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IT Productivity Paradox – A Duopoly Prospective

Jim Quan and Qing Hu
Department of Information Technology and Operations Management
College of Business–Florida Atlantic University
Boca Raton, FL 33431
(561) 297 - 3557 (phone), (561) 297 – 3043 (fax)
quan@fau.edu / qhu@fau.edu

ABSTRACT

Over the last two decades extensive empirical studies have been conducted on the contribution of information technology (IT) to productivity and other measures of firm performance. However, few theoretical studies have attempted to explain the contingencies under which IT investments may or may not be valuable to a firm in a competitive market. This research proposes a duopoly competition model to study the impacts of IT investments on firm productivity. We show that in a duopoly market, in order for firm productivity to benefit from IT investments, in addition to the condition under monopoly that its fixed cost has to be sufficiently large in relation to its market size, market sensitivities are also important factors. Moreover, the price sensitivity has a positive impact on the effect of IT investments on productivity and quality sensitivity has a negative impact.

INTRODUCTION

Is there an IT productivity paradox? There are plenty of empirical studies that provide both positive support [3, 8, 9] and negative support [1, 4, 5, 7] for answering this question. There are also studies that suggest the answer is contingent on firm characteristics and types of investments [6, 13, 14]. Mixed empirical results are an invitation to seek better theories. Soh and Markus suggest that a useful approach would be to focus less on the question of whether IT creates value and instead focus more on how, when, and why benefits occur or fail to do so [11]. Thus, there is a need for more rigorous theoretical studies that analyze the impact of IT investments on productivity and other performance measures in the context of complex interactions between the internal and external forces that all firms have to face in competitive market environments.

There are two theoretical studies that are particularly salient for our focus on better understanding the role of competitive market environments. The first, by Barua, Kriebel and Mukhopadhyay, proposes a duopoly model to study the impact of IT investments where in terms of IT costs one firm is more IT-efficient than the other for a given level service offered to customers [2]. Their analysis focuses on the special sector of the economy in which the services are not priced initially (e.g., financial services sector) and the benefits come indirectly (e.g., in the form of interest earned on consumer deposits or floating on checking accounts). The second study, by Thatcher & Oliver, addresses the IT productivity paradox in a more direct fashion [12]. They suggest that "one reason for these mixed empirical findings is that the studies have not effectively differentiated among (and often confuse) the goals of increasing production efficiency, improving product quality and increasing productivity." Thus, they proposed a closed-form analytical model to demonstrate the interactions among production efficiency, product quality and productivity under a single-product monopolist market condition. They found that while various efficiency-enhancing IT investments have unambiguously positive effects on a range of performance measures including revenue and profits, the impact on productivity was contingent on firms' fixed costs and market sizes.

In this study, we extend the work of Thatcher and Oliver [12] by introducing a duopoly market model and that of Burua et al. [2] by including both price and quality components. Our goals are to analyze the impact of IT investments on firm productivity and to draw comparisons between the outcomes under duopolistic and monopolistic market conditions. The conclusions drawn from our analysis should have wider and more general implications for both theoretical development and managerial practices. It is our belief that a duopoly is more reflective of market conditions than a monopoly and that firms compete on the basis of product price and quality in most of industries. We also argue that the effect of IT investments on the firm performance is influenced to a significant extent by the interactions between firms and market characteristics. In a monopoly market, the benefits of IT investments depend solely upon the firm's own production efficiency. However, in a duopoly market, such benefits also depend upon how the competition reacts to the investment decision. The benefits would be either greater or less than if the firm was in a monopoly market. In addition, we demonstrate that under a duopolistic market the contingency for IT investments to have a positive impact on productivity are different under monopolistic competition.

We introduce two types of market conditions in the proposed duopolistic model. In a market in which price is a critical factor in customers' purchasing decisions, the demand for one firm's products or services should be influenced by the competitor's pricing challenge. The goods and services in this type of markets are often regarded as commodities. On the other hand, in a market in which quality is a critical factor in customers' purchasing decisions, the demand for one firm's products or services should be influenced by the competitor's quality challenge. This is mostly likely the case in service industries where service providers use quality as a differentiation factor or in an industry where a firm enjoys a distinct name brand recognition. We demonstrate that the extent to which a profit-maximizing firm benefits from various efficiency-enhancing IT investments is a function of, among other things, market sensitivities to the prices and quality of the products and services it and its competitor offer. We show that the impact of IT investments moves in the same direction as market sensitivity to price but moves in the opposite direction of the market sensitivity to quality. Therefore, firms are much better off by making efficiency-enhancing IT investments if they operate in price sensitive markets than if they operate in quality sensitive markets.

