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Riding the waves of technology through the decades: The relation between industry-level information technology intensity and the cost of equity capital

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ABSTRACT

This paper examines the effect that information technology (IT) investments have on the industry cost of equity capital. We find that industry IT intensity, defined as the relative amount of IT investment to total fixed asset expenditures, is negatively related to the industry cost of equity capital. These results indicate that industries with higher levels of IT investment have lower cost of equity capital. We also find that the relation between IT intensity and cost of equity capital changes over time. Initially, investors viewed IT investments as risky ventures and demanded higher levels of cost of equity (or higher return on their investment) for those industries investing in IT. However, beginning in the 1980s, as IT became more reliable, more cost effective, and had the ability to transform businesses, investors viewed IT Intensity as a positive business strategy with less associated risks and reduced their required cost of equity capital (or lower return on their investment). Extrapolating from our industry results, IT investments allow firms to potentially raise capital at a lower price so they have more assets to employ, indicating that IT investments can be a key factor for business success.

1. Introduction

The past six decades have seen information technology (IT) continuing to evolve – from the original vacuum tube computer to the complex networking systems of today (Hirschheim and Klein, 2012). Each decade or "wave" of technology changed IT applications, system reliability, and managerial processes employed by the firm (Rockart, 1988). Given each wave's distinctive characteristics and associated risks, the relation between IT and firm performance measures is likely to be different for each wave. Accordingly, we examine the following research question: how is IT intensity, defined as the relative amount of IT investment to total fixed asset expenditures, associated with the cost of equity capital in each of the last six waves, or decades, of technology?

Various approaches and output measurements have been used to examine the impact of IT investments on firm performance (c.f. Kobelsky et al., 2014; Dedrick et al., 2003; Dehning and Richardson, 2002). Initially, little empirical evidence of the (positive) relation could be found leading to the term "productivity paradox" (Brynjolfsson and Hitt, 1996). However, more recently, research has found support for the relation. Firms strategically invest in technology to enhance their financial performance (Grabski et al., 2011; Dehning et al., 2003; Im et al., 2001; Dewan et al., 2007). For example, IT spending is an important aspect of a firm's value

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chain (Kobelsky et al., 2008) and this relation may be mediated through revenue enhancement and cost savings (Mithas et al., 2012). We extend this literature by examining IT's relation to the cost of equity capital, which is the rate of return that firms have to pay for the equity used (Easley and O'Hara, 2004).

The cost of equity capital varies between firms to reflect differences in risk (Barth et al., 2013). Higher risk firms are subject to a higher cost of capital, while lower risk firms enjoy a lower cost of capital (Easley and O'Hara, 2004). However, the relation among IT investment, risk and cost of equity capital is not obvious. On the one hand, due to the riskiness of new technologies and the potential obsolescence of existing technologies, IT can be viewed as increasing the overall risk of the firm (Ren and Dewan, 2015), suggesting a higher cost of equity capital.

On the other hand, investments in IT have been shown to reduce risks in firms (Otim et al., 2012). One potential reason for the reduction in risk is Bezos' Law, which states that the price of a single unit of computing power is reduced by 50% every three years (O'Connor, 2014), continually decreasing the total cost of ownership. This cost reduction means that firms can invest in IT in hopes of reducing coordination costs and eventually firm size (Dedrick et al., 2003) as well as increasing both productivity and revenue (Im et al., 2013). Another potential reason for the reduction in risk is that IT, if implemented effectively throughout the firm, allows managers to generate more accurate forecasts indicating that IT investments provide managers with higher quality information (Li 2012) (hopefully) leading to better strategic decisions. So, over time as the price drops, more computing power becomes available making investments in IT (potentially) have a greater strategic impact, which should decrease a firm's overall level of risk and its associated cost of capital.

To address our research question, we employ different measures than most extant IT productivity research. Instead of using IT spending or IT budgets, we use IT intensity, defined as the comparative investment of a firm on their IT resources, because the measure better captures the relative mix of IT used in strategic priorities (Stiroh, 2002). Our IT intensity measure is available at the industry level from the Bureau of Economic Analysis. Therefore, we examine the relation of industry-level IT intensity with the industry-level cost of equity capital, which captures the risk often associated uniquely with an industry (Fama and French, 1997). We also examine this relation over time to reflect the evolutionary changes in the IT waves since the 1950s.

Conducting our analysis at the industry level is appropriate because it eliminates any idiosyncratic issues that could be present at the firm level (Hu, 2005). Moreover, given that production environments tend to be highly correlated within industries because firms within an industry typically use similar ***technologies*** and face similar production functions, markets, ***and risks*** (Ely, 1991, emphasis added), the relative IT investment levels and cost of equity capital should be similar for firms throughout an industry.[1] This industry-level examination allows us to capture unique industry risks, attributes, and characteristics as well as provide a broader understanding of the effect (Brynjolfsson et al., 1994; Chou et al., 2012). Thus, by testing industry-level data, this study presents an overall understanding of a macro-level benefit of IT investment, potentially helping to evaluate the decades of studies on the "productivity paradox."

