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Information Intensity and Impact of IT Investments on Productivity: An Industry Level Perspective

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Abstract

Does it pay to invest in IT? Research over the last two decades has resulted in mixed findings. While many studies have shown a positive and significant relationship between IT investments and firm productivity and performance measures, the question of causality remains: Do higher IT investments contribute to better performance or does better performance contribute to higher IT investments? In this study, we examine this issue using explicit causal models and industry level data. Our results suggest that there is a significantly positive correlation as well as a significantly positive causal relationship between IT investments and productivity. IT investments do contribute to productivity in most of the industries in our sample. On the other hand, we find indications that firms allocate IT investments based on their productivity. We postulate that the impact of IT investments is moderated by the interaction between the product information intensity and value chain information intensity of firms.

Keywords
IT Payoff, IT Investments, Productivity, Causality, Information Intensity, Impact of IT

1. Introduction

Despite of the fact that there have been numerous attempts to quantify the contribution of IT investments to organization performance in both theoretical and empirical studies over the last two decades, there seems to be a clear disagreement between academics and practitioners. On one side, significant returns on IT investments have been reported in various academic studies at firm level (Brynjolfsson and Hitt, 1996), at industry specific sectors (Menon, et al., 2000), and at country level (Dewan and Kraemer, 1998). On the other side, practitioners seem to be less than certain about the contributions of IT investments (Strassman, 1996, 1997; McKinsey Global Institute, 2001; Olazabal, 2002). The debate over the well-known IT productivity paradox (e.g., Brynjolfsson and Hitt, 1996; Triplett, 1999) only highlights the complexity of this critical issue.

This study is motivated by the lack of explicit causality inquiries into the relationship between IT investments and productivity or other performance measures in the literature. This may have contributed directly to the conflicting findings in the IT investment studies and thus the on-going debate on IT productivity paradox. Instead of examining the "impact" of IT investments, it is "correlation" that is often being investigated. We are also intrigued by the idea of analyzing the impact of IT based on the information intensity of products and value chain of a firm as described in Porter and Millar (1985). We derive our theoretical framework from the previous works on information intensity (Porter and Millar, 1985), the resource based view of IT values (McKeen and Smith, 1993; Soh and Markus, 1995; Powell and Dent-Micallef, 1997), and the circular interaction framework of firm performance and IT investments (Weill, 1992).

The main contribution of this research can be summarized in the following two areas. First, we use explicit causality models for analyzing the relationship between IT investments and productivity, which enable us to state unequivocally that in many industries IT investments indeed lead to increases in productivity while in other industries higher productivity also leads to increases in IT investments. Second, we show why the contribution of IT investments is not uniform across industries using the framework of information intensity. We find that the impact of IT investments on productivity is moderated by the interaction between the product information intensity and the value chain information intensity of the firms in individual industries.

2. Theoretical Development

2.1 Research Framework

The value of IT to organizations has been clearly established in the MIS and management literature. Various theories and models have been proposed to explain how and why IT and IT investments contribute to the performances and productivities of organizations. Combining the process theory (Soh and Markus, 1995), the resources based view of value of IT to organizations (McKeen and Smith, 1993; Powell and Dent-Micallef, 1997), the information intensity matrix (Porter and Millar, 1985), and the circular relationship model between IT investments and firm performance (Weill, 1992), we postulate that IT investments create positive impact on the performance and productivity of a firm through enhancing existing business processes, enabling new business processes, and creating new business capabilities; however, the impact of the IT investments is moderated by the information characteristics of business processes and products of firms. At the meantime, performance and productivity of a firm in turn have a positive impact on the level of IT investments: better performing and highly productive firms tend to invest more in IT while firms in financial difficulties tend to cut IT budget in order to reduce cost and redirect resources to more essential areas. This view of IT impact on firms is depicted in Figure 1.
Our research model has its root in the resource based view of IT impact on organizational performance (McKeen and Smith, 1993). This view of IT value stems from earlier technology centric models that have largely ignored the organizational context when explaining how and why IT impacts organizational performance. The resource based view posits that it is not just IT investments, but the combination of resources – IT and people – that determines the impact of IT investments on organizational performance. Later studies augmented the resource based view by adding more resource dimensions, such as the relationship (Ross et al., 1996) that captures the shared risks and responsibilities between IT and its users. Powell and Dent-Micallef (1997) show that there are significant interactions

and interdependencies between firm performance and its human, business, and technological resources, providing empirical support for the resource based view of IT value.