The remainder of this article is organized as follows. The next section provides literature review and describes the research background. This is followed by an exposition of the research model. Next, we identify the impacts of various efficiency-enhancing IT investments on productivity. In the final section, we discuss the implications of this research for management and conclude with suggestions for future research.

THE MODEL

In a duopoly the demand (D_i) function for Firm i's product can be written as

$$D_i = a - b(P_i - \lambda P_j) + c(Q_i - \theta Q_j)\,, \tag{1}$$

where a, b, c > 0 are parameters. (P_i, P_j) and (Q_i, Q_j) are the combinations of the prices and quality levels of the products of Firms i and j, respectively. λ and θ, 0 < θ, λ <1, are the cross elasticity of substitution of price and quality, respectively.

λ In terms of cost, the firms have several cost components such as the fixed and overhead cost, the product design and development cost, and the variable cost of actual manufacturing and distributing the products. Following Thatcher & Oliver's formulation [12], the cost function for Firm i at a given output level D_i and a specified quality level Q_i can be defined as

$$C_i = F_i + fQ_i^2 + eQ_i D_i \,, \tag{2}$$

where f, e > 0 are parameters that characterize the firm's production capabilities and F_i > 0 represents the amortized fixed costs associated with running the business. Similar formula can be found in IT investments related literatures such as Barua et al. [2].

Next, we introduce productivity into our model. Before proceeding to formalize the functions for these terms, we rewrite equation (1) as follows:

$$D_i = a + b\lambda P_j - c\theta Q_j - bP_i + cQ_i \,, \tag{3}$$

or

$$D_i = A - bP_i + cQ_i \,, \tag{4}$$

where $A = a + b\lambda P_j - c\theta Q_j > 0$ can be defined as the market size for Firm i. The revenue of Firm i, R_i, can be defined as

$$R_i = P_i D_i = P_i (A - bP_i + cQ_i) \,, \tag{5}$$

profit,

$$\pi_i = R_i - C_i = (P_i - eQ_i)(A - bP_i + cQ_i) - F_i - fQ_i^2 \tag{6}$$

and productivity, r_i,

$$\rho_i = \frac{R_i}{C_i} \,, \tag{7}$$

which provides a best-case scenario for observing productivity gains from IT investments, under the assumptions of instantaneous impacts of IT investments and costless technology [12]. It could be argued that Á as defined in equation (7) does not meet the conventional definition of productivity since the productivity of a firm is endogenous to its internal processes and should be independent of the external market conditions that often determined revenue. However, if we consider the market equilibrium and assume that firms operate in a market will behave rationally, that is, they will not intentionally produce more than market demand, then Á in its current form can be considered as a proxy of the real productivity of firms in our duopoly model.

Based on the theoretical framework established above, we can now obtain the equilibrium values for price, quality, demand, cost, revenue, profit and productivity. Given that firms choose the appropriate levels of price and quality to maximize the profit, we take the partial derivatives of equation (6) with respect to P_i and Q_i, respectively and set them to zero, the first order condition for equilibrium. Solving the two simultaneous equations for P_i and Q_i, we obtain the equilibrium levels of price and quality

$$P_i = \frac{A[e(c - be) + 2f]}{\Delta} \,, \tag{8}$$

$$Q_i = \frac{A(c - be)}{\Delta} \,, \tag{9}$$

where $\Delta = 4bf - (c - be)^2 > 0$ is the determinant of the Hessian matrix for the second order condition. To ensure that the firm charges a positive price and chose a positive quality level of product, the assumption that $c > be$ has to be made [12].

If Firm i chooses P_i and Q_i, under the Nash equilibrium of the Bertrand duopoly model [7], Firm j would react to the market in the same way as Firm i in terms of its choice of P_j and Q_j. Thus:

$$P_j = \frac{B[e(c - be) + 2f]}{\Delta} \,, \tag{10}$$

$$Qj = \frac{B(c - be)}{\Delta} \,, \tag{11}$$

where D is the same as above and $B = a + b\lambda P_i - c\theta Q_i > 0$ can be defined as the market size for Firm j. Notice that this market size is a function of P_i and Q_i, the price and quality choices of Firm i. Assuming both firms exhibit rational behavior, the Nash Equilibrium condition imply that the response strategy of Firm j will be symmetric to the strategy of Firm i under the one product and two firm duopoly model. Thus, in the remainder of the paper we will focus only on the analysis of Firm i. The results are equally applicable to Firm j.

