	0.074**	0.068**	-0.585	-0.104	-0.118
R&D x IT x D4	-0.111	-0.034	-0.049	-0.202	0.010	0.045
Adj. R^2	0.47 (0.85, 0.69)	0.47	0.46	0.53 (0.85, 0.72)	0.70	0.71
F Value	16.82 (<.0001)	15.92 (<.0001)	15.37 (<.0001)	21.47 (<.0001)	23.46 (<.0001)	23.85 (<.0001)
No. of firm-year obs.	308			182		

- *p<0.1, **p<0.05, ***p<0.01. *p*-values are based on the z-statistic.

- Adjusted R2 values for instrumental variable regressions in the first stage of 2SLS are shown in parentheses for R&D and IT, respectively, in the row titled "Adj. R2."

- Standardized coefficients are provided

Conclusions

Given that innovation has been a fundamental source of technological change and productivity growth during the last two decades, there is no doubt that R&D is a key driver of such productivity improvements in the economy. In this study, we focus on the role of IT-enabled innovation and the importance of IT investments in moderating the productivity impact of R&D spending on firm performance. Considering that quantum strides in computing that have been made during the IT revolution since the mid-1990s, it is important to (a) understand the specific role of IT in improving the innovation capabilities of R&D processes, and (b) measure the interaction impact of R&D and IT investments on firm performance. While the literature has mostly focused on the impact of R&D or IT spending separately, our study focuses on the critical question: "Does IT spending enhance the effectiveness of the innovation output of R&D processes?"

We empirically test our conceptual research model using a seven-year, panel data set that reflects the significant technological changes since the first wave of Internet-based, commercial technologies in the last decade. Our study shows that R&D has a significant, positive impact on firm performance as measured by gross margin. Our results also indicate that the interaction between IT and R&D spending has a positive effect on firm performance. However, these effects cannot be generalized across all industries. Rather, we find support for the interaction impact of IT on firm profitability among those industrial firms that are relatively high R&D spenders but spend less than the industry median on IT. Among firms in the C&E industry, we find support for the direct impact of R&D and IT investments on firm profitability, but our results do not indicate a significant interaction impact.

Our study has several limitations. First, due to the secondary nature of the data, we do not have insight into the specific types of IT investments that firms in our sample have made during the time horizon in our study. Future research should focus on the allocation of the IT budget between various components such as software applications, consulting, and infrastructure investments. This may require combining our current data set with other data sources. Second, the product development time to market in some high-tech industries, such as semiconductors, can be in the range of three to five years. It is possible that the time period of our study did not allow us to observe the full effects of R&D and IT spending due to a decrease in the degrees of freedom required for robust econometric analyses. Third, our study uses data on large, global firms. This limits generalization of our findings to similar firms, and further exploration with data from smaller firms is needed. Fourth, since IT spending data is proprietary and our research design required a balanced panel across a multi-year, time period to capture the effects of R&D and IT, we are limited by the relatively small sample of firms for which complete data is available. Future research will seek to address these deficiencies by collecting a larger sample with firms from other industries to validate the effects that we observe among industrials and high technology firms.

Future research can extend this line of research to include firm efficiency measures using non-parametric estimation methods, such as data envelopment analyses, to study the impact of R&D and IT on firm efficiency. Another avenue for potential research includes studying the impact of R&D and IT on financial metrics such as stock returns and firm risk. While R&D investments are considered to be risky (since many R&D projects fail), smart IT investments can serve to lower the volatility of these risks by providing greater transparency into the execution of R&D projects, and improving coordination across multiple projects. New methodologies to estimate the impact of IT on these risks will need to be developed. Finally, additional case studies across different industries are needed to fully understand the process-level impact of R&D and IT investments on organizational innovation capabilities.

The results presented in our study have several implications for researchers and practitioners. Our analyses indicate that profitable innovation cannot be bought simply by throwing money on R&D projects. Based on our findings, we observe that R&D and IT spending are subject to diminishing marginal returns with respect to firm profitability. Spending above the inflection point results in lower returns since a firm will invest in high value projects first, followed by the next in line based on a rank-ordered scheme, until it is spending money on dubious projects. Our findings are consistent with the results reported by (Kandybin & Kihn, 2004) who conclude that "… the solution to innovation anemia is not to boost incremental spending, but to raise the effectiveness of base spending…"

The findings of our study imply that the IT can play a critical role in improving the effectiveness and efficiency of R&D processes by reducing coordination costs, increasing transparency, making better resource allocation decisions, and improving the overall business value of R&D. From a managerial perspective, an important implication of our study is to focus on the role of IT in improving innovation capabilities in their R&D organizations. Opportunities to use IT in all phases of the product innovation lifecycle should be explored. For instance, IT systems should be deployed to identify and sense emerging customer needs which will feed the product ideation phase. IT can be used to improve project governance through creation of project management software and disciplined stage-gate processes that streamline project workflows. From a research dimension, our study provides a fresh perspective into the drivers of firm financial and innovation performance and provides a new causal path that explains how IT can moderate the impact of R&D on profitability. It addresses a gap in the literature which has heretofore ignored the possibility of interaction effects when studying the relative productivity impact of IT and R&D on firm performance.