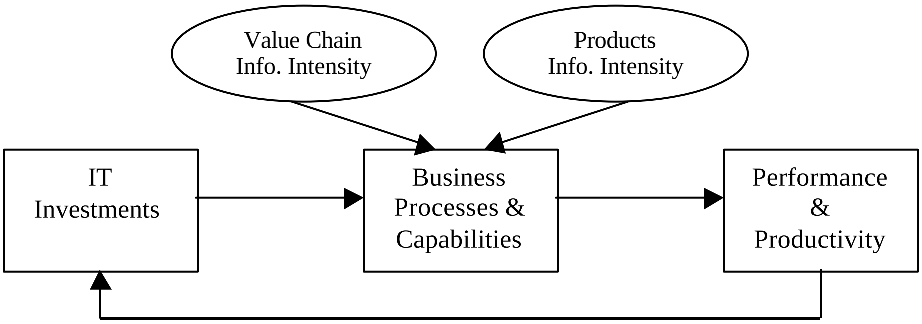

Figure 1: Research Framework

Incorporating the concept of "strategic fit" between IT and organizations, the process model of IT impact (Soh and Markus, 1995; Mooney et al., 1996) further expands the resource based model. The main underpinning of the process model is that IT investments are a necessary but not sufficient condition for superior performance. It postulates that impact of IT investments on organizational performance is the result of interactions among three processes: the IT conversion process in which the IT investments become IT assets, the IT use process in which the IT assets create impacts, and the competitive process in which the IT impacts are converted into organizational performance. Each of these processes is influenced by a multitude of technological, organizational, industry, and competitive environmental factors.

The resourced based view of IT value is complemented by the notion of IT as an enabler rather than the driver for organizational performance. Dewett and Jones (2001) provided a comprehensive review of the role of IT in organizations based on the framework of IT as an enabler and moderator between organizational characteristics (e.g., structure, size, culture, learning, and inter-organizational relationships) and organizational outcomes (e.g., organizational efficiency and innovation). Among many roles IT contributes to the organizational performance, information efficiencies, defined as cost and time savings that result when IT allows individual employees to perform their current task at a higher level, and information synergies, defined as the performance gains that result when IT allows two or more individuals or subunits to pool their resources and cooperate and collaborate across role or subunit boundaries, are found to be the most significant.

The resource based view of value of IT to organizations, however, does not properly address the issue of the information characteristics of business processes. Two firms could experience very different performance outcomes with identical or comparable IT and other resources. The concept of information intensity of value chain and products proposed by Porter and Millar (1985) can be used to complement the resource based view of IT value for a better understanding of IT impact on organizational performance. The value chain model posits that IT is changing the nature of competition in three vital ways: changing the structure of the industry by altering the balances of the five competitive forces, creating competitive advantages for firms that use IT to lower cost and differentiate products and services, and spawning new businesses that would be infeasible or do not exist without IT. However, the degree of influence of IT on these three areas is moderated by the interaction between the information intensity of the value chain and the information intensity of the products of a firm. Firms with high value chain information intensity and high product information intensity would benefit most from investments in IT resources while firms with low value chain information intensity and low product information intensity would benefit least from investments in IT resources.

While most of the studies seem to agree that there is a positive impact of IT on the performance and productivity of a firm, only a few have conjectured that firms with better performance and high productivity may invest more in IT resources. Weill (1992) formally described a circular causal relationship between IT investments and firm performance, that is, investment in IT leads to better performance, and better performance in turn leads to higher IT investments. Some later studies have also noted the possibility of reverse causality between IT investments and firm performance measures, e.g., Brynjolfsson and Hitt (1996), Hu and Plant (2001), and Hitt et al. (2002). Explicit testing using firm level data by Weill (1992) and Hu and Plant (2001) provide some statistical evidence to this conjecture. Thus it is only logical to include the feedback loop from firm performance to IT investments when constructing models of IT impact on organizations.