We find that the overall relation between IT intensity and cost of equity capital from 1950 to 2009 is significantly negative indicating that investors appear to have rewarded firms that invest in IT with a lower cost of equity capital. However, further inspection reveals that the relation between IT intensity and cost of equity capital changes over time. In the first decade marked by the first UNIVAC computer (1950s), industry-level IT intensity was positively related to the industry-level cost of equity capital, signifying a higher cost of equity for industries investing in IT. Thus, it appears that initially investors viewed IT investments as risky ventures with only limited applications and markets, therefore requiring a higher level of cost of equity for those industries investing in IT. During the 1960s and 1970s, there is no clear relation between IT intensity and the cost of equity capital. However, beginning in the 1980s, IT intensity is negatively related to cost of equity capital, signifying a lower cost of equity for industries investing in IT. The 1980s ushered in the PC, which increased IT's reliability, cost effectiveness, and transformational power (Brynjolfsson et al., 1994). At this point, investors likely began to view IT investments as a positive, less risky, business strategy thereby reducing their required cost of equity capital. Extrapolating from these industry results, effective IT investments appear to now lower cost of equity capital, allowing firms to raise capital at a lower price so they have more assets to employ. Finally, we find that the results are independent of industry.

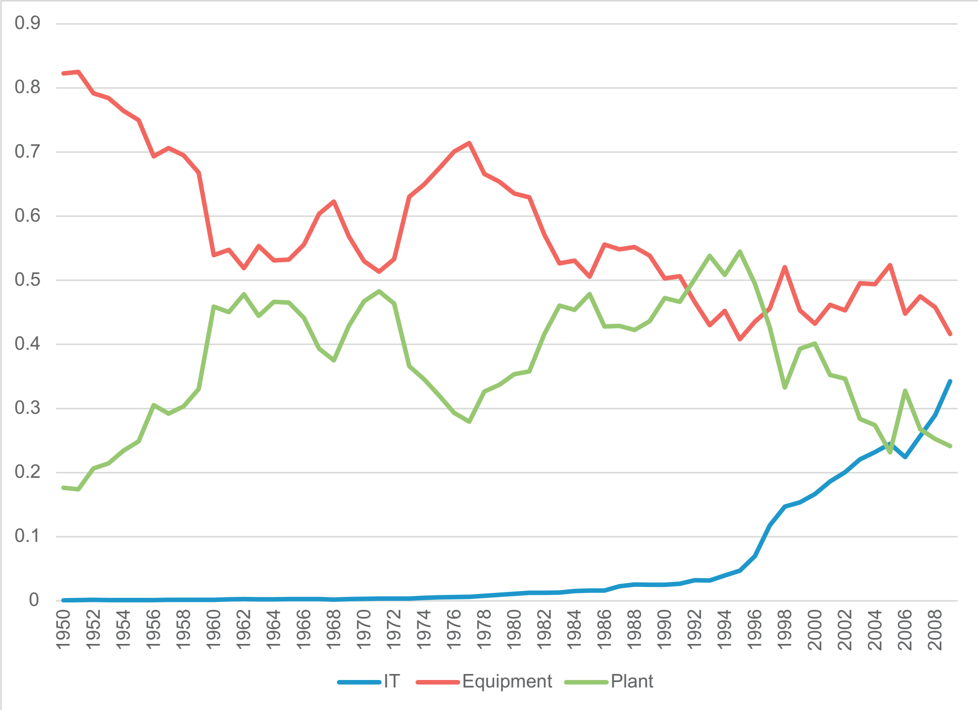
The remainder of the paper is organized as follows. Section 2 develops the hypotheses concerning the impact of IT intensity on the cost of equity capital. Section 3 presents the methods employed in this research. Section 4 presents the empirical findings. Finally, Section 5 concludes.

2. Hypothesis development

2.1. Cost of equity capital

Investors use cost of equity capital to evaluate investment opportunities. The cost of equity capital can be thought of as the rate of return that must be paid for equity (Easley and O'Hara, 2004). Thus, the cost of equity capital represents the compensation that the market demands in exchange for owning the asset and bearing the risk of ownership. This measure is often referred to as a risk metric because it provides investors with a sense of the market's perception of risk. Higher levels of risk require higher returns (i.e., a higher cost of equity capital) than lower levels of risk (Ashbaugh-Skaife et al., 2009).

[1] Thus, based on this argument, a firm-level analysis should provide similar results. Unfortunately, our IT intensity measurements are not available at the firm-level to confirm this conclusion.



IT stands for information technology.

Fig. 1. Capital expenditures on IT, equipment, and plant over the decadesIT stands for information technology.

At a firm level, the cost of equity capital directly impacts operations, investments, capital structure, and profitability (Easley and O'Hara, 2004). When the cost of equity capital decreases, it becomes easier to raise capital, which should increase available corporate resources and, in turn, positively impact operations and profitability. The cost of equity capital is therefore an important concept for both managers and investors – managers are concerned about how to raise capital efficiently and investors are interested in their risk-adjusted returns.