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References

Adler, P. . (1995). Interdepartmental interdependence and coordination: The case of the design / manufacturing interface. *Organization Science*, *6*(2), 147–167.

Ali, A., Chen, T.-Y., & Radhakrishnan, S. (2007). Corporate Disclosures by Family Firms. *Journal of Accounting and Economics*, *44*, 238–286.

Aral, S., & Weill, P. (2007). IT Assets, Organizational Capabilities, and Firm Performance: How Resource Allocations and Organizational Differences Explain Performance Variation. *Organization Science*, *18*(5), 763–780. https://doi.org/10.1287/orsc.1070.0306

Arnold, R., Peterson, J., & Dennis, R. (2005). *R&D and Productivity Growth*. *Background Paper*. https://doi.org/10.1787/652870318341

Banker, R. D., Bardhan, I. R., & Asdemir, O. (2006). Understanding the Impact of Collaboration Software on Product Design and Development. *Information Systems Research*, *17*(4), 352–373.

Bardhan, I. R. (2007). Toward a Theory to Study the Use of Collaborative Product Commerce for Product Development. *Information Technology and Management*, *8*(2), 167–184.

Barua, A., Kriebel, C. H., & Mukhopadhyay, T. (1991). An Economic Analysis of Strategic Information Technology Investments. *MIS Quarterly*, *15*(3), 313–331. https://doi.org/10.2307/249643

Bharadwaj, A. S. (2000). A Resource-Based Perspective on Information Technology Capability and Firm Performance: An Empirical Investigation. *MIS Quarterly*, *24*(1), 169–196.

Bloch, M., & Lempres, E. C. (2008). From Internal Service Provider to Strategic Partner. *McKinsey Quarterly*, 1–9.

Bresnahan, T. F., Brynjolfsson, E., & Hitt, L. M. (2002). Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-level Evidence. *Quarterly Journal of Economics*, *117*, 339–376.

Brynjolfsson, E. (1993). The Productivity Paradox of Information Tehcnology. *Business Computing*, *36*(12), 67–77. https://doi.org/10.1145/163298.163309

Brynjolfsson, E., & Hitt, L. (1996). Paradox Lost? Firm-level Evidence on the Returns to Information Systems Spending. *Management Science*, *42*(4), 541–558. Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Copyright+©2001.+All+Rights+Reserved.#0

Brynjolfsson, E., & Hitt, L. (2000). Beyond Computation: Information Technology, Organizational Transformation and Business Performance. *Journal of Economic Perspectives*, *14*(4), 23–48.

Brynjolfsson, E., & Hitt, L. (2003). Computing productivity: Firm-level evidence. *The Review of Economics and Statistics*, *85*(4), 793–808.

Carr, N. G. (2004). *Does IT Matter? Information Technology and the Corrosion of Competitive Advantage* (1st ed.). Harvard Business Review Press.

Chan, L. K. C., Lakonishok, J., & Sougiannis, T. (2001). The Stock Market Valuation of Research and Development Expenditures. *The Journal of Finance*, *LVI*(6), 2431–2456. https://doi.org/10.1111/0022-1082.00411

Chao, R., & Kavadias, S. (2013). R&D Intensity and the New Product Development Portfolio. *IEEE Transactions on Engineering Management, Vol. 60*(4), 664–675.

Charusilawong, N. (2014). *The effect of R&D, technological spillovers and absorptive capacity on productivity and profitability of automobile and electronics firms in Japan*. King's College London (University of London). Retrieved from http://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.650787

Chauvin, K. W., & Hirschey, M. (1993). Chauvin & Hirschey 1993.pdf. *Journal of the Financial Management Association*.

Cohen, W. M., & Levinthal, D. A. (1989). Innovation and learning: the two faces of R&D. *The Economic Journal*, *99*, 569–596.

Dedrick, J., Gurbaxani, V., & Kraemer, K. L. (2003). Information technology and economic performance. *ACM Computing Surveys*, *35*(1), 1–28. https://doi.org/10.1145/641865.641866

Dewan, S., & Min, C. (1997). The Substitution of Information Technology for Other Factors of Production: A Firm Level Analysis. *Management Science*, *43*(12), 1660–1675. Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Copyright+©2001.+All+Rights+Reserved.#0

Dos Santos, B. L., Peffers, K., & Mauer, D. C. (1993). The Impact of Information Technology Investment Announcements on the Market Value of the Firm. *Information Systems Research*, *4*(1), 1–23. https://doi.org/10.1287/isre.4.1.1

Ettlie, J. E. (1998). R&D and global manufacturing performance. *1Management Science*, *44*(1), 1–11.

