MEASURING THE POTENTIAL AND REALIZED VALUE OF IT[1]

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1. INTRODUCTION

Managers rely on prior beliefs and expectations to make decisions. Typically, IT investment decisions are made by weighing the <u>*potential*</u> benefits and <u>*actual*</u> costs of the investment. Hence, establishing an objective understanding of 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 to the actual payoffs of investments due to a variety of impediments in the value creation process. There often is a gap between potential and realized value of IT investments which needs to be defined and measured (Davern and Kauffman 2000, Chircu and Kauffman 2001). Most studies in the IT value literature focus on measuring the realized value of IT investments. Few have explored the issue of the potential value of IT. Moreover, of those who have, none has developed objective measures for potential value based on theory.

We address the gap between the potential and realized value of IT investments by developing a measurement model grounded in the theory of production economics. We apply this measurement model to examine the impact of competition faced in an industry based on the potential and realized value of IT investments. We ask: How can we measure the gap between the potential and realized gains from IT investment? How significant is the gap across industries? How will competition in an industry impact potential value and realized value of IT investments? How does industry competition impact changes in IT efficiency gains and value over time?

We explore these questions by first developing a measurement technique for computing the potential and realized value of IT investments. We then apply this model to examine the gap between realized and potential value of IT investments across industries. Finally, we provide some explanations of the impact of competitions on the value of IT investments.

2. THEORETICAL BACKGROUND

The *IT value* 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). To the best of our knowledge, all prior studies 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.

Potential Value vs. Realized Value. We define *potential value* as the <u>maximum</u> feasible payoff of an IT investment under efficient production conditions. This expected return on 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*, such as managerial

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intervention and environmental influences, play a key role in shaping the outcome of any IT investment, leading to *realized value* of the IT investment. Conversion effects occur at all levels of the organization and create a gap between potential and realized value. Realized IT value is most often measured in the literature, in spite of the fact that the potential value of an IT investment nevertheless is one of the key pieces of information that managers consider most often consider before they invest in an IT initiative.

IT Value Creation as an Economic Production Function. The creation of IT value is widely accepted as a process involving *economic production* (Dewan and Kraemer 2000; Hitt and Brynjolfsson 1996). Various studies have modeled this process under parametric production functions, such as Cobb-Douglas, translog and CES. To model the effects of potential and realized value of IT investments, we conceptualize the *creation of IT value as a piece-wise linear production technology* (Shephard 1970) where each economic unit, represented by a combination of input and output values, forms the possible technology set. The production function yields the linear trace of input-output boundary values, which is called the *production frontier*.

The production frontier represents the upper bound of output for any given mix of inputs in the production process, and all possible combination of input and output mixes must exist on or below this frontier. Both the potential and realized value of an IT investment can be represented and measured using this non-parametric economic production representation. This representation of the production technology models the frontier to delineate the potential value of the IT investment. The observed output values from the production process map to realized IT value.

3. ANALYSIS METHODOLOGY DEVELOPMENT

Under this production representation, we modify the *Malmquist productivity index* (Caves et. al. 1982) to model the changes in potential and realized value of IT over time. We mathematically show that overall change in IT efficiency over two time periods, *M*, depends on two factors: (1) the ability to realize value, and (2) the change in potential value – both over the same time period. This is expressed in terms of a production mapping, *D*:

$$M_o(x^{t+1}, y^{t+1}, x^t, y^t) \quad = \quad \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \quad \times \quad \left[\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1})}\right) \times \left(\frac{D_o^t(x^t, y^t)}{D_o^{t+1}(x^t, y^t)}\right)\right]^{1/2}$$

Δ Overall Efficiency = Δ Realized Value *x* *Δ Potential Value*

Firms with *changes in (Δ) overall efficiency,* $M_o(\bullet) > 1$, improve in efficiency for *t* to *t+1*. Those with $M_o(\bullet) < 1$ show decline in efficiency. *Changes in (Δ) realized value* measures the extent to which the firm creates IT value up to the forecast potential. Firms with high *Δ realized value,* $D_o^{t+1}(\bullet)/D_o^{\,t}(\bullet) > 1$, achieve realized IT value closer to potential value at time *t+1* than *t*. Conversely, firms with low *Δ realized value*, $D_o^{t+1}(\bullet)/D_o^{\,t}(\bullet) < 1$, realize less potential value at time *t+1* than *t*. See Figures 1a and 1b below.

Changes in (Δ) potential value measure movement of potential value from *t* to *t+1* for an appropriate economic unit. *Δ potential value* > 1 is an average gain in potential value for an input mix used by the firm from *t* to *t+1*. *Δ potential value* < 1 signifies a drop. See Figures 2a and 2b.