Recent studies have shown that improving the quality and the flow of information can decrease the cost of equity capital (Botosan et al., 2004; Cheng et al., 2006; Francis et al., 2005; Hail and Leuz, 2006; Mikhail et al., 2004). These studies document improvements in the availability and interpretability of information through more organizational transparency, legislation requiring additional disclosures, or higher accounting quality. We propose that an additional factor, IT intensity, may also improve the quality and flow of information impacting the cost of equity capital.

2.2. IT intensity

IT intensity is defined as the relative amount of IT investment to total fixed asset expenditures. Prior studies have used IT intensity to indicate industries' different propensities to invest in IT (Mittal and Nault, 2009; Stiroh, 2002). IT intensity is part of an IT investment strategy (Ravichandran and Liu, 2011), and, hence, directly associated with IT capabilities (Bharadwaj, 2000; Chang and Gurbaxani, 2012). Intensive IT investments allow firms to foster organizational learning and make use of other inputs more effectively (Ayal and Seidman, 2009; Mitra, 2005). Accordingly, firms with higher IT intensity may be better able to leverage the capabilities of innovations (DiRomualdo and Gurbaxani, 1998; Quinn, 1999). Given that firms in an industry use similar technologies and face similar production functions, markets, and risks (Ely, 1991), higher levels of IT intensity at the industry level should indicate that the overall industry, as well as its individual firms, utilize more IT in their operations.

Fig. 1 graphs total capital expenditures for IT, equipment, and plants from 1950 to 2009. The graph depicts that IT's share of total capital investment began to significantly increase in the late 1980s and continued to accelerate over the next twenty years. Fig. 1 supports Stiroh (2002) finding that in the late 1980s industries began to see IT investments as a significant contribution to their productivity and, as a result, saw IT not only as a niche, but also as a required competitive investment.

Studies on productivity show that IT intensity varies across industries, and that the level of IT intensity is associated with an industry's economic performance. For example, Dumagan et al. (2003) finds that industries with higher IT intensity experience higher output growth and productivity growth than lower-IT-intensity industries. Similarly, Stiroh (2002) finds that industries that are either producers or heavy users of IT (i.e., IT-intensive industries) make a significantly greater contribution to productivity acceleration in the United States in the late 1990s compared to the rest of the economy. In addition, IT investment has both direct and indirect effects on productivity while the latter one is through augmentation of non−IT capital and labor (Mittal and Nault, 2009).

Investments in IT can result in improvements in the quality and the flow of information. For example, IT has been shown to be able to improve the accuracy of management forecasts (Li 2012). Furthermore, Dorantes et al. (2013) provide direct evidence that IT investments can improve information quality. They find that after implementing enterprise systems firms are not only more likely to issue management forecasts, but also issue more accurate forecasts due to “access to improved internal information” (p. 1428). Thus, on the one hand, IT intensity is an important aspect of reducing operational cost and improving both economic performance and information quality, which should decrease risk and cost of equity capital.

On the other hand, investors must continuously interpret the impact of IT intensity and IT investments and how they relate to performance. One difficulty in making these interpretations is that often the information available to investors about IT investments is incomplete or untimely, thereby making it difficult to fully predict how the information may impact future performance (Brynjolfsson and Hitt, 1996). Information risk may ultimately impede an investor's ability to make sound investment decisions as it is not possible to determine the true financial position. Therefore, investors may expect a higher return (i.e., higher cost of equity capital) on their investment given the higher risk (Francis et al., 2005) associated with IT investments.

While the literature does not provide clear guidance regarding the relation between the impact of IT intensity on the cost of equity capital, we believe the preponderance of evidence suggests that IT intensity reduces the cost of equity capital. IT improves information quality, productivity, and economic performance because IT provides the foundation for an effective system of internal controls over financial and managerial reporting (e.g. Masli et al., 2010; Li et al., 2012; Dorantes et al., 2013), reducing risk, which should, in turn, lower the cost of equity capital. Therefore, we predict an overall negative relationship between the industry-level IT intensity and the industry-level cost of equity capital. The first hypothesis, stated in the alternative form is:

H1. There is a negative association between IT intensity and cost of equity capital.

2.3. *Waves of technology*[2]

IT has continued to evolve and change significantly through the decades. Each decade or “wave” of technology transformed IT applications, system reliability, and managerial processes employed by the firm (Rockart, 1988). As IT changed over the decades, we predict that the relation between IT intensity and the cost of equity capital changed reflecting the changes in IT's impact on information quality as well as investors' perceived risk associated with IT investments.

In the 1950s, the “Accounting Era,” the first generation of (UNIVAC) computers for business use was introduced for $750,000 (approximately seven million dollars today) (Anonymous, 2016). These computers were slow, focused on accounting applications, and had questionable reliability (Rockart, 1988). Thus, IT was considered highly risky and very expensive making IT investments associated with a higher cost of equity capital as investors would require a higher return to offset the increased risk.

