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A Modeling Approach to Evaluating Strategic Uses of Information Technology

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ABSTRACT: Traditional static benefit–cost methods were useful when evaluating transaction processing systems. Strategic benefits are more difficult to evaluate, since they involve dynamic interactions between customers, suppliers, and rivals. In an attempt to gain a competitive advantage, there is a strong incentive to be the first implementor of new technology. However, information technology (IT) costs decline over time, so there is an incentive to delay implementation. A model is developed that enables managers to evaluate this trade-off and choose the best implementation time. The model emphasizes competition between large firms in a regional (or national) market, interacting with firms in a local market. The model is illustrated with an application to the banking industry. It compares the implementation times of larger regional banks vis-à-vis smaller local banks, and shows how the banks might use technology to respond to various changes in the banking industry.

KEY WORDS AND PHRASES: evaluating strategic investments, game theory, strategic information systems.

MANAGEMENT INFORMATION SYSTEMS WERE INITIALLY DEVELOPED to address transaction-based applications. In this environment, it was relatively easy to determine the value of information systems. If implementation and operating costs were less than

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the benefits (which usually arose from decreased labor costs), the system was economically feasible and the project was undertaken. Impacts on customers, suppliers, and the industry, or changes over time were rarely considered.

Today's systems are more complex and the benefits often involve strategic objectives with respect to customers, suppliers, and competitors. These information systems require a more sophisticated evaluation mechanism. As Banker and Kauffman [3] point out, the benefits to strategic applications tend to affect the entire company and are difficult to measure with traditional techniques. Similarly, the introduction of new technology (hardware, software, or methodology) often generates potential strategic applications. Since few (or no) firms have experience with this application of technology, it is difficult to estimate the benefits, and it is arduous for users to forecast how valuable the technology might become.

Traditional benefit–cost and user satisfaction analyses are not very helpful in evaluating strategic alternatives—especially since projected benefits often involve the entire firm and its position in the industry. An important additional consideration in strategic evaluation is that the costs and benefits change over time. In most cases it can be cheaper to wait for hardware, software, and design costs to decline. Yet, the longer a firm waits, the more likely it is that a rival will create a similar system and win market share by being the first implementor. To evaluate modern strategic IT systems, we need a model that examines how the IT will affect the firm, customers, suppliers, and reactions by rivals.

As explained by Porter [30], strategic applications in business are focused on external agents. Strategic impacts are customarily evaluated in terms of vendors, buyers, competitors (existing and potential), product offerings, and the effect on underlying cost structures. In order to evaluate a strategic project accurately, it is important to incorporate these variables. However, these effects are not easy to evaluate. First, each agent evaluates his or her their choices over time. Second, a strategic decision must incorporate the responses of the other agents. Also, as illustrated by Vitale [41], strategic gains can change rapidly.

Other IT evaluation methods fail to incorporate an important aspect of information technology: costs tend to decline over time. Coupling a declining cost structure with potential responses of rivals leads to the crux of the decision. It will be cheaper to implement a new technology at a future date. However, the longer a firm chooses to wait, the more likely it is that a competitor will implement the technology first, reducing any gains the firm may have achieved.

A cost–benefit analysis approach that fails to incorporate the dynamics of customer response, rivalry, and the dynamics of the IT industry will tend to make incorrect assessments. Using cost–benefit analysis focuses on current costs; since these costs are measurable, this tends to be a poor long-run strategy. A better approach is to model the effect of IT implementation on the entire organization, instead of the apparent costs and benefits. This paper presents a method to evaluate strategic IT decisions.

There are eight major sections to the paper: examination of difficulties, comments and suggestions from the existing literature; derivation of a model that can be used to evaluate dynamic aspects of IT; questions that can be examined by applying the model

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to electronic banking issues; sample estimation of the base parameters of the model; primary results of the application and comparison with prior observations; strategic implications of the model; limitations and future work; and a summary of conclusions.