Figure 1a. Improving realized value

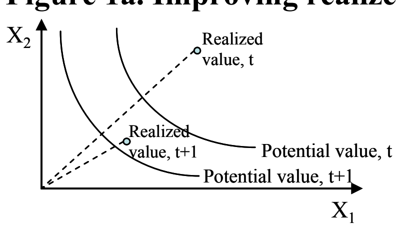


Figure 1b. Declining realized value

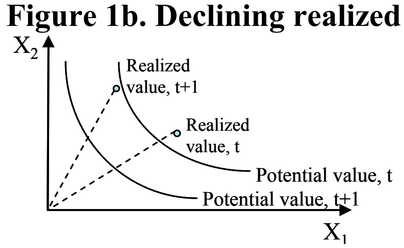
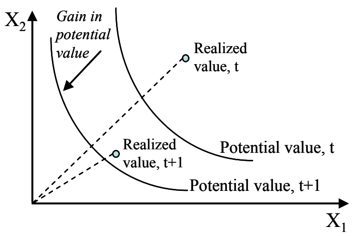
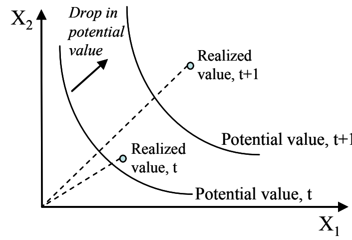


Figure 2a. Improving potential value **Figure 2b. Declining potential value**





We apply this model to examine the gap between realized and potential value for different industries and the role of industry competition. We formulated a number of hypotheses based on theoretical knowledge related to IT value literature and industry competition:

i. **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.*
ii. **Hypothesis 2 (The Potential Value Hypothesis):** *Industries that exhibit higher (lower) levels of competition utilize IT and other production factors which result in higher (lower) potential value over time for firms.*
iii. **Hypothesis 3 (The Realized Value Hypothesis):** *Less competitive industries will outperform more competitive industries in realizing potential value over time.*
iv. **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.*

The hypotheses are motivated by the following observations. In highly competitive environments, different investments, technologies and initiatives exist and the market forces will allow only the fittest to survive, weeding out the weakest. Industries in highly competitive environments have greater incentive to adopt new technologies and investments (Motta 2004) and competition motivates firms to put in more effort in making investment decisions to improve their competitive position, resulting in higher potential value. Industries in highly competitive environments experience higher aggregated fixed costs, and the "crowding out" effect dampens their ability to fully realize value from IT investments. Despite being in a production space for high potential value, these industries face forces that will lead to less realized value.

4. METHODOLOGY

Our measurement model is solved using *data envelopment analysis* (DEA) techniques. DEA does not require the specification of the functional form of the economic production and or many assumptions. These properties improve the robustness of the estimates.

Data and Variables. We apply our model to U.S. Bureau of Economic Analysis (BEA) industry-level data from 1992 and 1997, and examine effects of industry competition on potential and realized IT value. We include all five-digit BEA industries that invested in IT. Using IT capital, non-IT capital and labor costs as inputs for the production process and gross GDP as the output, we computed the value indices for the industries. We used the widely-accepted *four-firm concentration ratio* (4FCR) as our *industry competitiveness measure*. Based on 1992 ICMs, we separated industries into high/low competition categories. Industries with 4FCRs < 40% are highly-competitive; those with 4FCRs > 40% are less-competitive (Gilligan 1999).

Empirical Estimation and Robustness Testing. We compute two key value indices for each of the key factors. To compute the components of the measurement model, $D_o^t(x^t,y^t)$, $D_o^t(x^{t+1},y^{t+1})$, $D_o^{t+1}(x^t,y^t)$ *and* $D_o^{t+1}(x^{t+1},y^{t+1})$, we set up a series of linear programs and solved them under non-increasing, non-decreasing and variable returns-to-scale (NIRS, NDRS, VRS). We then put these components into the measurement model to obtain the value indices.

Banker and Chang (1995) developed statistical tests for returns-to-scale and estimation robustness. To ensure empirical robustness, we modified their single-period DEA test statistics to match our two-period measurement model. We conducted a series of three tests—for consistent returns-to-scale, boundary values and inner values—and showed that our estimates are robust.

To test our hypotheses, we computed odds ratios for three indices—*Δ overall efficiency*, *Δ realized value* and *Δ potential value*—based on high and low competition groups. The corresponding *p*-values of the odds ratio are computed to test for the significance of the result. We also used the non-parametric *Fisher's exact test* to test if there is a non-random relationship between the competition categories and the different value returns measures. The test performs inference from the data by using the exact distribution, rather than a large sample approximation, without assumptions about the variable's underlying distribution. It ensures that our results are generalizable to other distributional assumptions made with the DEA analysis.