In the 1960s, the “Operational Era,” large firms began to adopt smaller (and more affordable) minicomputers within their business operations. This generation of innovation was characterized by mainframes and minicomputers, which were faster and more reliable than prior computers, but were highly technical and required a specialized set of knowledge to understand. Much of the software developed during this time was created by teams with little oversight thereby causing the software to have poor design and have a high malfunction rate (Lewis, 1957). This inability to produce stable functioning software resulted in businesses not being able to fully leverage the capabilities of IT and investors not being able to properly value the innovations leading to higher cost of equity capital for IT investments.

In the late 1970s, the “Information Era,” business use of personal computers increased giving employees access to computing power. These computers used relational databases and changed the focus of computers from just transaction processing to the use of information (Rockart, 1988). Thus, these innovations improved the work functions of many employees. However, since much of the innovation was only for internal process automation, suppliers and customers often perceived little value from these innovations (Poppel, 1982). As a result, investors often regarded IT innovations as necessary for businesses to compete, but not sufficient to gain a competitive advantage (Lim et al., 2012) resulting in IT investments not having much of an impact on the cost of equity capital.

The 1980s ushered in the “Wired Society” Era. During this era, computer hardware and software became more cost effective and higher band-with communications allowed multi-organizational and multi-functional systems. These changes became even more prominent in the Internet boom of the 1990s, which changed the way businesses leverage technology. This “Internet Era” allowed millions of people to access data simultaneously. For example, electronic data interchange allows the sharing of data and information from dispersed locations so organizations can coordinate their supply chains (Sawabini, 2001). As a result of these network externalities, the business value of IT innovations also increased (Mukhopadhyay et al., 1995) because the flow of information was improved, which should have lowered the perceived risk of IT investments as well as the associated cost of equity capital.

In the 2000s, the “Enterprise System Era,” almost every company heavily invested in IT widely adopting such technologies as enterprise systems. On the one hand, due to the ubiquitous nature of IT innovations at this point in time, IT investments may not provide a sustainable competitive advantage (Carr, 2003), which should increase the cost of equity capital demanded for IT investments. On the other hand, after 1991, IT investments improved productivity, financial performance, (Brynjolfsson and Hitt, 1996), and the quality of information (Li et al., 2012). Consequently, investors' perception of the risk associated with IT investments may have decreased. Investors may continue to believe that higher IT intensity will still improve productivity and financial performance in the future and as a result demand a lower cost of equity capital for IT investments.

[2] This discussion is based on Rockart (1988).

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Table 1
Tabulation of industry-year observations in sample.

Beginning industry years available (49 Fama-French industries of 60 years)	2880
Less: missing IT intensity from Bureau of Labor Statistics	(874)
Less: missing industry returns	(64)
Less: missing industry book-to-market ratio	(4)
Total industry years available for study	1938

In summary, in the early stages of the waves of technology, IT intensity should be positively associated with cost of equity capital as IT uses were limited and not always effective. By the more recent waves of technology, businesses continued to invest in technology and understand how IT innovations could be leveraged for competitive advantage to increase information flow and quality. Further, over time, investors have become more accepting with respect to technology and its strategic impact (Muhanna and Stoel, 2010). As such, over time, the association between IT intensity and cost of equity capital is expected to continue to decline (i.e., IT intensity should be associated with a lower cost of equity capital). Consequently, the second hypothesis is:

H2. The association of IT intensity with the cost of equity capital decreases over time.

3. Research methods

3.1. Sample and measures

IT Intensity is defined as the ratio of IT investment to total capital investment and signifies the industry's IT investment as a percentage of the industry's total non-residential fixed assets for a given year. IT investment is defined as the sum of computer and peripheral equipment, software, and communications. Total capital investment is defined as the sum of equipment and software and structures. The IT Intensity ratio (*ITIntensity*) is calculated on an annual basis. The IT investment and the total capital investment data are collected from Current-Cost Net Capital Stock of Private Nonresidential Fixed Assets tables as described by the Bureau of Economic Analysis (BEA) (2004). BEA provides data describing non-current fixed asset capital investments for the last one hundred years by industry.

Using the BEA data, we first collected IT investment and total capital investment data for 1950 through 2009. Then, we grouped the industries into the Fama and French's (1997) 49-industry categorization. Our initial sample consisted of 2880 industry-year observations. We then removed observations missing IT investment (874 industry-years) as well as industry returns and book-to-market ratios (70 industry-years), resulting in 1938 industry-year observations in our final sample. We further defined six decades to reflect the different waves or eras of IT. Table 1 presents a cross-tabulation summary of the final sample used in this study.

We measure industry cost of equity capital (*COE*) using the Fama-French three factor model. The Fama-French three factor model is an extension of the Capital Asset Pricing Model (CAPM) where the three factors are market risk, portfolio size, and portfolio value (Fama and French, 1997).[3] We obtained all data other than *ITIntensity* from the Fama-French website (French, 2014).