2.2 Research Hypotheses

In this study, we focus on the issue of IT impact on the productivity of firms from an industry perspective. Productivity measures have many benefits over financially oriented performance measures often found in empirical studies, such as profitability, sales growth, Tobin's q, and return on assets or return on equity. Productivity is more or less an internal measure that reflects the operational efficiency of organizations or industries and not necessarily a zero sum game at the aggregated level. All or many firms in one industry or market segment can improve their productivity together without some having to lose. Financial measures, on the other hand, are dependent as much on the external competitive and economic conditions as on internal operational efficiency. Difficulties often arise when firms are aggregated together for analysis of financial performance due to the redistribution effect: one firm's gain may come from the loss of one or more firms in the marketplace.

Even though all of the theoretical models discussed have their roots in individual firms, the collective behavior of all firms in an industry should reflect in general the behavior of the majority of the individual firms. It is reasonable to assume that at the economy level, each individual industry has its own value chain activities and strategies, just like individual firms, that represent the collective behavior and characteristics of the firms in the industry. From this point of view, the use of productivity rather than financial performance measures becomes essential when the analysis is anchored at the industry level.

Based on the theoretical models discussed above, we postulate that industries with high product information intensity, such as banking, financial, and insurance services, should benefits much more from IT investments than industries with low product information intensity, such as energy, mining, and construction. This is because when the product moving through the primary value chain activities is primarily information, extensive use of IT can result in significant improvement of operational efficiency. On the other hand, if the product is physical goods, the impact of IT on the operational efficiency of the value chain activities may not be as profound as in the former case. This line of thought leads to our first research hypothesis:

> *H1. Investments in IT should have positive and significant impact on the productivity of the industries that are product information intensive, such as finance, insurance, and wholesales industries, other factors being equal.*

Similarly, industries with high value chain information intensity, such as retail, manufacturing, and transportation, should benefit much more from investments in IT than those with low value chain information intensity, such as small businesses in service sector and building materials industry. The main characteristic of these industries is that the efficiency of the entire value chain heavily relies on the efficiency of information processing due to the extreme complexity of inbound and outbound logistics and internal material flow and control. Use of computer applications such as ERP and supply-chain management systems can significantly increase the efficiency of the value chain and greatly reduce errors, slacks, cycle time, and etc. This line of thought leads to our next research hypothesis:

> *H2: Investments in IT should have positive and significant impact on the productivity of the industries that are value chain information intensive, such as retail and services industries, other factors being equal.*

The dynamics between product information intensity and value chain information intensity must also be considered. For industries that involve both high product information intensity and high value chain information intensity, such as manufacturing and transportation, the effects of IT on product information intensity and on value chain information intensity could multiply, further heightening the impact. We postulate that IT investments should have the most significant impact on the productivity of firms in these industries because of the combined effects of the value chain and product information intensities. This line of thought leads to the following research hypothesis:

> *H3: Investments in IT should have positive and the most significant impact on the productivity of industries that are both value chain information intensive and product information intensive, such as manufacturing and transportation industries, and other factors being equal.*

For industries with low product information intensity and low value chain information intensity, the impact of IT on productivity could be very limited. Consider the case of construction and building materials industries where productivity is mainly dependent on the production technology. IT investments can improve the efficiency of certain aspects of the supportive value chain activities, such as human resource management, procurement, and technology development, their contribution to productivity is relatively minor. Some segments of the service industry, such as restaurants and auto repair businesses, also fall into this category. Installation of computer applications such as point-of-sales and payroll systems certainly helps but rarely can significantly change the productivity measured by customers served per hour or revenue per employee. Thus we have:

> *H4: Investments in IT should have positive but insignificant impact on the productivity of the industries that are neither value chain information intensive nor product information intensive, such as construction and building materials, and small service businesses, other factors being equal.*

In summary, we postulate that the impact of IT investments on productivity of an industry, as a reflection of the collective behavior of the firms in that industry, is dependent on the information intensities of their products and value chain and the interaction between the two. These hypotheses are congruent with the fundamental underpinning of the resource based view of value of IT, as discussed earlier.