5. MODEL APPLICATION AND HYPOTHESIS TEST RESULTS

Our empirical results indicated that most industries are not operating at their potential in the presence of IT. For both years, less than half of the industries are realizing more than 70% of their potential value. Further analysis show a significant increase in the change in proportion of realized value from 1992 to 1997, signifying that industries were realizing more of the potential value created by IT investments. (See Table 1.)

Table 1. Test for Gap between Potential Value and Realized Value

VARIABLE	N	MEAN	STDDEV	DIFF FROM 1	INTERPRETATION
Ratio of realized value to potential value (1992)	79	0.629	0.145	-0.371***	Ratio of realized to potential value much lower than 1
Ratio of realized value to potential value (1997)	79	0.682	0.174	-0.318***	Ratio of realized to potential value much lower than 1
Δ realized value index	79	1.106	0.282	0.106***	Greater proportion of value realized in 1997 than in 1992
Note: *** = $p < 0.001$					

Table 2. Competitiveness and Potential Value, Realized Value and Overall Gains

COMPETITION	DECLINE	IMPROVE	FISHER'S *p*-VALUE	ODDS RATIO
	Δ POTENTIAL VALUE			
Low	59	0	0.014	Odds ratio = 23.8, $p < 0.012$ → Higher industry competitiveness leads to more growth in potential value. Fisher's exact test: significant relationship between value growth and competitiveness.
High	17	3		
Note: The cells above show 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.				
	Δ REALIZED VALUE		0.035	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.
Low	21	38		
High	12	8		
Note: The cells above show 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.				
	Δ OVERALL EFFICIENCY		0.148	Odds ratio = 0.638, $p < 0.20$ → Industry competitiveness has no significant impact on overall IT efficiency gains. Fisher's exact test: competitiveness and efficiency gains unrelated.
Low	32	37		
High	13	7		
Note: The cells above show 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.				

Our results support all three competition-related hypotheses in Table 2. Highly-competitive industries have higher managerial and selection pressures. These lead to better production input mix selection decisions. With pressure, managers are mindful of making the right IT investment decision and the IT value creation process will have a higher potential value over time. The opposite is true for less competitive industries. Managers in monopolistic or oligopolistic industries feel less operational pressure. So IT investment decisions have an underlying value creation process that falls with lower potential value. *Managerial slack* may lead to 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 region of higher potential IT value for their investments, highly-competitive industries are less likely to fully realize it. Operating in a more competitive environment implies mores firm in an industry, each having to compete harder for *limited market share*. The increased number of firms also requires that *higher fixed costs* must be borne in their operations. Moreover, the *duplication of fixed costs across firms* in the industry dampens the scale economies possible industry-wide (Motta 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. Thus, we 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 crowding out and lost scale size effects.

6. CONCLUSION

We have operationalized the constructs of *potential value* and *realized value* for an industry-level evaluative model, a non-parametric economic measure that builds on the Malmquist productivity index. With BEA data, we showed that a gap exists between the potential and realized value of IT investments among U.S. industries. Although the industries are realizing proportionally more value in 1997 than 1992, less than half of the industries realized more than 70% of their IT investments' potential value. We showed 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) have reported related to IT investments and the tradeoff between higher product quality and lower firm productivity—nevertheless leading to optimal firm value. We report that the overall efficiency gains of the industries were not by the nature of industry competitiveness.

7. REFERENCES

1. Banker, R.D., and Chang, H. "A Simulation Study of Hypothesis Tests for Difference in Efficiencies," *Intl. J. Prod. Econ.* (39:1), 1995, 37-54.
2. Caves, D.W., Christensen, L.R., and Diewert, W.E. "Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity," *Econometrica* (50:6), 1982, 1393-1414.
3. Chircu, A. M., and Kauffman, R.J. "Limits to Value in Electronic Commerce-Related IT Investments," *JMIS* (17:2), 2000, 59-80.
4. Davern, M.J., and Kauffman, R.J. "Discovering Potential and Realizing Value from IT Investments," *JMIS* (16:4), 2000, 121-143.
5. Dewan, S., and Kraemer, K.L. "IT and Productivity: Evidence from Country-Level Data," *Mgmt. Sci.* (46:4), 2000, 548-562.
6. Gilligan, T.W. "Industrial Concentration," in *Concise Encyclopedia of Economics*, 1999.
7. Hitt, L.M., and Brynjolfsson, E. "Productivity, Business Profitability, and Consumer Surplus: Three Different Measures of IT Value," *MISQ* (20:2), 1996, 121-142.
8. Motta, M. *Competition Policy: Theory and Practice.* Cambridge Univ. Press, UK, 2004.
9. Shephard, R.W. *Theory of Cost and Production Functions* Princeton Univ. Press, NJ, 1970.
10. Thatcher, M., and Pingry, D. "An Economic Model of Product Quality and IT Value," *ISR*, (15:3), 2004, 268-286.