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An Industry-Level Analysis of the Potential and Realized Value of IT

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AN INDUSTRY-LEVEL ANALYSIS
OF THE POTENTIAL AND REALIZED VALUE OF IT

Valuing IT Opportunities

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Abstract

IT investments are typically evaluated by weighing the potential benefits and actual costs of the investments. Potential benefits of IT investment, however, do not always translate directly to actual payoffs due to a variety of impediments in the value creation process. There often is a gap between the potential and realized value of IT investments which needs to be defined and measured. We explore the methodological tools available to measure potential and realized value of IT investments and address the gap between them by developing a measurement model grounded in production economics. We adopt the Malmquist productivity index to model the potential and realized value of IT and apply data envelopment analysis (DEA) techniques to solve the model. Using this model, we examine IT investments in industries in the United States during the 1992 to 1997 period. We also examine the impact of within-industry competition. The methodology that we use to address the research questions has two stages. First, we develop a measurement model for computing potential and realized value, and then we apply it to examine and explain the impact of competition. There are five main findings. (1) Less than half of the industries that we examined realized more than 70% of their potential value. Over time though, the industries improved their capacity to realize potential value. (2) Firms in industries that face high levels of competition invest in IT assets with higher potential value. (3) Industries experiencing low levels of competition invest in IT assets with lower potential value. (4) Despite having IT investments with higher potential value, highly competitive industries are less likely to realize potential value compared to industries in less competitive environments. (5) Finally, industry competitiveness does not impact overall IT efficiency gains over time due to countervailing effects.

Keywords: Business value, data envelopment analysis, industry analysis, IT investment, IT value, Malmquist productivity index, potential value, production economics, realized value, value conversion

Introduction

Managers rely on prior beliefs and expectations to make decisions. Typically, IT investment decisions are made by weighing the expected benefits and the actual costs of the investment, so establishing an objective understanding of the potential value of investments is crucial to ensure an effective IT investment decision making process. Potential benefits of IT investment, however, do not always translate directly into organizational payoffs from investments due to a variety of impediments that occur in the value creation process. There often is a gap between the potential value and the realized value of IT investments which needs to be defined and effectively measured (Davern and Kauffman 2000, Chircu and Kauffman 2001).

Industry leaders also recognize the extent to which IT investments also fall short of delivering their expected value. Former Managing Director of Morgan Stanley, Charles Philips, claims that in the early 2000s, there was excess IT spending, and that the associated returns largely fell short of corporate expectations. This resulted in widespread
skepticism about IT initiatives, and many firms slashed their IT budgets. Senior management understanding of the relationship between the expected value of IT investments and actual payoffs is crucial for achieving effective future investment decisions.

Previous studies in the value of IT literature have predominantly focused on measuring the realized value of IT investments (e.g. Barua et al. 1995, Bharadwaj 2000, Brynjolfsson and Hitt 1996, Dewan and Kraemer 2000, Menon et. al. 2000). We define realized value as the actual payoff of an IT investment under existing production conditions (Davern and Kauffman 2000). Fewer researchers have studied the potential value of IT (e.g. Davern and Kauffman 2000, Massey et al. 2001). We define potential value as the maximum feasible payoff of an IT investment under efficient production conditions. To our knowledge, there are no studies which have developed objective measures for the potential value of IT based on theory. In this paper, we will measure and compare the potential value and the realized value of IT using a model for measurement which is based on the microeconomic theory of production. We also will apply this model to examine the impacts of competition on industry performance.

We provide answers to the following research questions: How can we measure the gap between potential and realized value? How significant is the gap across industries? How will the degree of competition faced by firms within an industry impact the value of IT investments? What theoretical basis can we provide to effectively explain the results? How does industry competition impact changes in IT efficiency gains and value that are observed over time? Industry-level analysis offers some promise for delivering useful insights related to these questions.

The methodology that we use to explore the research questions is laid out in two stages in the next section. Stage 1 is the measurement development stage, which develops a measurement model for computing the potential and realized value of IT investments. We begin this stage with a discussion of the theoretical perspectives, followed by a more formal development of our measurement model. Stage 2, the explanation stage, applies this model to examine the gap between realized and potential value of IT investments across industries, and explains the observed impacts of competition. In the third section, we lay out a series of explanatory hypotheses, and then discuss our research methodology in the fourth section. Our empirical analyses and key findings are presented in the fifth section. The sixth section offers an in-depth discussion of some related IT investment strategies, with additional empirical analysis. We conclude by drawing some conclusions about the relevance and limitations of our findings, as well as some thoughts on future research.

Theory and Modeling Preliminaries

We next discuss the literature behind the measurement of IT value, and the potential and realized value of IT investments. We show how these concepts can be modeled based on production economics. We also describe the Malmquist productivity index (Caves et al. 1982) and modify it to develop the measurement model for this study.

Measuring the Realized Value of IT

The value of IT commonly refers to the impact of IT on organizational performance. Previous studies characterize this value using profitability measures, productivity and efficiency measures, customer value, competitive advantages, cost and inventory levels (Melville et al. 2004). Despite all the prior work on IT value, measuring the business value of IT is still a key challenge. Researchers have made ongoing efforts to improve existing measurement methods and create new ones. For example, some studies have attempted to quantify the value of IT based on profitability measures that are closely linked to firm performance (Hitt et al. 2002, Hitt and Brynjolfsson 1996, Menon et al. 2000). Others have concluded that IT investments result in higher firm profitability based on financial ratios (Barua et al. 1995, Bharadwaj et al. 1999). In addition, the use of economic efficiency measures for assessing the value of IT has been frequent (Brynjolfsson 1993, Hitt and Brynjolfsson 1996). The various studies adopting these measures have arrived at a variety of conclusions pertaining to IT value. Over the past decade, the measurement of IT value has taken yet another form — the assessment of customer value. Devaraj and Kohli (2002) and Hitt and Brynjolfsson (1996) have concluded that IT investment results in the creation of value for customers, and that this aspect must be incorporated as a key measure in future studies. Apropos to these observations, Brynjolfsson (1993) singled out the mis-measurement of IT value as one of the key reasons for the earlier findings related to the productivity paradox of IT. So establishing effective measurement methods to assess the value of IT is of critical importance.
All the studies we have discussed use metrics or proxies that measure the realized value of IT investments. Although the idea of potential value is not entirely left out of the prior studies, still, no study formally addresses the nature and measurement properties of this construct. We find this omission to be interesting since potential value is often the key construct used in managerial decision making prior to the investment.

Studies that examine the value of IT have focused on the organization as the unit of analysis. These studies conclude that the generation of firm-level value is contingent upon organizational factors, such as business processes, management practices, organizational structures and business environment (Melville et al. 2004). There is relatively less research that examines IT issues at an aggregate level of analysis of the economy or the industry, with most of the work performed during the past decade (Dewan and Kraemer 2000, Morrison and Berndt 1990). Devaraj and Kohli (2002) have noted that most aggregate analysis, especially at the economy level, reports mixed relationships between IT investments and value flows due to the potential difficulty of isolating the impact of IT. However, the authors point out that industry analysis of IT value is critical for understanding industry trends in value conversion.