In addition, the resource based view of firms also posits that firms must continuously invest in new resources and upgrade existing resources in order to stay competitive and acquire new competitive advantages (Collis and Montgomery, 1995). The corollary to this theorem is that firms will invest in IT assets to enhance their strategic and operational capabilities whenever conditions are favorable, such as when they have or anticipate better performance or productivity. The conjecture of a circular causal relationship between IT investments and productivity, or performance in general, is thus called for:

> *H5: There is a positive feedback causal relationship between IT investments and productivity: higher IT investments lead to higher productivity, which in turn stimulates higher IT investments in industries.*

Many researchers have noted this possibility in their studies. Weill (1992) and Hu and Plant (2001) found firm level empirical evidences that support the existence of reverse causality, though tests by Brynjolfsson and Hitt (1996) using 2SLS have shown insignificant results. However, data sets used in these studies are usually over a short period of time. In the following section, we intend to test this and other hypotheses developed above using explicit causal models and industry level IT investments and productivity data over 30 year period in an attempt to provide more concrete evidence for or against these hypotheses.

3. Data and Analytical Methods

3.1 Characteristics of the Datasets

Industry-level IT investments and productivity data are collected from government databases available online. Three separated data sets are gathered. The first data set contains nonresidential capital investment real-cost valuation (in 1996 dollar) of more than 60 categories of equipment and structural assets in different industry groups from 1947 to 1999 obtained from BEA (Bureau of Economic Research) web site. Out of these asset categories, 15 are identified as IT assets and 46 are non-IT assets. The second data set contains the Gross Domestic Product (GDP) of nine industries also obtained from BEA (Bureau of Economic Research) web site. The industry groups in the investment data set are regrouped according to the industry groups of the GDP data set based on the SIC code, and all statistics are aggregated accordingly. The third data set contain employment statistics for these nine industries obtained from the online database of BLS (Bureau of Labor Statistics).

The working definition of productivity in this study is GDP per employee for each industry, which scales the outputs all industries to the same comparable measure. It is essentially a labor productivity which we believe is appropriate for this research because it is considered more sensitive to the changes of IT capital than the more general multifactor productivity (Triplett, 1999; Gordon, 2002). Similar definitions of productivity have been used in other IT investment studies (Dewan and Kraemer, 1998). The annual GDP data for each industry in the data sets are all converted to the 1996 real dollar value using the GDP price deflators published in BEA web site.

3.1 Analytical Method

There is a surprising lack of explicit testing of the causal relationship between IT investments and productivity or related measures in the literature. The overwhelming use of economic production functions and the related log-linear regression models as the base research model for estimating the contribution of IT investments to productivity leaves the question of causality largely unanswered (Brynjolfsson and Hitt, 2000). The analysis of firm level IT spending data by Hu and Plant (2001) suggests that it is more likely that better financial performance leads to higher IT spending than the other way around. In their study of the impact of ERP implementation on firm productivity and performance, Hitt et al. (2002) point out that there is no strong theoretical grounding for using log-linear type of models to assess the impact of IT on firm performance since the relationship established is actually correlations rather than causality when the dependent variables are not the output of economic production.

To overcome this deficiency of correlation based research models, many research hypotheses are stated in neutral tones such as "firms with higher IT investments have better performance", leaving their real meaning subject to interpretation of the readers. What is truly interesting to practitioners as well as academics is not whether IT investments are "related" to higher productivity or superior performance but whether IT investments "cause" or, from a resource based view, "enable" better performance and productivity. The main objective of this study is to establish such explicit causal relationship between IT investments and productivity with well established causal modeling techniques.

There are quite a few statistical models for testing causal relationship. Among them the Granger (1969) causality model is of special interest to us. The main strength of the Granger model is that it can simultaneously test all possible causal relationships between two variables or vectors of variables without any predetermined causal assumptions. Let $\mathbf{x}_t$ and $\mathbf{y}_t$ be two time series data, the general Granger causal model with the consideration of possible instantaneous causality can be written as:

$$
\begin{aligned}
x_t &= b_0 y_t + \sum_{j=1}^{n} a_j x_{t-j} + \sum_{j=1}^{n} b_j y_{t-j} + \varepsilon_t \\
y_t &= c_0 x_t + \sum_{j=1}^{n} c_j x_{t-j} + \sum_{j=1}^{n} d_j y_{t-j} + \eta_t
\end{aligned}
\qquad (1)
$$

where ε_t and η_t are two uncorrelated white noise error terms with zero means.

This definition of causality implies that $\mathbf{y}$ causes $\mathbf{x}$ only if some of the b_j's are not zero, and $\mathbf{x}$ causes $\mathbf{y}$ only if some of the c_j's are not zero. A feedback relationship between $\mathbf{x}$ and $\mathbf{y}$ exists if both of these events occur. If b_0 is not zero, then the instantaneous causality is occurring and the knowledge of $\mathbf{y}_t$ will improve the "prediction" or goodness of fit of the first equation for $\mathbf{x}_t$, and vice versa if c_0 is not zero.