Solving equations (8), (9), (10) and (11) for P_i, Q_i, P_j and Q_j, we get the equilibriums for P_i and Q_i:

$$P_i^* = \frac{a(e(c - be) + 2f)}{Z} \,, \tag{12}$$

$$Q_i^* = \frac{a(c - be)}{Z} \,, \tag{13}$$

where

$$Z = 2bf(2 - \lambda) - (c - be)((1 - \theta)c - (1 - \lambda)be) \,,$$

and the conditions $Z > 0$ and $c - be > 0$ have to be imposed to guarantee positive price and quality levels. Substituting them back to (7), we obtain:

$$\rho_i^* = \frac{2a^2 bf(e(c - be) + 2f)}{Z^2 F + a^2 f(c^2 - b^2 e^2)} \,. \tag{14}$$

ANALYSES AND IMPLICATIONS

Given that productivity is defined as in Equation (14), it is straightforward to see the impact of IT investment aiming at reducing fixed and overhead cost, F,

$$\frac{\partial \rho_i^*}{\partial F} = \frac{-2a^2 bfZ^2[2f + e(c - be)]}{[FZ^2 + a^2 f(c^2 - b^2 e^2)]^2} < 0 \,, \tag{15}$$

which indicates an unconditional productivity gain from such an investment, the same as it is monopoly, Thatcher and Oliver [12].

To demonstrate the interactions among market characteristics, changes of F, and the productivity, numeric simulations based on equation (15) are conducted and the results are shown in Table 1.

Table 1. Changes in Productivity from IT investments reducing F (Initial values: a = 100, b = 5, c = 10, e=1, and f =10; F changes from 1200 to 1000)

θ/λ	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
0.1	0.13	0.14	0.17	0.19	0.22	0.26	0.30	0.35	0.41
0.2	0.12	0.14	0.16	0.18	0.21	0.24	0.28	0.33	0.38
0.3	0.11	0.13	0.15	0.17	0.20	0.23	0.27	0.31	0.36
0.4	0.11	0.12	0.14	0.16	0.19	0.22	0.25	0.29	0.34
0.5	0.10	0.12	0.13	0.15	0.18	0.20	0.24	0.28	0.32
0.6	0.10	0.11	0.13	0.14	0.17	0.19	0.22	0.26	0.30
0.7	0.10	0.11	0.12	0.14	0.16	0.18	0.21	0.24	0.28
0.8	0.09	0.10	0.11	0.13	0.15	0.17	0.20	0.23	0.27
0.9	0.09	0.10	0.11	0.12	0.14	0.16	0.19	0.22	0.25

Proposition 1a: *In a duopoly market, as in a monopoly market, regardless market sensitivity to price and quality changes, IT investments aimed at reducing fixed overhead cost have a positive impact on firm productivity, other factors being equal.*

Proposition 1b: *In a duopoly market, for IT investments aimed at reducing fixed overhead cost, the impact on productivity is positively affected by price sensitivity and is negatively affected by quality sensitivity.*

The case for the interaction among market characteristics, changes in the cost of research and development, and productivity, however, is more complex. The effect of f alone can be defined in the following partial derivative:

$$\frac{\partial \rho_i^*}{\partial f} = -2a^2 b \frac{e(c-be)ZF(2bf(2-\lambda)+(c-be)((1-\theta)c-(1-\lambda)be)+2f[ZF(2(c-be)((1-\theta)c-(1-\lambda)be))-a^2 f(c^2-b^2e^2)]}{[Z^2F+a^2 f(c^2-b^2e^2)]^2}$$

(16)

However, the sign of (16) is ambiguously. The condition for a negative sign is

$$F > \frac{a^2 f(c+be)}{[2bfe(2-\lambda)+(e(c-be)+4f)((1-\theta)c-(1-\lambda)be)]Z}, \quad (17)$$

if $(1-\theta)c-(1-\lambda)be) > 0.$ (18)