**Potential Value and Realized Value**

We develop the concepts of potential and realized value of IT investments by adapting ideas proposed by various authors (e.g. Belcher and Watson 1993, Davern and Kauffman 2000, Fichman 2004). The potential value of an IT investment is the maximum possible gain that can be derived from the investment under perfect information, and the ideal technological, organizational and market conditions. In reality, this expected return of investment is seldom achieved due to factors that arise in the process of implementing the IT or in running the business process in which it is used. Value conversion effects occur due to managerial interventions and environmental influences that play a key role in shaping the business value outcome of any IT investment. Such effects ultimately will lead to the realized value of an IT investment. Value conversion effects occur at all levels of the business process, the organization and the market, and create a gap between potential and realized value.

Although the realized value of an IT investment is what is often measured in most studies (e.g. Barua et al. 1995, Bharadwaj 2000, Dewan and Kraemer 2000, Menon et al. 2000), the potential value of an IT investment nevertheless is one of the key pieces of information that managers must consider before investing in IT initiatives. Tools for measuring the potential value facilitate the investment decision making process. We next discuss how the potential and realized value of an IT investment can be represented and measured using an economic production process. Framing the issue of potential and realized value in this way will permit us to apply a measurement approach that permits the discovery of how IT value accrues over time.

**IT Value Creation as an Economic Production Function**

The creation of IT value is widely accepted as the result of an economic production process (Dewan and Kraemer 2000, Hitt and Brynjolfsson 1996, Hitt et al. 2002). Various studies have modeled this process using parametric production functions, such as Cobb-Douglas, translog and CES, where IT investment is viewed as an input along with other input factors, such as labor and capital, to generate economic rents. These works include the long stream of research that investigated IT and productivity (Brynjolfsson and Hitt 1996, Hitt and Brynjolfsson 1996), but actually measured only the realized output of the IT production process.

To model the potential and realized value of IT investments, we will conceptualize the creation of IT value in terms of a piece-wise linear production technology (Shephard 1970). In this conceptualization, each economic unit, represented by a combination of its input and output values for production, forms the production possibility set. Relying on the axioms of production theory, the production function yields a linear trace of input-output boundary values called the production frontier. Under the assumptions of strong disposability of inputs, a bounded and closed technology set, the production possibility set at time $t$ is represented by:

$$y'_{jm} = f(x'_{jn}, \varepsilon')$$  (1)

with $n$ inputs $x$ and $m$ outputs $y$ for $j$ decision making units or firms. As not all production units are producing efficiently, $\varepsilon'$ represents the vector of inefficiency deviations from the production frontier. (Refer to Appendix A for complete mathematical notation.)
From the representation of the production possibilities set in Equation 1, we use the output distance function to measure the extent of efficiency in the use of technology (Shephard 1970). The output distance function is a quantitative efficiency measure of an economic unit relative to the efficiency frontier: the maximum level of output possibly produced with the given set of inputs. We can represent the output distance function by:

\[ D_o(x,y) = \min_{\theta > 0} \{ y / \theta \in Y(x) \} \text{ for all } x \]  

We interpret this measure as the proportional increase of output \( y \) that is feasible under a fixed level of input \( x \) for a given decision making unit. When \( D_o(x,y) \) is equal to 1, the producer is technically efficient and the observation lies on the efficiency frontier. When \( D_o(x,y) \) is less than 1, the producer is technically inefficient and its observation lies below the technology curve. To illustrate, we consider the efficiency frontier for a decision making unit with a single input and output shown in Figure 1, where \( (x^0, y^0) \) represents the input level of an inefficient economic unit lying below the frontier. The output distance function, \( D_o(x,y) \), is represented by \( y^*/y^0 \).

![Figure 1. Efficiency Frontier for a Decision Making Unit with a Single Input (x) and Output (y)](image)

The efficiency frontier (the line in Figure 1) measures the maximum possible level of output for any given set of inputs and represents the potential value of the input set. When IT investment is one of the inputs in the production process, the output distance function, \( D_o(x,y) \), measures the extent to which the realized value deviates from the potential value of the investment.

**Measuring Change in Potential and Realized Value over Time**

The output distance function is only useful to understand efficiency at a single point in time. To compare and measure changes in technical efficiency between two time periods, we will utilize a modified ratio of the output distance measure known as the Malmquist productivity index. The index was first introduced by Caves et al. (1982) and subsequently refined by Fare et al. (1994), as follows:

\[ M_o(x^{t+1}, y^{t+1}, x^t, y^t) = \left[ \frac{D_o'(x^{t+1}, y^{t+1})}{D_o'(x^t, y^t)} \times \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^t, y^t)} \right]^{1/2} \]  

\[ M_o(x^{t+1}, y^{t+1}, x^t, y^t) = \left[ \frac{D_o'(x^{t+1}, y^{t+1})}{D_o'(x^t, y^t)} \times \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^t, y^t)} \right]^{1/2} \times \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o'(x^t, y^t)} \]  

Economic units with index value \( M_o(\bullet) > 1 \) indicate an improvement in technical efficiency from \( t \) to \( t + 1 \), and a value of \( M_o(\bullet) < 1 \) represents a decline in efficiency over the same period. Fare et al. (1994) showed that the Malmquist index can be decomposed into the product of two components: a shift in technology, and a change in relative efficiency.

\[ \Delta \text{ overall efficiency} = \Delta \text{ in technology} \times \Delta \text{ relative efficiency} \]
A shift $\Delta$ in technology measures the movement of the efficiency frontier from period $t$ to $t + 1$ for a particular economic unit. In the case of IT investments, in practice, the efficiency frontier will represent the potential value of the investment.\(^1\) Hence, a shift in the technology measure with values greater than 1 represents a gain in potential value at the input mix of the producer on the average for both period $t$ and $t + 1$. In contrast, values less than 1 represent a drop in potential value at the input mix of the producer on average for period $t$ to $t + 1$. Figure 2a illustrates the instance where a producer experiences shift in technology measure to greater than 1, and for both input mixes at period $t$ and $t + 1$, the potential value curve shift towards the origin along the dotted lines in the figure, representing an increase in potential value for the investment inputs in both time periods.

Figure 2a. Improving Potential Value

Figure 2b. Declining Potential Value

Figure 2b represents the opposite situation, where the shift in the technology measure is less than 1 and for both input mixes at period $t$ and $t + 1$, and the potential value curve shifts away from the origin, signifying a drop in potential value.