Table 2 presents the descriptive statistics for the variables used in the study as well as the correlation matrix. Our average cost of capital during the sixty year period is 13.9%. The *ITIntensity* variable has a mean of 8.8%. The correlation matrix shows that *ITIntensity* is highly correlated with each of the three factors. Specifically, *ITIntensity* is significantly negatively correlated with cost of equity capital (*COE*), indicating that for the entire sample period IT investments are associated with lower levels of cost of equity capital. Examination of the correlation matrix depicts quite high correlations among the study variables. In fact, only three pairs of correlations are not statistically significant, which is consistent with prior research using the Fama-French models.

3.2. Model specifications

To test H1, we employed ordinary least squares (OLS). To test H2, we employed generalized linear models (GLM). Our study uses the three factor model because of its ability to explain over 90% of a diversified portfolio returns (Fama and French, 2004). Similar to other studies employing the Fama-French model (e.g. Francis et al., 2005), we expand the base Fama-French model with the addition of the *ITIntensity* variable to test its effect on the industry cost of equity capital, resulting in Eq. (1).

$$COE_{\mathrm{t}} = \alpha + \beta_1 (R_{mt} - R_{ft}) + \beta_1 SMB_i + \beta_2 HML_i + \beta_3 ITIntensity_i + \varepsilon_i \quad (1)$$

where[4]:

- $COE{:}R_{it} - R_{ft}$ is the industry excess returns (the industry returns in excess of the risk free rate in a given time period)
- $R_{mt} - R_{ft}$ is the market excess returns (the market returns in excess of the risk free rate in a given time period)

[3] Multiple financial models can estimate the cost of equity capital. The Capital Asset Pricing Model (CAPM) is the original model to capture this effect. The CAPM measures the market risk premium (i.e., reward-to-risk ratio) of the individual firm to the relative performance of an industry. The Fama-French Three Factor Model (Fama and French, 1997, 2004) addresses the weaknesses of CAPM, and as a result, has emerged as one of the most commonly used models for estimating the cost of equity capital.

[4] Except for IT Intensity, all variables names and definitions match those on the Fama-French website.

Table 2
Descriptive statistics and correlation matrix of study variables[a].

	Mean	St. Dev	1	2	3	4	5
1. *CEC*	13.944	26.874	1.000				
2. *Rm-Rf*	7.669	18.350	0.648***	1.000			
3. *SMB*	1081	2692	0.025	− 0.003	1.000		
4. *HML*	0.647	0.359	− 0.033*	0.002	− 0.225***	1.000	
5. *ITIntensity*	0.088	0.115	− 0.047**	− 0.048**	0.648***	− 0.302***	1.000

[a] *CEC* is the cost of equity capital. *Rm-Rf* is the market's annual return adjusted for the annual risk-free rate. *SMB* (Small Minus Big) is constructed by six value weighted portfolios taking the difference between the average return on the three small portfolios and the average return on the three big portfolios. *HML* (High Minus Low) is constructed by six value weighted portfolios taking the difference between the average return on the two value portfolios minus the average return on the two growth portfolios. *ITIntensity* is defined as the relative amount of IT investment to total fixed asset expenditures at the industry-level.
*** Identifies significance at $p < 0.01$.
** Identifies significance at $p < 0.05$.
* Identifies significance at $p < 0.10$.

Table 3
Ordinary Least Squares (OLS) results for the impact of IT intensity on the cost of equity capital[a]:
$COE_t = \alpha + \beta_1(R_{mt} - R_{ft}) + \beta_1 SMB_i + \beta_2 HML_i + \beta_3 ITIntensity_i + \varepsilon_{i.}$

Source	Parameter estimate	t-Statistic	*p*-Value
(Intercept)	9.23	8.04	< 0.0001
Rm-Rf	0.99	39.1	< 0.0001
SMB	0.002	3.37	< 0.0001
HML	− 3.12	− 2.45	0.014
IT Intensity	− 17.98	− 3.44	< 0.0001
R-square	0.4496		
Coeff var	145.582		
Root MSE	19.835		

[a] Variables are defined as follows:
$COE: R_{it} - R_{ft}$ (Cost of Equity) is the industry excess returns (the industry returns in excess of the risk free rate in a given time period).
Rm-Rf: the market's annual return adjusted for the annual risk-free rate.
SMB: (Small Minus Big) is constructed by six value weighted portfolios taking the difference between the average return on the three small portfolios and the average return on the three big portfolios.
HML: (High Minus Low) is constructed by six value weighted portfolios taking the difference between the average return on the two value portfolios minus the average return on the two growth portfolios.
ITIntensity: the ratio of IT investment to total capital investment for a given year for a given industry.

- *SMB* measures the size effect on the portfolio. This is the difference in excess returns between large and small firms based on the firm's total assets.
- *HML* measures the value effect on the portfolio. This is the difference in excess returns between large and small cap portfolios.
- *ITIntensity* is the ratio between IT capital investment and total capital investment for the industry.

For H1, our variable of interest is *ITIntensity*. We expect a negative coefficient on *ITIntensity* indicating that IT investments are associated with a reduced cost of capital. H2 examines the association of IT intensity and cost of equity capital over time. To measure the time effect, our analysis partitions the data into six decade categories (1950s, 1960s, 1970s, 1980s, 1990s and 2000s). To test H2, we run Eq. (1) for each of the six decades of the study period. The coefficient of *ITIntensity* is expected to change over time, moving from positive to negative, indicating that early IT investments were perceived as risky and required higher levels of return by investors while later IT investments were perceived as improving the information quality and efficiency of the industry. In order to identify any significant changes in the *ITIntensity* coefficient, we performed the Chow Test.