4. Results and Analyses

The original BEA data covers nine industries and over a time span of 50 years. Before it can be used in the statistical models, some preprocessing must be done to eliminate or reduce data problems such as multicollinearity. First, only eight industry groups are included due to availability of necessary data. They are mining, construction, manufacturing, transportation and public utility, wholesale, retail, finance and insurance, and services. Second, only the data points from 1970 to 1999 are used. This is because that significant use of IT by businesses and organizations did not start until late 1960's. If IT investments have any measurable impact on industrial productivity, it should be reflected in the statistics of 1970 and later. Third, preliminary tests show sever degrees of multicollinearity between IT investments and non-IT investments in the data sets, with condition index values between the two time series of all industries well exceeding the threshold of 20 as suggested by Greene (1997). To overcome this problem and still preserve the fundamental meaning of the statistical models, the ratio of IT investments to total capital investments (IT/TOT) is used as a proxy for IT investments in estimating the Granger causality model. The use of IT/TOT as the proxy for IT investments has an additional benefit: the ratio scales all industries to the comparable level, which is critical to the use of SUR (seemingly unrelated regression) procedure. Similar ratio as measure of IT investments has been used other studies (e.g., Weill, 1992).

In order to determine the exact nature of the relationship, we estimate the Granger causality model as specified in equation (1), where *x* and *y* are defined as follows:

$$x_{ti} = (IT/TOT)_{ti}$$
$$y_{ti} = \frac{GDP_{ti}}{EMP_{ti}} \qquad i=1, 2, \ldots 8;\ t = 1, 2, \ldots 30 \qquad (2)$$

where *i* represents the industry under consideration and *t* represents a particular year in the time period from 1970 to 1999.

Before we can use the model as specified in equation (1), two issues with the data series have to be addressed. First is the stationarity issue of the time series. The original Granger model requires that the time series $\mathbf{x}_t$ and $\mathbf{y}_t$ be I(0) stationary and purely non-deterministic (Granger, 1969). However, later studies have shown that these conditions can be relaxed without affecting the validity of the inference so long as only linear relations are of interest (Geweke, 1984), which is the case of this study. Just to be sure, the time series x_{ti} and y_{ti} are tested for stationarity. The results show that all data series are I(0) stationary except retail productivity series, which is a non-stationary I(1). The second issue is the multicollinearity between $\mathbf{x}_{ti}$ and $\mathbf{x}_{(t-1)i}$ and between $\mathbf{y}_{ti}$ and $\mathbf{y}_{(t-1)i}$, which turns out to be problematic, with condition index values well above the threshold of 20. To address this issue, the instantaneous causality terms, $\mathbf{x}_{ti}$ and $\mathbf{y}_{ti}$ are dropped from the Granger model as specified in equation (1). This change should not affect the model's ability in detecting causal relationships between IT investments and productivity in any material significance since it is widely acknowledged that it takes time for IT investments to show any measurable impact on firm performance due to learning and process adaptation. The effect of multiple time lags is not tested due to the same multicollinearity issues. As a result, only one time lag is used in the Granger model (1).

We use the SUR (seemingly unrelated regression) procedure to estimate the Granger model. The main argument for using SUR is that the industries in our data set operate in the same general economic environment and an integrated economy. For this reason, SUR is a preferred procedure since it estimates all causal functions together with the additional information of covariances among the industries, while OLS estimates the causal functions independently for each industry. In cases where these covariances are zeros, SUR simply collapses to OLS. In that sense, SUR is a more general procedure than OLS. The results are presented in Tables 1 and 2.

The results support the basic hypotheses that IT investments contribute positively to the productivities of industries where at least one of the information intensities is deemed as high. As it is shown in Table 1, out of the eight industries, all but two (Construction and Finance) have statistically significant c_1's, establishing not only the correlation, but also temporal sequence, a strong indication of causal relationship. The overall model fits well with the data, with a system weighted R^2 = 0.970, and a system weighted MSE=0.974.