The symbol $\Delta$ is a metric for the shift in technology over time, and it measures the shift in the potential value of a particular set of inputs from period $t$ to $t + 1$. In the context of the study of the potential value and the realized value of IT, the meaning of the measure shifts to represent changes in potential value of the IT investment.

A change in relative efficiency measures the extent to which observed production is moving closer to the frontier over time. The actual production represents the output produced by a particular set of inputs, and this corresponds to the realized value for the IT investment in the economic production process. Applying this concept to our study on the potential and realized value of IT investments, we expect to observe the following. Producers with high relative efficiency measures (i.e., values greater than 1) over time achieve realized value that is closer to potential value, represented by the efficiency frontier. With a given set of inputs employed over two time periods, producers with high relative efficiency measures are able to narrow the gap between potential and realized value from time period 1 to 2. From this definition, we observe that the change in relative efficiency measures the extent of which the input investments achieve their potential value over time. We define this change in relative efficiency as the change in realized value.

To illustrate, we consider the production space of a firm with two inputs $x_1$ and $x_2$. The inputs are represented by the two axes and the potential value of the investment is represented by production curves in each of two periods, $t$ and $t + 1$. Figure 3a depicts one firm with a high realized value measure (i.e., a value greater than 1) and Figure 3b depicts another producer with a low realized value measure (i.e., a value less than 1). From both figures, it is clear that the producer with high realized value comes closer to appropriating the potential value of its IT investment in period $t + 1$.

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\(^1\) The reader should recognize that this is a statement about the ideal case. In practice, we expect that most companies won’t be able to get 100% of the potential value out of their IT investments, since they will all be subject to the vagaries of the investment environments that occur within the firm (where strategy, personnel and operational procedures are often changing) and surrounding the firm (where markets, consumer demand, government regulations and competitors’ strategies are ever changing. So the best observed practices still may not reach full potential value, although measuring them still is the best proxy for the potential value.
than in period $t$. The opposite is true for a producer with a low relative efficiency measure.

![Figure 3a. Diminishing Realized Value](image)

![Figure 3b. Improving Realized Value](image)

To summarize and formally represent the measurement model discussed in this section, we redefine the original Malmquist productivity index as:

$$
\Delta \text{overall efficiency} = \Delta \text{potential value} \cdot \Delta \text{realized value}
$$

**Hypothesis Development**

In this section we will propose hypotheses that characterize the gap between realized and potential value for different industries and relate industry competition to the potential and realized value of IT investments. Our hypotheses are grounded in the economic theories of production and competition.

**The Gap between Potential and Realized Value**

The realization of IT value is impacted by both external and internal factors (Melville et al. 2004). Davern and Kauffman (2000) describe these factors as *moderators of IT value* and highlight their impacts on IT value realization. *External factors* represent environmental forces that impact the firm and the realization of IT value. Examples of these factors include changes in the competitive environment, the actions of governmental regulators and changes in the technological environment. *Internal factors* are forces within the organization that often involve the action of management and are crucial in ensuring effective implementation and utilization of the IT systems. Internal factors are controllable compared to external factors, which the reader can think of as being exogenously given to the firm. The organizational factors have an influential role relative to the production process involving IT that occurs within the firm.

Reaping the potential value of IT investments involves a concerted effort within the firm, coupled with supportive environmental conditions (Massey et al. 2001). This process, however, is hindered by uncertainty in firm operations that cause these antecedents of value creation to vary across firms and over time. This variation results in the gaps between the potential and realized value (Davern and Kauffman 2000, Chircu and Kauffman 2000, Fichman 2004). Gurbaxani et al. (2000) show that the underlying production process at an aggregate level — such as the economy level and the industry level — mirrors the production process at the lower level of the firm. This permits comparisons to be made for industry-level and firm-level results. These observations lead us to assert our first hypothesis:

- **Hypothesis 1A (Potential and Realized Value Gap Hypothesis).** Most industries do not fully realize the potential value of IT, resulting in a gap between the potential and realized value of IT investments among industries.

- **Hypothesis 1B (Changing Potential and Realized Value Gap Hypothesis).** The magnitude of the gap between the potential and realized value of IT investments across different industries changes over time.

**Changes in Potential Value**
Analysis of the effects of competition on efficiency dates back to the essays by Adam Smith. There is a consensus among economists that firms operating under conditions where competition is lacking tend to use less efficient production technologies, even when more efficient ones exist. Managerial slack which results from the “quiet life” — a term coined by Leibenstein (1966) — is one main reason behind this inefficiency. Managers in less competitive environments face less pressure and have fewer incentives to make an effort. Principal agent models (Hart 1983, Scharfstein 1988) suggest that the relationship between managerial slack and competition is complex. Scharfstein (1988) further suggests that competition increases managerial effort only if managers are risk-averse.

A second argument suggests that competition leads to higher efficiency because it acts like a pressure-driven selection mechanism. Industries that exhibit increasing levels of competition initially allow a diverse collection of efficient and inefficient firms to exist. But, over time, competition will force the weakest, least efficient firms to exit and higher production of output will occur at a lower cost, improving social welfare (Motta 2004) (if not profitability, as we have learned from the airlines industry in the past twenty years). This Darwinian process has been tested and affirmed empirically by Ollay and Pakes (1996), who examined the impact of competition on the telecommunication industry in United States during 1963 to 1987.

Industries in less competitive environments have few incentives to adopt new technologies and make investments (Motta 2004). But competition pushes firms to invest to improve their position relative to their competitors. The absence of competitors reduces incentives to innovate and makes the production process less efficient. Furthermore, in a non-competitive environment, managers tend to become more conservative and avoid the private costs of adopting new technologies that may increase the risks of bankruptcy (Aghion et al. 1999). As a result, it turns out that the observed level of competition is likely to determine the level of innovation within an industry.

Industries adopt different input mixes for their production processes, and these production decisions will impact the potential value of production for the industry over time. Industries facing high competition will be under pressure to make better IT investment decisions and this will lead to higher potential value for IT investments over time. On the other hand, industries in less competitive environments that experience managerial slack and fewer incentives to innovate will make poorer IT investment decisions, and these will have lower potential value over time for the firm.

The forces of competition suggest the following hypothesis:

- **Hypothesis 2 (The Potential Value Hypothesis):** Industries that exhibit higher levels of competition utilize IT and other production factors which result in higher potential value over time for firms. Industries that exhibit lower levels of competition adopt inputs of IT and other production factors which result in lower potential value over time.

Since few, if any industries, have been experiencing declining competition during the past couple decades, and because IT has been exogenously improving in quality in the American economy, we do not argue that the potential value of IT investments will become less and less.