4. Results

The OLS results reported in Table 3 show a significant effect of IT intensity (*ITIntensity*) on an industry's cost of equity capital ($p < 0.01$). Consistent with H1, higher levels of industry-level IT intensity are associated with a significantly lower industry-level cost of equity capital. These results indicate that, in general, investment in IT does matter and is rewarded with lower levels of cost of equity capital.[5]

To examine whether a temporal effect exists in the association between IT intensity and the cost of equity capital, we first examined whether a difference exists in the effect of IT intensity on the cost of equity capital across decades by adding a the

[5] We also performed the Hausman Test (a test for reverse causality) to determine whether any of the explanatory variables exhibit endogenity (either omitted variable biased, measurement error, or reverse causality) and found no evidence. These results suggests that IT intensity is indeed exogenous.

Table 4
Generalized Linear Model (GLM) results for IT intensity on the cost of equity capital by decade (wave of technology)[a]:
$COE_t = \alpha + \beta_1(R_{mt} - R_{ft}) + \beta_1 SMB_i + \beta_2 HML_i + \beta_3 ITIntensity_i + \beta_4 Decade^{*} ITIntensity + \varepsilon_i$.

Source	DF	Type III SS	Mean square	F value	Pr > F
Rm-Rf	1	613,508.1	603,876.50	1562.98	0.001
SMB	1	1621.468	2386.89	6.18	0.013
HML	1	3131.825	4190.67	10.85	0.001
IT Intensity	1	9974.515	130.86	0.34	0.5607
*Decade * IT Intensity*	5	23,989.218	15,646.04	8.1	0.001
R-square			0.461		
Coeff var			144.264		
Root MSE			19.656		
vwret mean			13.625		

[a] Variables are defined as follows:
COE: $R_{it} - R_{ft}$ (Cost of Equity) is the industry excess returns (the industry returns in excess of the risk free rate in a given time period).
Rm-Rf: the market's annual return adjusted for the annual risk-free rate.
SMB: (Small Minus Big) is constructed by six value weighted portfolios taking the difference between the average return on the three small portfolios and the average return on the three big portfolios.
HML: (High Minus Low) is constructed by six value weighted portfolios taking the difference between the average return on the two value portfolios minus the average return on the two growth portfolios.|
ITIntensity: the ratio of IT investment to total capital investment for a given year for an industry.
Decade: The data is partition into six decade categories (1950s, 1960s, 1970s, 1980s, 1990s and 2000s) using dummy variables equal to one for each decade.

interaction between IT Intensity and a dummy variable for decade (*Decade* ITIntensity*). Table 4 shows a significant temporal effect of the impact of IT intensity on cost of equity capital.

To further examine the nature of the difference, we divided the data into six sub-samples, one for each decade. Table 5 reports the results of IT intensity on cost of equity capital for each decade. We find a significant positive association between IT intensity and cost of equity capital during the 1950s, the "Accounting Era," when computers were not very reliable and IT investments may have been perceived as risky-increasing the cost of equity capital. We find significant negative associations in the 1980s, 1990s, and 2000s when computers became more ubiquitous, reliable, cost effective, and businesses used them to leverage/improve operations. At first glance, we find preliminary support for H2 in this study.

To assess the stability of *ITIntensity*, we used the Chow (1960) test[6] as presented in Eq. (2) which was developed by Gujarati (1970) and used by a number of scholars (c.f. Venkatesh et al., 2003). Table 6 presents the results of the Chow test for the pairwise comparisons. As shown, *ITIntensity* is substantially stable for the decades from 1950 through the 1980s. The impact of *ITIntensity* is markedly different for the 1980s and 1990s as well as the 1990s and 2000s. In general, our findings suggest that IT intensity is generally significant and positive (increases the cost of equity capital) during the early waves of IT decades and significant and negative (decreases the cost of equity capital) during the most recent waves of IT.

$$Chow\ Statistic = \frac{(S_C - (S_1 + S_2))/(k)}{(S_1 + S_2)/(N_1 + N_2 - 2k)} \tag{2}$$

where:

- s_C is the sum of squared residuals from the combined data from *both comparison groups* (waves of technology)
- s_1 is the sum of squared residuals from the *first comparison group* (wave of technology)
- s_2 is the sum of squared residuals from the *second comparison group* (wave of technology)
- N_1 and N_2 are the number of observations in each group
- k is the number of regressors