Griliches, Z. (1994). Productivity, R & D, and the Data Constraint. *American Economic Review*, *84*(1), 1–23.

Griliches, Z., & Mairesse, J. (1984). Productivity and R&D at the Firm Level. In Z. Griliches (Ed.), *R&D, Patents, and Productivity*. Illinois: University of Chicago Press.

Gruman, G. (2007). IT Value Metrics: How to Communicate ROI to the Business. Retrieved from http://www.cio.com/article/print/144451

Hall, B. H., & Mairesse, J. (1995). Exploring the relationship between R&D and productivity in French manufacturing firms. *Journal of Econometrics*, *65*(1), 263–293. https://doi.org/10.1016/0304-4076(94)01604-X

He, Z., & Wintoki, M. B. (2016). The cost of innovation: R&D and high cash holdings in U.S. firms. *Journal of Corporate Finance*, *41*, 280–303. https://doi.org/10.1016/j.jcorpfin.2016.10.006

Hitt, L., & Brynjolfsson, E. (1996). Productivity , Profit and Consumer Welfare : Three Different Measures of Information Technology âğ™ s Value. *MIS Quarterly*, (June), 1–20. https://doi.org/10.1145/280324.280332

Jana, R. (2009). Dusting off a big idea in hard times. *BusinessWeek*.

Jaruzelski, B., Schwartz, K., & Staack, V. (2015). The 2015 Global Innovation 1000 - Innovation's new world order. *Strategy&*, (October), 1–20.

Kandybin, A., & Kihn, M. (2004). *Raising Your Return on Innovation Investment*.

Kogut, B., & Zander, U. (1992). Knowledge of the Firm, Combinative Capabilities, and the Replication of Technology. *Organization Science*, *3*, 383–397.

Kohli, R., & Devaraj, R. (2003). Performance Impacts of Information Technology: Is Actual Usage the Missing Link? *Management Science*, *49*(3), 273–289.

Lee, J., & Shim, E. (1995). Moderating effects of R&D on corporate growth in U.S. and Japanese hi-tech industries: An empirical study. *Journal of High Technology Management Research*, *6*(2), 179–191. https://doi.org/10.1016/1047-8310(95)90013-6

Lev, B., & Sougiannis, T. (1996). The capitalization, amortization, and value-relevance of R&D. *Journal of Accounting and Economics*, *21*(1), 107–138. https://doi.org/10.1016/0165-4101(95)00410-6

Loch, C. H., & Terwiesch, C. (1998). Communication and Uncertainty in Concurrent Engineering. *Management Science*, *44*(8), 1032–1048.

Marwaha, S., Patil, S., & Singh, N. (2007). Using IT to Speed Up Clinical Trials. *McKinsey Quarterly, 12-19*, 12–19.

McGrath, M. E., & Iansiti, M. (1998). Envisioning IT-Enabled Innovation. *PRTM Insight*,.

Mithas, S., Tafti, A., Bardhan, I., & Goh, J. M. (2012). Information Technology and Firm Profitability : Mechanisms and Empirical Evidence. *MIS Quarterly*, *36*(1), 205–224. https://doi.org/10.5465/amr.2011.0193

Morbey, G. K. (1988). R&D: Its Relationship to Company Performance. *Journal of Product Innovation Management*, *5*, 191–200.

Nambisan, S. (2002). Complementary Product Integration by High-Technology New Ventures: The Role of Initial Technology Strategy. *Management Science*, *48*(3), 382–398.

Nonaka, I., & Takeuchi, H. (1995). *The Knowledge-Creating Company*. New York, NY: Oxford University Press.

Rai, A., Patnayakuni, R., & Patnayakuni, N. (1997). Technology Investment and Business Performance. *Communications of the ACM*, *40*(7), 89–97. https://doi.org/10.1145/256175.256191

Robert U Ayres. (2016). *Energy, Complexity and Wealth Maximization*. Switzerland: Springer International Publishing.

Sakakibara, M., & Branstetter, L. (2001). Do Stronger Patents Induce More Innovation? Evidence from the 1988 Japanese Patent Law Reforms. *RAND Journal of Economics*, *32*(1), 77–100.

Shah, R., & Shin, H. (2007). Relationships among information Technology, Inventory, and Profitability: An Investigation of Level Invariance Using Sector Level Data. *Journal of Operations Management*, *25*(4), 768–784.

Thouin, M. F. (2008). Modeling and Simulation for Drug Discovery and Development: Current Practices and Opportunities for Advancement. *Expert Opinion Drug Discovery*, *3*(6), 591–593.

Villas-Boas, M., & Winer, R. S. (1999). Endogeneity in Brand Choice Models. *Management Science*, *45*(10), 1324–1338.

Zeithaml, V. A., & Bitner, M. J. (1996). *Services Marketing*. Singapore: McGraw Hill.