**Realized Value**

Higher competitive pressures increase the potential value of industry IT investments. So one might conclude that it is likely that with a larger number of firms in the industry, total welfare will also be higher. But this is not the case. Instead, a crowding-out effect will obtain, as discussed in Josefek and Kauffman (1997). A larger number of firms associated with higher intra-industry competition also will lead to a higher aggregate level of fixed costs that firms in the industry will have to bear in the conduct of their business. Fixed costs determine the value-maximizing scale economies of production. This suggests a trade-off between increased potential value and higher fixed costs. The associated effect is that inefficient duplication of fixed costs brought about by high competition will result in lower producer surplus. Total welfare, meanwhile, depends on the balance between the increase in consumer welfare brought about by increased competition and the corresponding decrease in producer surplus.

Higher aggregate fixed costs and the crowding-out effect will tend to dampen the ability of competitive industries to fully realize the potential value of their IT investments. So, despite being in a production space of higher potential value, these industries will have to bear the brunt of the market dynamics and this will result in lower realization of potential value. Thus, we propose:
• **Hypothesis 3 (The Realized Value Hypothesis):** Less competitive industries will outperform more competitive industries in realizing potential value over time.

Competition is like a double-edged sword that provides the industry with a higher impetus to invest, innovate and adopt new technologies, but, at the same time, it also hampers the industry’s ability to fully appropriate the potential value leading from the associated value-creating activities. So we believe that the ongoing debate about the impacts of competition on efficiency—including the impacts on firm and industry performance from IT investments—is far from over. This leads us to state the following null hypothesis with respect to overall IT efficiency gains in industry:

• **Hypothesis 4 (The Overall IT Efficiency Gains Hypothesis).** Different levels of competition faced by different industries do not result in differences in overall IT efficiency gains over time.

Table 1 provides a summary of the hypotheses that will be tested in this study.

<table>
<thead>
<tr>
<th>HYPOTHESIS</th>
<th>NAME OF HYPOTHESIS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1A</td>
<td>Potential and Realized Value Gap</td>
<td>A gap between potential and realized value of IT exists.</td>
</tr>
<tr>
<td>H1B</td>
<td>Changing and Realized Value Gap</td>
<td>A gap between potential and value of IT changes across time.</td>
</tr>
<tr>
<td>H2</td>
<td>Potential Value</td>
<td>High competition leads to higher levels of potential value over time. Low competition leads to lower levels of potential value over time.</td>
</tr>
<tr>
<td>H3</td>
<td>Realized Value</td>
<td>High competition leads to lower levels of realized value over time. Low competition leads to lower levels of realized value over time.</td>
</tr>
<tr>
<td>H4</td>
<td>Overall IT Efficiency Gains</td>
<td>Different levels of competition do not lead to changes in overall IT efficiency gains over time.</td>
</tr>
</tbody>
</table>

**Methodology**

Output distance functions can be optimized using *data envelopment analysis* (DEA) techniques. Unlike parametric regressions, DEA does not require the specification of the functional form of the economic production and or many assumptions (Banker and Slaughter 1997). These properties improve the robustness of the estimates. Unlike other measurement models that examine realized value, to establish the potential value of IT investments, our theoretical measurement model (Equation 4) is developed based on the principles of a *piece-wise linear production technology*. This can be optimally solved using DEA techniques (Fare et al. 1994). To compute the various efficiency measures based on the output distance function, $D_o$, and the components of the Malmquist productivity index, we set up the following linear program to solve for $D_o$:

$$D_o(x^t_j, y^t_j') = \max \theta^k t$$

subject to

$$\sum_{j=1}^J y_{jm}' \lambda_j' \geq \theta_j y_{jm}'; \quad m = 1,2,\ldots,M$$

$$\sum_{j=1}^J x_{jn}' \lambda_j' \leq x_{jn}'; \quad n = 1,2,\ldots,N$$

$$\lambda_j' \geq 0$$

We can compute the measures under different returns to scale by adding constraints as follows:

$$\sum_{j} \lambda_j' \leq 1 \quad \text{Non-increasing returns to scale}$$

$$\sum_{j} \lambda_j' \geq 1 \quad \text{Non-decreasing returns to scale}$$
\[
\sum_{j} x_{ij}^j = 1 \quad \text{Variable returns to scale} \quad (5g)
\]

(Again, refer to Appendix A for a full description of the mathematical notation.)

The Malmquist productivity index consists of four different forms of output distance functions: \(D_o^t(x^t, y^t), D_o^{t+1}(x^{t+1}, y^{t+1}), D_o^{t+1}(x^t, y^t)\) and \(D_o^{t+1}(x^{t+1}, y^{t+1})\).

- \(D_o^t(x^t, y^t)\) is the output distance function of the decision making unit at time \(t\).
- \(D_o^{t+1}(x^{t+1}, y^{t+1})\) represents the output distance function of the decision making unit at time \(t+1\) under the production technology of time \(t\).
- \(D_o^{t+1}(x^t, y^t)\) is the output distance function of the decision making unit at time \(t\) under the production technology of time \(t+1\).
- Finally, \(D_o^{t+1}(x^{t+1}, y^{t+1})\) stands for the output distance function of the production unit at time \(t+1\) under the production technology of time \(t+1\).

The linear program constructed in Equations 5a through 5g can be used to compute all four distance functions by substituting the appropriate inputs and outputs of the different time periods into the primary distance function shown in Equation 5a. The *Malmquist productivity index* is the geometric mean of the ratios of these four distance functions.

**Data and Variables**

The inputs used in our research are IT capital, non-IT capital and total labor cost. The corresponding output used is *gross domestic product* (GDP). This mix of input variables is widely accepted as providing the key factors to specify the organizational production process at the firm level in the IS literature (Dewan and Kraemer 2000, Hitt and Brynjolfsson 1996, Hitt et al. 2002). We obtained the data from the national economic census conducted by the Bureau of Economic Analysis (BEA) of the United States in 1992 and 1997. The data set contains census information for all industries classified in the 1997 North American Industrial Classification System (NAICS) format at the level of five-digit industry codes.

We filtered the data set to include only industries that have invested at least US$500,000 of *IT capital* during each of the census years 1992 and 1997. The census does not report any capital flows less than that amount — an amount which the BEA considers as negligible. Since we focus on the practices of IT-investing industries, omitting sectors that have negligible levels of IT capital input does not hamper attaining our research objective. Using the same data set, we obtained the corresponding *GDP output*, *non-IT related capital flows*, and the *total labor cost* of the NAICS industries. Based on our selection criteria, the final sample consists of 79 data points per year, each representing an industry from one of thirteen sectors. Table 2 shows the descriptive statistics for the primary inputs and outputs.