Extant research shows that persistent differences in performance across industries can result from different industry characteristics (Dehning et al., 2005; Porter, 2008). In particular, studies have found that industry type can have a significant impact on a variety of organizational outcomes (Dehning et al., 2005; Otim et al., 2012). To further test the robustness of our results, the sample was divided into manufacturing and non-manufacturing industries because IT investments have been shown to have a greater impact in industries that are more IT intensive. Specifically, Bloom et al. (2014) find that effective performance monitoring, targets and incentives in manufacturing firms are strongly linked to more intensive use of IT. IT investments can also increase the productivity of non-manufacturing employees (e.g. Aral et al., 2012; Elbashir et al., 2008). However, a survey of executives reveals that executives from some (non-specified) industries estimated a lower financial impact from improved use of IT (Genpact, 2014). Therefore, to see if there is a difference in our results between different types of industries, we add an additional dummy variable, *Industry*, to Eq. (1). We dichotomized our sample into two broad categories by grouping Fama and French's (1997) 49-industry categorization into manufacturing (*Industry* = 1) and non-manufacturing (*Industry* = 0). The results shown in Table 7 do not show a

[6] The Chow test statistic follows an F-Distribution with k and $N_1 + N_2 - 2k$ degrees of freedom.

Table 5

Ordinary Least Squares (OLS) results for the impact of IT intensity on the cost of equity capital by decade[a]:

$COE_t = \alpha + \beta_1(R_{mt} - R_{ft}) + \beta_1 SMB_i + \beta_2 HML_i + \beta_3 ITIntensity_i + \varepsilon_i$.

	1950–1959		1960–1969		1970–1979		1980–1989		1990–1999		2000–2009	
Source	Parameter estimate	t-Statistic	Parameter estimate	t-Statistic	Parameter estimate	t-Statistic	Parameter estimate	t-Statistic	Parameter Estimate	t-Statistic	Parameter estimate	t-Statistic
(Intercept)	6.469	2.32**	10.984	3.72***	5.365	1.82*	13.816	5.31***	23.075	5.91***	24.749	2.7***
Rm-Rf	0.908	15.21***	1.33	16.63***	1.167	21.3***	0.836	11.99***	0.963	12.58***	1.024	17.06***
SMB	-0.003	− 0.69	− 0.004	− 1.38	− 0.002	− 0.43	0.005	2.32**	0.007	6.04***	0.0001	0.13
HML	-4.322	− 1.87*	− 6.451	− 1.78*	1.131	0.41	− 3.769	− 1.51	− 22.303	− 4.8***	5.83	1.27
ITIntensity	523.986	1.76*	220.694	1.28	48.084	0.71	− 63.901	− 2.28**	− 118.348	− 6.44***	− 62.07	− 2.3**
R-square	0.558		0.477		0.566		0.305		0.421		0.502	
Coeff var	77.307		147.232		236.989		98.908		120.606		237.849	
Root MSE	15.197		21.264		20.556		17.036		18.342		21.031	
vwret mean	19.657		14.442		8.674		17.224		15.208		8.842	

[a] Variables are defined as follows:

COE: $R_{it} - R_{ft}$ (Cost of Equity) is the industry excess returns (the industry returns in excess of the risk free rate in a given time period).

Rm-Rf: the market's annual return adjusted for the annual risk-free rate.

SMB: (Small Minus Big) is constructed by six value weighted portfolios taking the difference between the average return on the three small portfolios and the average return on the three big portfolios.

HML: (High Minus Low) is constructed by six value weighted portfolios taking the difference between the average return on the two value portfolios minus the average return on the two growth portfolios.

ITIntensity: the ratio of IT investment to total capital investment for a given year for an industry.

* Indicates significance at $p < 0.10$

** Indicates significance at $p < 0.05$

*** Indicates significance at $p < 0.01$

Table 6
Chow Test of the impact IT intensity on the cost of equity capital across the six decades (waves of IT).

Decade comparison	Chow statistic
1950s and 1960s	1.4
1960s and 1970s	1.61
1970s and 1980s	0.18
1980s and 1990s	3.55*
1990s and 2000s	22.69***

* Indicates significance at $p < 0.10$.
** Indicates significance at $p < 0.05$.
*** Indicates significance at $p < 0.01$.

Table 7
Generalized Linear Model (GLM) results for Eq. (1) plus industry[a]:
$COE_t = \alpha + \beta_1(R_{mt} - R_{ft}) + \beta_1 SMB_i + \beta_2 HML_i + \beta_3 ITIntensity_i + \beta_4 Industry + \varepsilon_i$.

Source	DF	Type III SS	Mean square	F value	Pr > F
Rm-Rf	1	593,838.3619	593,838.3619	1491.5	< 0.0001
SMB	1	3786.9955	3786.9955	9.51	0.0021
HML	1	2258.6827	2258.6827	5.67	0.0173
IT Intensity	1	4191.8122	4191.8122	10.53	0.0012
Industry	2	42.4649	21.2325	0.05	0.9481
R-square			0.45		
Coeff var			146.568		
Root MSE			19.954		
vwret mean			13.613		

[a] Variables are defined as follows:
COE: $R_{it} - R_{ft}$ (Cost of Equity) is the industry excess returns (the industry returns in excess of the risk free rate in a given time period).
Rm-Rf: the market's annual return adjusted for the annual risk-free rate.
SMB: (Small Minus Big) is constructed by six value weighted portfolios taking the difference between the average return on the three small portfolios and the average return on the three big portfolios.
HML: (High Minus Low) is constructed by six value weighted portfolios taking the difference between the average return on the two value portfolios minus the average return on the two growth portfolios.
ITIntensity: the ratio of IT investment to total capital investment for a given year for an industry.
Industry: Fama-French 49 industries are partitioned into two industry categories: manufacturing and non-manufacturing. A dummy variable equals one if the industry is in manufacturing.

significant effect of industry suggesting no difference exists across industry types for the relation of IT intensity and the cost of equity capital.