The interaction among market characteristics, reduction of production and operation cost, and productivity has similar characteristics, as shown in the following equations:

$$\frac{\partial \rho_i^*}{\partial e} = 2a^2 bf \frac{a^2 f[c(c-be)^2+4b^2ef]+ZF[(c-2be)(2bf\lambda-(c-be)(1-\lambda)be)-[4bf+(c-be)c](1-\theta)c}{[Z^2F+a^2 f(c^2-b^2e^2)]^2},$$

(19)

The conditions for a negative sign is

$$F > \frac{a^2 f(c-be)^2+4b^2ef}{[(c-2be)(-2bf\lambda+(c-be)(1-\lambda)be)+[4bf+(c-be)c](1-\theta)c]Z}, \quad (20)$$

and

$$(c-2be)(2bf\lambda-(c-be)(1-\lambda)be)-[4bf+(c-be)c](1-\theta)c < 0. \quad (21)$$

Conditions (17) and (20) specify that in order for the productivity of a firm to benefit from IT investments aimed at reducing the firm's fixed overhead cost (f) or research and development cost (e), the firm must have a sufficiently large fixed asset (F) in comparison to the market size of the firm. If this is not true, then the productivity will be adversely affected by such investments. However, these statements depend on the market sensitivities, conditions (18) and (21). Numeric simulations based on equations (16) and (18) are presented in Tables 2 and 3.

These results partially confirm what Thatcher and Oliver [12] discovered when studying the impact of IT investments in a monopolistic model, that is, IT investments aimed at reducing the costs of research and development as well as variable production and operational costs should have a positive effect on a firm's productivity subject to the condition that the firm's overhead costs is sufficiently large in comparison to its market size, or such effect may become negative. But in a duopolistic model, market sensitivities also play a key role in determining whether a firm's productivity would benefit from the IT investment. What we have shown here is that in a duopoly market, the effect, when positive (large F), is strengthened in a price sensitive market environment, and it is weakened in a quality sensitive market environment. The effect, when negative (small F), is weakened further in both price sensitive and quality sensitive market environments. This leads to our final set of propositions:

Table 2. Changes in Productivity from IT investments reducing f, F=1200 (Initial values are a=100, b=5, c=10, and e=1; f changes from 10 to 8)

θ/λ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.1	0.07	0.09	0.11	0.14	0.19	0.25	0.34	0.46	0.61
0.2	0.05	0.07	0.09	0.11	0.15	0.20	0.27	0.36	0.48
0.3	0.04	0.05	0.07	0.09	0.12	0.15	0.21	0.28	0.37
0.4	0.03	0.04	0.05	0.07	0.09	0.12	0.16	0.21	0.28
0.5	0.02	0.03	0.04	0.05	0.07	0.09	0.12	0.16	0.21
0.6	0.02	0.02	0.03	0.04	0.05	0.06	0.08	0.11	0.15
0.7	0.01	0.01	0.02	0.02	0.03	0.04	0.06	0.08	0.10
0.8	0.00	0.01	0.01	0.01	0.02	0.02	0.03	0.05	0.06
0.9	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.03

Table 3. Changes in Productivity from IT investments reducing f, F = 100 (Initial values are a=100, b=5, c=10 and e=1; f changes from 10 to 8)

θ/λ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0.1	-0.14	-0.18	-0.23	-0.29	-0.37	-0.46	-0.57	-0.70	-0.85
0.2	-0.16	-0.19	-0.24	-0.30	-0.37	-0.45	-0.56	-0.68	-0.81
0.3	-0.17	-0.20	-0.25	-0.30	-0.37	-0.45	-0.54	-0.66	-0.78
0.4	-0.18	-0.21	-0.25	-0.31	-0.37	-0.44	-0.53	-0.64	-0.76
0.5	-0.19	-0.22	-0.26	-0.31	-0.37	-0.44	-0.53	-0.63	-0.74
0.6	-0.20	-0.23	-0.27	-0.32	-0.37	-0.44	-0.52	-0.61	-0.72
0.7	-0.21	-0.24	-0.28	-0.32	-0.38	-0.44	-0.52	-0.61	-0.71
0.8	-0.22	-0.25	-0.29	-0.33	-0.38	-0.44	-0.52	-0.60	-0.70
0.9	-0.23	-0.26	-0.29	-0.34	-0.39	-0.45	-0.51	-0.59	-0.69

Proposition 2a: *Unlike in a monopoly market, in a duopoly market, not only fixed and overhead costs but also market sensitivities affect the impact on productivity by IT investments that reduce the product design and development cost and production and operation variable cost.*