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2 The thirteen NAICS sectors are: Accommodation and Food Services; Administrative and Support Waste Management and Remediation Services; Arts, Entertainment and Recreation; Finance and Insurance; Health Care and Social Assistance; Information; Manufacturing; Other Services; Professional, Scientific, and Technical Services; Real Estate and Leasing; Trade; Transportation and Warehousing; and finally, Utilities.
Table 2. Descriptive Statistics for the Data

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<td>41,713</td>
<td>10,230</td>
<td>41,713</td>
</tr>
<tr>
<td>StdDev</td>
<td>1,439</td>
<td>41,487</td>
<td>42,020</td>
<td>116,397</td>
<td>1,973</td>
<td>62,218</td>
<td>50,240</td>
<td>156,124</td>
<td>50,240</td>
<td>156,124</td>
</tr>
<tr>
<td>Min</td>
<td>0</td>
<td>461</td>
<td>262</td>
<td>821</td>
<td>0</td>
<td>677</td>
<td>375</td>
<td>1,226</td>
<td>375</td>
<td>1,226</td>
</tr>
<tr>
<td>Max</td>
<td>9,930</td>
<td>194,376</td>
<td>238,038</td>
<td>591,265</td>
<td>16,425</td>
<td>330,400</td>
<td>280,488</td>
<td>808,056</td>
<td>280,488</td>
<td>808,056</td>
</tr>
</tbody>
</table>

**Empirical Analysis**

For each industry, we ran a linear program to obtain the output distance measure \( D_o \). To generate the Malmquist productivity index, each industry requires the four levels of distance functions, \( D_o^1(x^t, y^t) \), \( D_o^1(x^{t+1}, y^{t+1}) \), \( D_o^{t+1}(x^t, y^t) \) and \( D_o^{t+1}(x^{t+1}, y^{t+1}) \), to be computed. In addition, we performed three sets of analysis under different returns to scale assumptions to check for empirical robustness: constant returns to scale (CRS), non-increasing returns to scale (NIRS) and non-decreasing returns to scale (NDRS). In all, we solved \( 79 \times 4 \times 3 = 948 \) linear programs.

Banker (1993) has shown that the estimated performance levels for decision making units in the solutions of DEA math programs are asymptotically-consistent maximum likelihood estimators of the true parameters, under stochastic output levels. Our analysis is in line with these assumptions as the data set contains the entire population of relevant industries in the United States. Based on these conclusions, we developed and applied statistical tests for returns to scale and robustness of estimates (Banker and Chang 1995, Banker and Slaughter 1997). We modified these tests for a single-period distance measure to test the multi-period Malmquist productivity index.

**Test for Empirical Robustness**

The computation of DEA scores is sensitive to outliers, which can bias the estimation of the production frontier. To test the empirical robustness of the computed Malmquist productivity indices, we will perform a series of hypothesis tests on the returns to scale of the production frontier across time and across groups of industries. Similar to how Banker and Chang (1995) and Banker and Slaughter (1997) applied statistical tests in their articles, we assume that the DEA estimators are either independent and identically exponentially-distributed (or i.i.d. exponential for short) or independent and identically half-normal-distributed (or i.i.d. half-normal). When the DEA estimators are i.i.d. exponential, the test statistic to determine the returns to scale is:

\[
\sum_{j} \left( \theta_{j}^{\text{Null}} - 1 \right) / \sum_{j} \left( \theta_{j}^{\text{Alternative}} - 1 \right)
\]

(6)

then \( \theta_{j}^{\text{Null}} \) represents the DEA estimator under the null hypothesis and \( \theta_{j}^{\text{Alternative}} \) represents the DEA estimator under the alternative hypothesis. Also, \( j = \{1, \ldots, J\} \) represent each industry in the sample (similar to the decision making unit or firm). The test statistic follows an F-distribution with \( (2J, 2J) \) degrees of freedom. When the DEA estimators are assumed to be i.i.d. half-normal, the associated test statistic is:

\[
\sum_{j} \left( \theta_{j}^{\text{Null}} - 1 \right)^2 / \sum_{j} \left( \theta_{j}^{\text{Alternative}} - 1 \right)^2
\]

(7)

This statistic follows an F-distribution with \( (J, J) \) degrees of freedom.
The Malmquist productivity index consists of various stochastic components. This permits us to conduct the above tests by examining the individual components of the index. This procedure involves the following steps:

- **Step 1 (Testing for Returns to Scale)**. Test the returns to scale of the components that make up the index at the industry level for the level of analysis that is chosen. Specifically, we compute the efficiency measures of the economic units in two time periods, 1992 and 1997.

- **Step 2 (Evaluating Returns to Scale Differences)**. Evaluate the extent to which the differences between the components that make up the index are significant at the industry level. Establishing consistency in returns to scale between the two time periods lends support to the robustness of the results.

Table 3 indicates that the production process exhibits similar patterns of returns to scale for both periods 1992 and 1997.

<table>
<thead>
<tr>
<th>HYPOTHESIS</th>
<th>DISTRIBUTION</th>
<th>1992</th>
<th>1997</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F-VALUE</td>
<td>F-VALUE</td>
<td>P-VALUE</td>
</tr>
<tr>
<td></td>
<td>(P-VALUE)</td>
<td>(P-VALUE)</td>
<td></td>
</tr>
<tr>
<td>Null: NIRS</td>
<td>Exponential</td>
<td>1.13 (0.221)</td>
<td>1.18 (0.153)</td>
</tr>
<tr>
<td>Alt: IRS</td>
<td>Half-normal</td>
<td>1.20 (0.209)</td>
<td>1.27 (0.143)</td>
</tr>
<tr>
<td>Null: NDRS</td>
<td>Exponential</td>
<td>1.13 (0.223)</td>
<td>1.06 (0.357)</td>
</tr>
<tr>
<td>Alt: DRS</td>
<td>Half-normal</td>
<td>1.14 (0.278)</td>
<td>1.06 (0.403)</td>
</tr>
</tbody>
</table>

Second, to ensure that the analysis is not biased by the presence of outliers, following Richmond (1974) we dropped the most efficient industry observations in our first analysis for both time periods and redid the linear optimization process under different assumptions of returns to scale. With this approach, five industries were removed from the 1992 sample and nine industries were removed from the 1997 sample. We conducted similar return to scale tests and reached the same conclusions on the returns to scale in production for both the full and reduced data set in both time periods. The consistency in statistical conclusions that emerged for both sets of tests diminishes the possibility that the presence of outliers drives the results, leading to inappropriate conclusions.