5. Discussion

Academics and IT managers have attempted to determine the value of IT since the purchase of the first commercial UNIVAC computer in the 1950s. While prior research has tended to focus on the firm-level value of IT investments, we use a different approach for assessing the impact of IT investments – the relation between industry-level IT intensity and the industry-level cost of equity capital. The cost of equity capital reflects investors' perceived risk about an investment. IT increases the operational risk if it fails to perform or is deficient (Brown, 2001).

In general, our empirical findings demonstrate that IT investment does matter and can have a significant impact on the cost of equity capital. Looking at the periods of 1950–2009, IT intensity has a (overall) negative relationship with cost of equity capital (i.e., lower cost of equity capital). Thus, investors appear to incorporate IT intensity into their required cost of capital when evaluating investment opportunities. Overall, investors likely perceive IT investments as lowering risk and they (i.e., investors) are therefore willing to receive a lower return on their investment.

Analyzing the breakdown by decade also yields some interesting insights. The relation between IT intensity and cost of equity capital changes over time. Initially in the early decades of computer use (1950–1979), investors appear to perceive costly IT investments as risky ventures thereby requiring higher levels of cost of equity (or higher return on their investment) for those industries investing in IT. The situation reversed with the advent of PCs and the Internet in the 1980s (or the Wired Society Era) when the external network dramatically increased the value of IT by improving information flow and quality. Witnessing the great success of IT-intensive companies such as Microsoft and IBM, it is likely that investors were/are enthusiastic (and more confident) about IT investments and therefore potentially were more willing to accept a lower return. Thus, as IT became more reliable, more cost effective, and had a better ability to transform businesses, investors viewed IT intensity as a positive business strategy, reducing operating risk as well as investors' required cost of equity capital (or lower return on their investment).

It is interesting to note that while the coefficient on IT Intensity is significantly negative during the 1980s and 2000s, the *ITIntensity* coefficients are smaller than the coefficient during 1990s. This changing relation makes sense. The 1980s marked the advent of the affordable computer which allowed more firms to purchase IT, and connect computers to primarily automate processes (Dehning et al., 2003). The 1990s ushered in the Internet Era which allowed firms to leverage technology to streamline business processes more than ever before. In fact, Stiroh (2002) finds that real productivity benefits from IT surged after the mid-1990s.

One potential explanation for the smaller coefficient in the 2000s is likely due to the dotcom bust in the late 1990s. During the 1990s, the irrational exuberance of investors (potentially) overestimated the value of IT. It is likely that many investors simply ignored the risk of IT investment and held the belief that *any* IT investment would certainly bring benefits to the industry resulting in huge valuations for many IT firms that never had any profits. After the dotcom bust, investors now acknowledged the *realistic* value of IT investments and recognized that IT, in itself, did not ensure financial profitability. Rather, firms must have a sound business model strategically using IT to succeed.

From a practical perspective, by extrapolating from our industry-level results, this research provides some suggestions for top management. First, if management increases the portion of IT investment, they may receive the benefit of a lower cost of equity capital, giving them more valuable corporate resources to allocate. Second, management must strategically invest in IT to improve information quality and flow. Current investors are cautious and well informed about the risks (and value) of IT. Hence, overspending on reckless IT investments may not be appreciated, or rewarded, by investors.

While industry-level measures give us an overall, macro-level perspective on the benefit of IT investment, we are unable to test our hypothesis at the firm-level. Therefore, we must extrapolate our results to a firm-level analysis assuming that what is true for the industry holds true for its firms because firms within an industry typically use similar technologies and face similar production functions, markets, and risks (Ely, 1991). Despite this limitation, our study provides context and support for the initial "productivity paradox" results and subsequent (success) findings of the value of IT research after 1991 (Brynjolfsson and Hitt, 1996; Dehning et al., 2004). It would be interesting for researchers to examine how firm-level IT intensity varies across an industry and to what extent industry-level results hold for individual firms.

Finally, researchers have often used traditional accounting-based measures to measure the impact of IT investments. We encourage additional research on IT intensity as well as other measures of IT investments and how they are related to firm performance and different forms of financing, like the cost of debt. Research at both the industry-level and firm-level is needed to better understand how investors (and others) perceive industry/firm risks and how that impacts the value of IT investments. Future research can also determine if IT investments impact the cost of equity capital and cost of debt in the same manner. We also hope that the results of this study will encourage the integration of asset pricing and portfolio management models as well as other alternative models to the value of IT research stream.

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