Proposition 2b: *In a duopoly market, if fixed and overhead costs are sufficiently large, for IT investments aimed at reducing the product design and development cost and production and operation variable cost, the impact on productivity is positively affected by price sensitivity and is negatively affected by quality sensitivity.*

CONCLUSIONS

In this paper we employ a duopoly model to study the effect of the market competitive forces on contributions of IT investments to firms' productivity and performance. We draw comparison between our results and those under the monopolistic assumption made by Thatcher and Oliver [12]. We discover that under duopolistic competition the benefits from various efficiency-enhancing IT investments are not as unambiguously deterministic as under monopolistic competition. Further, we submit that the impact of IT investments on a firm's performance depends on the market sensitivities to changes in its competitor's price and quality levels. We demonstrate that in a market environment where products and services are commodities the contribution of IT investments is usually enhanced. On the other hand, in a market environment where perceived quality of products and services is the decisive factors for consumers in their decisions, the contribution of IT investments is usually diminished.

Like many analytical models, ours has inevitably its share of limitations. First, from the operational and managerial point of view, it is hard to quantify the economic and business meaning of some of the complicated mathematical relationships. This makes the empirical verification of the model somewhat difficult. Second, the model specifications could be more generalized to include oligopoly and multiple products. When there are more than two players with many products in the market interacting with each other, the model can become overly complex. Game theory may shed some light on this area of future research. And finally, in order for some of the results to make sense, we imposed several assumptions including the firm's ability to adjust quality and price simultaneously. In reality the firm may not be able to change quality in the short-run. Studies on multiple period IT investments may be warranted.

REFERENCES

1. Barua, A, and Lee, B. The Information Technology Paradox Revisited: A Theoretical and Empirical Investigation in the Manufacturing Sector, *The International Journal of Flexible Manufacturing Systems*, 9, 2 (1997), 145-166.

2. Barua, A., Kriebel, C. H. and Mukhopadhyay, T. An Economic Analysis of Strategic Information Technology Investments, *MIS Quarterly*, 15, 3 (1991), 313-331.

3. Berndt, E. R. and Morrison, C. J. High-Tech Capital Formation and Economic Performance in U.S. Manufacturing Industries: An Exploratory Analysis, *Journal of Econometrics*, 65, 1 (1995), 9-43.

4. Brynjolfsson, E. and Hitt L. Paradox Lost? Firm-Level Evidence on the Return to Information Systems Spending, *Management Science*, 42, 4 (1996), 541-558.

5. Dewan, S. and Kraemer, K. L. International Dimensions of the Productivity Paradox, *Communications of the ACM*, 41, 8 (1998), 56-62.

6. Gordon, R. J. Technology and Economic Performance in the American Economy, National Bureau of Economic Research Working Paper # 8771, 2002

7. Lichtenberg, F. R. The Output Contributions of Computer Equipment and Personnel: A Firm-Level Analysis, National Bureau of Economic Research Working Paper #4540, 1993

8. Loveman, G. W. An Assessment of the Productivity Impact of Information Technologies, in T. J. Allen and M. S. Morton (Eds.) Information Technology and the Corporations of the 1990s: Research Studies, Cambridge MA: MIT Press, 1994

9. McKinsey Global Institute. US Productivity Growth 1995-2000: Understanding the Contribution of Information Technology Relative to Other Factors, McKinsey and Company Inc., Washington, DC., 2001

10. Mukhopadhyay, T, Rajiv, S., and Srinivasan, K. Information Technology Impact on Process Output and Quality, *Management Science*, 43, 12 (1997), 1645-1659.

11. Soh, C. and Markus, M. L. How IT Creates Business Values: A Process Theory Synthesis, Proceedings of the Sixteenth International Conference on Information Systems, Amsterdam, 1995, 29-41.

12. Thatcher, M. E. and Oliver, J. R. The Impact of Technology Investments on a Firm's Production Efficiency, Product Quality, and Productivity, *Journal of Management Information Systems*, 18, 2 (2001), 17-45.

13. Triplett, J. E. The Solow Productivity Paradox: What do Computers do to Productivity? *Canadian Journal of Economics*, 32, 2 (1999), 309-334.

14. Weil, P. The Relationship between Investment in Information Technology and Firm Performance: A Study of the Valve Manufacturing Sector, *Information Systems Research*, 3, 4 (1992), 307-333.