Third, to establish the consistency of the estimates based on observations that are further away from the frontier, we repeated the process of dropping the most efficient industries from the reduced sample and re-estimated the frontier for both years. In this iteration, we removed seven additional industries in 1992 and fourteen additional industries in 1997 from our sample. The final reduced sample for 1992 is 84.8% of the original size and the corresponding reduced sample for 1997 is 70.8% of the original size. This reduction of observations around the frontier enables us to test the consistency of all estimates with greater confidence. Similar to the previous iteration, the results from this iteration support our earlier conclusion on returns to scale. Table 4 provides our statistical conclusions for the robustness tests.
Table 4. Test of Returns to Scale after Dropping the Most Efficient Industries

<table>
<thead>
<tr>
<th>HYPOTHESIS</th>
<th>DISTRIBUTION</th>
<th>F-VALUE (P-VALUE)</th>
<th>F-VALUE (P-VALUE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Null: NIRS</td>
<td>Exponential</td>
<td>1.20 (0.13)</td>
<td>1.18 (0.17)</td>
</tr>
<tr>
<td>Alt: IRS</td>
<td>Exponential</td>
<td>1.29 (0.14)</td>
<td>1.25 (0.17)</td>
</tr>
<tr>
<td></td>
<td>Half-normal</td>
<td>1.13 (0.23)</td>
<td>1.12 (0.25)</td>
</tr>
<tr>
<td></td>
<td>Half-normal</td>
<td>1.12 (0.31)</td>
<td>1.13 (0.30)</td>
</tr>
</tbody>
</table>

Note: NIRS = non-increasing returns to scale. IRS = increasing returns to scale. DRS = decreasing returns to scale.

Analyzing Industry Competitiveness

We used the widely-accepted *four-firm concentration ratio* (4FCR) as our *industry competitiveness measure*. This measure is widely accepted in the economics literature as an indicator of industry competitiveness. This data was also available from the BEA. Based on the 4FCR in 1992, we separated the industries into high (4FCR < 40%) and low competition (4FCR > 40%) categories. A 40% cutoff is used in similar studies; the long-run average of the concentration ratio for all industries in the United States falls in the middle of the middle 20% of the industry categories (Gilligan 1999).

To test our hypotheses, we computed odds ratios for three indices based on the high and low competition groups: Δ*overall efficiency*, Δ*realized value* and Δ*potential value*. We also computed the corresponding p-values of the odds ratio to test for significance. We also tested to see whether there was a non-random relationship between the competition categories and the different value returns measures, via the non-parametric *Fisher’s exact test* (Agresti 2002). The test enables the analyst to make an inference from the data based on the observed or exact distribution in the data, rather than a large sample approximation of it. No assumptions about the variable’s underlying distribution are required. This test provides evidence that the results obtained from our study will generalize when some distributional assumptions are made about the DEA estimation results.

Empirical Results

Our empirical results indicated that most industries are not operating at their potential in the presence of IT. Figures 4a and 4b show the distribution of the ratio of realized value to potential value for the years 1992 and 1997 and Table 5 shows the descriptive statistics of the two distributions.
Figure 4a. Realized Value (1992)

![Histogram for Realized Value in 1992]

Figure 4b. Realized Value (1997)

![Histogram for Realized Value in 1997]

Table 5. Descriptive Statistics for the Ratio of Realized Value to Potential Value, 1992 and 1997

<table>
<thead>
<tr>
<th>Ratio of Realized Value to Potential Value</th>
<th>N</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>StdDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>For 1992</td>
<td>79</td>
<td>0.396</td>
<td>1.000</td>
<td>0.6817</td>
<td>0.1735</td>
</tr>
<tr>
<td>For 1997</td>
<td>79</td>
<td>0.400</td>
<td>1.000</td>
<td>0.6288</td>
<td>0.1451</td>
</tr>
</tbody>
</table>

For both 1992 and 1997, the minimum ratio of realized value to potential value is approximately 0.40 and the mean ratio of realized value to potential value across industries is around 0.63 in 1992 and 0.68 in 1997. The means of both ratios are significantly less than 1. (See Table 6).

Table 6. Test for Gap between Potential Value and Realized Value

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean</th>
<th>StdDev</th>
<th>Difference from 1</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio of realized value to potential</td>
<td>79</td>
<td>0.629</td>
<td>0.145</td>
<td>-0.371***</td>
<td>Ratio of realized to potential value much lower than 1</td>
</tr>
<tr>
<td>value (1992)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ratio of realized value to potential</td>
<td>79</td>
<td>0.682</td>
<td>0.174</td>
<td>-0.318***</td>
<td>Ratio of realized to potential value much lower than 1</td>
</tr>
<tr>
<td>value (1997)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δ realized value index</td>
<td>79</td>
<td>1.106</td>
<td>0.282</td>
<td>0.106***</td>
<td>Greater proportion of value realized in 1997 than in 1992</td>
</tr>
</tbody>
</table>

Note: *** = p < 0.001

This suggests that, on average, industries are not realizing the full potential value of the IT investments that they make. Further, it is evident that for both years, less than half of the industries are realizing more than 70% of their potential value (ratio of less than 0.7). This further suggests that there is an opportunity for industries to realize greater value from their IT investments. We also examined the nature of the gap across the 13 sectors that comprise these 79 industries. There is significant dispersion in the gap between realized and potential value among the industries—even from the same sector for both time periods. (See Figure 5.)
Figure 5. Boxplots of the Ratio of Realized Value to Potential Value across 13 Sectors

Note: Boxplots in the figure represent the central 95% of the respective distributions of the ratio of realized value to potential value by industry sector. The ends of the arms for each boxplot represent the 2.5 and 97.5 percentile observations and the black bar represents the mean. O and $\star$ represent outliers in the distributions.

For example, the industries within the “Transportation and Warehousing” sectors have differences in value gaps of as much as 45%. We assessed the dispersion of the value gap by measuring the standard deviation of the ratios of realized value to potential value across the 13 sectors and found that the dispersion is significant for both 1992 and 1997. (See Table 7.)

Table 7. Dispersion of Gap between Potential Value and Realized Value across 13 Sectors

<table>
<thead>
<tr>
<th>STDDEV FOR RATIO OF REALIZED VALUE TO POTENTIAL VALUE</th>
<th>N</th>
<th>MEAN</th>
<th>STD. ERR.</th>
<th>DIFFERENT FROM ZERO?</th>
<th>INTERPRETATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>For 1992</td>
<td>13</td>
<td>.047</td>
<td>.0329</td>
<td>.0468***</td>
<td>Std. devs. of ratio of realized value to potential value across 13 sectors $&gt; 0$</td>
</tr>
<tr>
<td>For 1997</td>
<td>13</td>
<td>.058</td>
<td>.0426</td>
<td>.0581***</td>
<td>Std. devs. of ratio of realized value to potential value across 13 sectors $&gt; 0$</td>
</tr>
</tbody>
</table>

Note: *** = $p < 0.001$

We also conducted a sample $t$-test on the $\Delta$ realized value index to examine if there is a change in the realization of IT value across time. As shown in Table 6, our test indicates that there is a significant increase in the change in proportion of realized value from 1992 to 1997, signifying that industries are realizing more of the potential value created by IT investments from 1992 to 1997. Our subsequent findings show support for the next three hypotheses. (See Tables 8, 9 and 10.)
Table 8. Relationship between Competitiveness and Growth in Potential Value

<table>
<thead>
<tr>
<th>Level of Competition</th>
<th>∆ Potential Value</th>
<th>Fisher’s Value p-</th>
<th>Odds Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decline</td>
<td>Improve</td>
<td>0.014</td>
<td>Odds ratio = 23.8, p &lt; 0.012 → Higher industry competitiveness leads to more growth in potential value. Fisher’s exact test: significant relationship between value growth and competitiveness.</td>
</tr>
<tr>
<td>Low</td>
<td>59</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>17</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Note: This table shows the distribution of 79 industries according to the level of competition (low or high) in the industry and the change in potential value from 1992 to 1997.