The insignificance of the construction industry is consistent with hypothesis H4. But the insignificance of the finance industry seems to contradict hypothesis H1 and thus deserves some discussion. Our hypothesis posits that IT investments should have strong and significant impact on the productivity of the firms in the finance industry, so why is the test insignificant? We believe it can be attributed to the phenomenon of diminishing rate of return of IT investments. The very nature of high product information intensity and low value chain information intensity of the finance industry makes it the ideal candidate for using IT to improve its productivity. As a mater of fact, firms in the finance industry are among the first that embraced IT for operational and strategic applications and are the heaviest users of IT comparing to all other industries. As a result, any significant productivity improvement by further investing in IT would be difficult simply because the potential of IT assets may be close to or already at their limits.

Industry	Intercept	t-value	c_1	t-value	d_1	t-value
Mining	0.344***	3.26	1.278*	1.73	0.658***	6.23
Construction	0.047	1.43	0.046	1.16	0.879***	9.91
Manufacturing	0.041*	1.99	0.136**	2.36	0.859***	11.62
Transportation	0.097***	3.74	0.177**	2.38	0.797***	12.54
Wholesale	0.026	0.81	0.039*	1.72	0.936***	12.43
Retail	0.023	1.29	0.043***	3.35	0.875***	10.18
Finance	-0.114**	-2.53	-0.160	-1.48	1.151***	19.73
Service	0.082***	5.29	0.106***	5.95	0.625***	8.98

Table 1: Testing for Causality: GDP/EMP as dependent variable (system weighted R^2 = 0.970, and system weighted MSE=0.974 with 208 degrees of freedom).

Industry	Intercept	t-value	a_1	t-value	b_1	t-value
Mining	0.017*	2.01	1.081***	18.26	-0.014	-1.68
Construction	-0.076***	-3.10	1.039***	32.55	0.213***	3.22
Manufacturing	-0.057	-1.40	0.922***	8.13	0.208	1.44
Transportation	-0.029	-0.94	0.909***	10.12	0.094	1.23
Wholesale	-0.111**	-2.37	0.959***	28.65	0.295**	2.67
Retail	-0.118***	-2.84	1.102***	30.33	0.555**	2.76
Finance	-0.080**	-2.32	0.919***	10.32	0.098**	2.14
Service	0.106	1.19	1.237***	11.93	-0.538	-1.34

Table 2: Testing for Causality: IT/TOT as dependent variable (system weighted R^2 = 0.962, and system weighted MSE=0.958 with 208 degrees of freedom).

When the hypothesis that higher productivity leads to higher IT investments (H5) is tested, it is also supported, but only in four of the eight industries. Out of the four industries that have significant estimates of b_1, only the Wholesale and Retail industries are also significant in the previous causal model, suggesting that feedback causality exists between IT investments and productivity in these two industries. Interestingly, the construction and finance industries show an unequivocal causal relationship: higher productivity in the previous year leads to higher IT investments in the subsequent year but not the other around.

In both of the causal test results, a_1 and d_1 represent auto-correlation in the time series of GDP/EMP and IT/TOT, respectively. The dominant magnitude of the estimates and the strong statistical significance ($p < 0.01$) clearly indicates that the primary influencing source on the current levels of productivity and IT investments are their previous levels, an indication of the existence of momentous trend in both series. In practical terms, the results suggest that productive firms tend to continue to be productive and the amount of future IT investments of firms is largely based on the current levels.

Since our data span over a period of 30 years, it is reasonable to conjecture that there might be some changes in terms the degrees of IT capital penetration and how IT assets are used by different industries when the IT infrastructure and applications shifted from mainframe base centralized architecture to client/server based networked architecture. This shift occurred after the proliferation of PCs in corporate computing environment starting in the mid-1980s. We decide to test the causality models in two time periods: 1970-1984 and 1985-1999, which divide the data sets evenly and coincide with the architectural shift as well. The results are shown in Tables 3 and 4.

The results suggest that there are indeed differences between these two time periods. For instance, Table 3 suggests that the impact of IT investments to the productivity of retail and wholesale industries, though significantly positive overall, only become significant in the later period. The trend seems to suggest that the impact of IT investments became significant in more industries in the later time period. This might explain why earlier studies on IT impact tend to find negative or insignificant results while later studies tend to find positive and significant results (Wilson, 1993). It also shows that the contribution of IT investments to productivity in the transportation and utilities industries had disappeared in the later period, perhaps a result of IT capital saturation and diminishing rate of return.