Table 9. Relationship between Competitiveness and Growth in Realized Value

<table>
<thead>
<tr>
<th>Level of Competition</th>
<th>∆ Realized Value</th>
<th>Fisher’s Value p-</th>
<th>Odds Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decline</td>
<td>Improve</td>
<td>0.035</td>
<td>Odds ratio = 0.368, p = 0.03 → Higher industry competitiveness leads to less realized value. Fisher’s exact test: significant relationship between competition and realized value.</td>
</tr>
<tr>
<td>Low</td>
<td>21</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>12</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

Note: This table shows the distribution of 79 industries according to the level of competition (low or high) in the industry and the change in realized value from 1992 to 1997.

Table 10. Relationship between Competitiveness and Change in Overall Gains

<table>
<thead>
<tr>
<th>Level of Competition</th>
<th>∆ Efficiency Overall Efficiency</th>
<th>Fisher’s Value p-</th>
<th>Odds Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decline</td>
<td>Improve</td>
<td>0.148</td>
<td>Odds ratio = 0.638, p &lt; 0.20 → Industry competitiveness has no significant impact on overall IT efficiency gains. Fisher’s exact test: competitiveness and efficiency gains unrelated.</td>
</tr>
<tr>
<td>Low</td>
<td>32</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>13</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

Note: This table shows the distribution of 79 industries according to the level of competition (low or high) in the industry and the change in overall efficiency from 1992 to 1997.

Based on both the parametric odds ratios and the non-parametric Fisher’s exact test, we found that industries facing high competition adopted a mix of IT and other production inputs that resulted in higher growth in potential value as proposed in the Potential Value Hypothesis (H2). In contrast, industries facing low competition adopted a mix of IT and production inputs that resulted in lower potential value over time. Highly-competitive industries have higher managerial and selection pressures. These, in turn, lead to better production input mix selection decisions. With pressure, managers are more mindful of making the right IT investment decision. The result is higher potential value of IT over time. The opposite, meanwhile, is true for less competitive industries. Managers in such industries (e.g. monopolistic or oligopolistic industries) feel less operational pressure. So IT investment decisions have an underlying value creation process that offers lower potential value. Earlier, we referred to managerial slack and the “quiet life” as reasons for inefficient decision making. Managers in less competitive settings face less pressure, are more averse to hard work, and have fewer incentives to make an all out effort to achieve high value.

Our results show that despite being in a zone of higher potential IT value for their investments, highly-competitive industries are less likely to fully realize value, as suggested by the Realized Value Hypothesis (H3). Operating in a more competitive environment means that every firm will have to compete harder for limited market share. Having more firms in any industry also typically means that there are higher fixed costs that must be borne in the industry’s operations (as opposed to an industry with fewer firms and more consolidated market share). Moreover, the duplication of fixed costs across firms in the industry dampens the scale economies possible industry-wide (Motta
Valuing IT Opportunities

2004). Higher competition also results in crowding-out effects in the industry, hampering the ability of industries to fully appropriate the economic rents that should accrue from their IT investments.

In determining the overall change in efficiency gains, we have to consider both the impacts of potential value growth and success with the realization of potential value, based on the results we obtained. Although industries in more competitive environments show growth in potential value, they lack the capability to appropriate or realize value. The reverse is true for industries in less competitive environments. With the tension and offsetting forces in support of value creation, we see that our results tend to support the assertion that more and less competitive industries may not differ significantly in terms of the overall gains that they exhibit in efficiency. This supports our Overall IT Efficiency Gains Hypothesis (H4).

Table 11 provides a summary of the results for the last three hypotheses tested. From the summary, we can see that competition is a double-edged sword. It provides an industry with incentives to invest, innovate and adopt new ITs, resulting in higher potential value. But it also curtails an industry’s ability to capture the potential value of IT investments, due to the crowding-out and lost scale-size effects.

<table>
<thead>
<tr>
<th>HYPOTHESIS</th>
<th>ODDS RATIO</th>
<th>FISHER’S EXACT TEST</th>
<th>CONCLUSION DRAWN</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2</td>
<td>23.80**</td>
<td>0.0144**</td>
<td>Higher competition → Higher potential value</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lower competition → Lower potential value</td>
</tr>
<tr>
<td>H3</td>
<td>0.368**</td>
<td>0.0350**</td>
<td>Higher competition → Lower realized value</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lower competition → Higher realized value</td>
</tr>
<tr>
<td>H4</td>
<td>0.638</td>
<td>0.148</td>
<td>Competition → No net impact on efficiency gains</td>
</tr>
</tbody>
</table>

Note: Significance level: ** = p < 0.05

Discussion

The results we obtained from testing the four hypotheses provide new insights into the relationship between industry-level IT investment patterns and payoffs. In this section, we will discuss some IT investment strategies that appear to follow from these findings.

Right-Sizing IT investments

IT managers are often faced with the challenging question of how to optimize the level of IT investments within their organizations. Managers must justify every capital investment within the firm to ensure efficient use of available capital, and maximization of the returns on investment. Making the right level of IT investment commitments ensures both allocative and productive efficiency within the firm, and by association, within the industry. To address this issue, we first analyzed the relationship between the degree of competition in the industry (measured by 4FCR) and the corresponding proportion of factor inputs (IT capital, Non-IT capital and labor). Table 12 shows the correlations between these variables.

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>COEFFICIENT ESTIMATES AND p-VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IT Capital</td>
</tr>
<tr>
<td>Industry Concentration</td>
<td>0.335***</td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
</tr>
</tbody>
</table>

Note: *** p < 0.01. Results based on 79 industries in 1992.

We observe that industry concentration is positively correlated with IT capital: firms in less competitive industries on average invest in larger shares of IT investments than firms in more competitive industries. From Table 13, we further can see that IT capital on average represents 3.86% of total factor inputs used in industries with low levels of competition. In industries with high levels of competition, this percentage is only 0.92%. Tying this result back to
our initial findings, we conclude that industries which experience low levels of competition are more likely to allocate larger percentages of their total capital in IT spending. However, due to poorer quality investment decisions, this higher level of investment does not translate into higher potential value for the industry. In contrast, industries in more competitive environments on average allocate smaller percentages of their total capital into IT investments, but through optimal investment decisions, they tend to create high potential value with these investments.

Table 13. Proportions of Factor Inputs

<table>
<thead>
<tr>
<th>Industry Concentration</th>
<th>MEAN PROPORTION OF TOTAL INPUTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>IT Capital 3.86% Non-IT Capital 68.09% Labor 28.04%</td>
</tr>
<tr>
<td>Low</td>
<td>IT Capital 0.92% Non-IT Capital 57.54% Labor 41.54%</td>
</tr>
</tbody>
</table>

From this finding, it is clear that a higher proportion of IT investment does not necessarily lead to higher potential IT value. Rather, IT investment selection decisions combine with allocation choices and factor mix, and these together affect the extent to which potential value develops. The role of complementary and related investments (e.g., in process-related training, implementation activities, procedures and policies, tool use, etc.) to maximize IT investments potential is crucial (Clemons and Row 1991). To this end, we will next suggest strategies for achieving an optimal mix of factor inputs.

**Finding the Optimal Mix of Factor Inputs Involving IT**

The difference in the competitive environment that a firm faces within an industry impacts its production decisions as well as the firm’s ability to obtain inputs. Determining the right relative mix of factor inputs has an impact on the potential and realized value of the corresponding IT investments made by the organization. In addition to establishing that competition impacts potential and realized IT value, the methodological framework proposed in this study serves as a tool to better understand the impact of relative sizes of factor inputs. The application of our proposed methodological representation is best explained by the use of a graph shown in Figure 6.

**Figure 6. Production Boundaries for Two Time Periods**

To represent our ideas in a two-dimensional graph, we adopt a hypothetical production process that utilizes two factor inputs, $x_1$ and $x_2$. By using the methodology developed in this paper, we are able to plot the potential value curves for the process for periods $t_1$ and $t_2$. From the potential value curves, it is evident that there are two possible value loci, A and B, which exhibit different changes to the potential value of the IT investment. For Locus A, there is a gain in potential value from $t_1$ to $t_2$ as the potential value curve shifts towards the origin over time. Correspondingly for Locus B, there is a drop in potential value from $t_1$ to $t_2$. 
If we were to represent the industry data that are being analyzed in this study, industries experiencing high competition would lie in Locus A and industries experiencing low levels of competition would lie in Locus B. By theoretically classifying various input mixes into their respective value loci based upon past investment mix patterns, we are able to achieve the following goals. First, decision makers are able to better understand the potential value trajectory of a particular input mix over time and can fine-tune their IT investment plans. Second, decision makers can utilize this more holistic picture of the value growth potential of their IT investments to set realistic targets and benchmarks for IT initiatives. Targets set using this theoretically-developed and empirically-established framework will result in realistic goals promoting stronger goal-directed motivation. Third, by measuring the value growth potential as well as the realized value of IT investments for all industries, this framework provides policy-makers with an objective measure of the potential and actual returns for each industry. Information of this kind is critical for future resource allocation decisions to be value-maximizing.

Conclusion

In this study, we have explored how to assess IT potential value and realized value in an industry-level model, via a non-parametric DEA-based measurement approach that builds on the Malmquist productivity index.

Contributions

Using data from the BEA, we showed that a gap exist between the potential and realized value of IT investments among United States industries. Although the industries are realizing proportionally more value in 1997 than 1992, less than half of the industries realized more than 70% of its potential value. We found that industry competitiveness has a positive impact on the growth of potential value of IT investments. But it has a negative impact on the realization of potential value. This conclusion is similar in flavor to what Thatcher and Pingree (2004) reported related to IT investments and the tradeoff between higher product quality and lower firm productivity—nevertheless leading to optimal firm value. An understanding of the impacts of competition on the potential and realized value of IT helps managers to identify the shortcomings in mainstream investment strategies across different competitive environments and improve future IT investment decision-making processes. The results from our hypotheses tests extend the IS literature on IT value by merging economic theories on competition with existing theoretical foundations.

We further report that the overall efficiency gains of the industries in our sample were not affected by the nature of industry competitiveness. Although competitiveness affects the potential and realized value of IT investments, due to the interrelated nature of these impacts, on the whole, competitiveness does not affect the overall efficiency. This highlights the strength of the measurement model set out in this paper. A similar analysis using existing measurement methods of IT value will inaccurately conclude that competitiveness does not affect the value creation process of IT investment. Using our model will provide appropriate granularity for the components of the value creation process, and insights about how to maximize IT value flows.

This study also makes a number of methodological contributions. To the best of our knowledge, it is the first measurement model that is developed to objectively measure the changes in potential and realized value of IT investment. This measurement model advances the IS literature by contributing a theoretically-developed and empirically-tested model to measure the potential and realized value of IT. The measurement model also extends the IS literature on IT value measurement by incorporating economic theory and management science methods that offer particular leverage for understanding this complex problem. Our specification of the model is flexible, and can be applied for measurements at different levels of analysis, such as the firm or process level—in addition to the aggregate industry level that we have explored. The applicability of this model will facilitate research and enable practitioners to better understand the gap between the potential and the realized value of IT investments. Our measurement approach creates objective measures that will form the basis for judgment and justification for IT investment decisions by managers.

Limitations and Future Research

We used census data from two time periods to measure the impact of competition on potential and realized value of IT investments. Since the census is conducted every five years, data from multiple years are not available.
Analyzing more time periods may reveal additional insights about the phenomenon of potential and realized value. Given the flexibility of our measurement model, it is possible to analyze the shifts of potential and realized value of IT investments for more than two time periods.

The potential and realized value of IT investments is affected by competition, along with a wide variety of other factors. In this study, we chose only to examine the impact of competition (to the extent we could show interesting results) and the lack of consensus in the literature. This research serves as a building block for future research that measures the impacts of other drivers of the potential and realized value of IT.

References


### Appendix A. Mathematical Notation Used in the Measurement Model

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t$</td>
<td>Time period $t$</td>
</tr>
<tr>
<td>$x$</td>
<td>Input $x$</td>
</tr>
<tr>
<td>$y$</td>
<td>Output $y$</td>
</tr>
<tr>
<td>$Y(x)$</td>
<td>Set of possible output(s)</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Weights of the observations</td>
</tr>
<tr>
<td>$j$</td>
<td>Number of firms or decision making units, with $j = {1,\ldots,J}$. Also used to represent different industry sectors in the DEA analysis</td>
</tr>
<tr>
<td>$M_0(\bullet)$</td>
<td>Malmquist productivity index</td>
</tr>
<tr>
<td>$D_0(\bullet)$</td>
<td>Output distance function from frontier at time $t$</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Efficiency level</td>
</tr>
<tr>
<td>$K$</td>
<td>Vector of efficiency levels</td>
</tr>
<tr>
<td>$m, M$</td>
<td>Number of outputs, with $m = {1,\ldots,M}$; total number of outputs</td>
</tr>
<tr>
<td>$n, N$</td>
<td>Number of inputs, with $n = {1,\ldots,N}$; total number of input</td>
</tr>
</tbody>
</table>