Industry	**1970-1984**	**1985-1999**	**Overall**
	c_1	**c_1**	**c_1**
Mining	4.273**	3.319***	1.278*
Finance			
Service	0.102***	0.081***	0.106***
Retail		0.143***	0.043***
Whole Sale		0.438***	0.039*
Transportation	0.344***		0.177**
Construction			
Manufacturing	0.340***	0.194***	0.136**

*Table 3: Causality over different times: GDP/EMP as dependent variable (only significant **c_1** values are shown).*

Industry	**1970-1984**	**1985-1999**	**Overall**
	d_1	**d_1**	**d_1**
Mining			
Finance		0.362***	0.098**
Service			
Retail	-0.585*	1.253***	0.555***
Whole Sale	0.349*	0.926***	0.295***
Transportation		1.009***	

Construction	0.417**	0.213***
Manufacturing		

Table 4: Causality over different times: IT/TOT as dependent variable (only significant $\boldsymbol{d_1}$ *values are shown).*

The results in Table 4 are even more revealing. They indicate that the IT investments in more industries are influenced by productivity in the later time period than that in the earlier time period. We believe this is largely the result of the "IT as a strategic necessity" phenomenon (Powell and Dent-Micallef, 1997) that occurred in the 1990s when many firms, especially in the high information intensity industries, simply have to invest in IT just to stay in business. Under such competitive environment, firms tend to allocate more capital spending when they are in good financial situation and less when they are under financial pressure.

5. Discussions

Using IT/TOT as a proxy for IT investments in industries and the Granger causality model for explicitly testing the causal effect of IT investments on industry productivity, we have shown that IT investments indeed contribute positively to the labor productivity in six out of the eight industries studied in the time period between 1970 and 1999. All of our first four hypotheses are supported by the testing results both in terms of statistical significance and causal directions. Finance industry is the only exception, which we have provided explanations in the previous section when the results are presented. Due to the fact that we use labor productivity and IT/TOT ratio as the proxy of IT investments, the magnitude of the coefficients estimates from both the regression model and the Granger causality model can be meaningfully compared across all eight industries.

When IT investments are considered as the effect and productivity as the cause, the Granger causality model also shows solid support for hypothesis H5. Combining with the findings above, we can conclude that not only IT investments have contributed to the increases in productivity in most industries, more and more firms in industries are determining their IT investments based on their experience with productivity. In industries such as Wholesale and Retails, there seems to be a feedback causal relationship between IT investments and labor productivity. Table 5 summarizes the results of the hypotheses testing.

Hypotheses	Significance	Magnitude
H1	Partially supported	Partially supported
H2	Supported	Supported
H3	Supported	Supported
H4	Supported	Supported
H5	Partially supported	N/A

Table 5: Summary of Hypotheses Testing

6. Conclusions

Although the overwhelming majority of the studies of the impact of IT on organizations seem to confirm a positive impact of IT investments on productivity, we argue that many previous studies have only established a positive correlation, not necessarily a causal relationship, between IT investments and productivity or other performance measures. In this study, we use the Granger causality model to test the exact nature of this "positive correlation" between the two variables with industry level data from 1970 to 1999. Our results suggest that there is indeed a causal relationship between IT investments and firm productivity, that is, IT investments have contributed positively to productivity of six out of eight industries in our sample. We also confirm, through the causality model, that there is indeed a feedback causal relationship between IT investments and productivity: IT investments have contributed positively to productivity, and better productivity has in turn led to more investments in IT in many industries. Furthermore, we confirm that the significance of the impact of IT investments on firm productivity is modulated by the information characteristics of the business value chain and products of the firm.

We have highlighted the issue of causality vs. correlation in the studies of IT investments impact on productivity and performance in general of organizations. With a few noted exceptions, explicit investigations of the causal relationship between IT investments and performance have not attracted much deserved attention from academic researchers. We see more and more recent studies electing to use neutral terms when presenting research hypotheses pertaining to this critical relationship, which only underscores the sense of urgency for more explicit testing of the postulated causal relationship between IT investments and performance or productivity of organizations. Future causal studies at process or firm level should be most interesting from the perspectives of better understanding and better management practices and the causal modeling techniques should also be expanded beyond the Granger causality.

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