Existing Literature

DERIVATION OF THE MODEL PRESENTED HERE BUILDS ON TECHNIQUES and comments by other writers in many different areas. The key background research is cited in this section, while specific papers that directly affect the model building and parameter estimation are cited in the modeling section.

The model has evolved from four primary areas of research: (1) static cost–benefit analysis, (2) competitive advantage and strategic evaluation of IT, (3) models of rivalry, and (4) banking behavior and modeling. The references are summarized by category in Table 1.

Static Cost–Benefit Analysis

IT researchers initially utilized basic economic net-present-value (NPV) techniques to evaluate IT. This approach worked well for early IT investment that concentrated on transaction-processing systems. In these situations, the primary goal of IT investment was to reduce operating costs. The benefits of reduced costs are strung out over time and are compared with the high initial development costs.

Many writers have examined issues involved in traditional static cost–benefit analyses in IT evaluation. For example, Zmud [42] and Clemons [7, 8] examine issues in applying NPV to the evaluation of IT. Banker and Kauffman [3] and Banker et al. [4] illustrate the concepts with application to business cases. Additional variations of economic cost–benefit analysis are examined by King and Schrems [19], Ahituv [1], and Alpar and Moshe [2].

As the use of IT moved beyond transaction processing into tactical and strategic applications, more sophisticated evaluations of IT became necessary. In particular, the benefits become more difficult to measure and they depend on the actions and reactions of rivals in the industry. Clemons [7] and Clemons and Weber [10] provide excellent analyses of the difficulties of evaluating strategic information systems. In particular, they note the need for a methodology that goes beyond traditional cost–benefit analysis that can incorporate the variety of strategic benefits and the interaction from rivalry.

Strategy Discussions

The literature on strategic uses of IT has exploded in the last ten years. Several in-depth reviews of the literature exist, such as Lederer and Mendelow [21] and Grover [13], who provide a more complete summary of the literature. Only a limited subset is presented here.

Much of the existing work in strategy stems from Porter [30], who applied economic

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Table 1 Categorization of References

Conceptual area	Reference
IT and banking	3, 5, 8, 11, 12, 22, 25, 26, 28, 35, 37, 39
Strategic information systems	7, 10, 13, 18, 20, 21, 24, 29, 30, 32, 33, 40, 41
IT valuation	1, 2, 4, 6, 9, 19, 42
Economic foundations	14, 16, 17, 27, 31, 34, 36, 38

analysis to show how firms could focus on strategic alternatives to gain a competitive advantage in the market. Rumelt, Schendel, and Teece [33] present a brief history of the development of the strategic approaches. More detailed comments and alternative approaches can be found in Lamb [20] and Teece [40]. The application of strategy to IT concepts was initially stressed by Parsons [29], McFarlan [24], and Clemons [6]. Basic options were summarized by King et al. [18].

From a quantitative perspective, Alpar and Moshe [2] take a cost model and apply it to an evaluation of IT in banks. However, the model only analyzes costs and production; it ignores common strategic effects on consumers, suppliers, and rivals. Similarly, Banker et al. [4] examine a model that quantifies the operational benefits from a single firm case. While these models provide a useful beginning, Clemons [7] notes that strategic IT is a different type of investment and that it must be evaluated from a distinct focus that is not cost–benefit driven but incorporates the benefits and risks from a broader strategic perspective. What is needed is a method to evaluate the component benefits of IT along with reactions of the market participants.

Models of Innovation and Rivalry

The industrial organization literature in economics has investigated the question of how competition and rivalry might affect the decision of firms to innovate. Although there is a wide variety of literature, much of it stems from the innovative research by Scherer [36] and Kamien and Schwartz [16]. These researchers built mathematical-economic models to explain the trade-off between the costs of investment in research and development of new products and the potential return, which depends on the action of rivals. Reinganum [31] combined elements from both approaches to examine the characteristics of an optimal investment path over time.

More recently, Katz and Shapiro [17] focused on a race to implement technology that reduces costs. Clemons and Knez [9] examine this model and provide more in-depth coverage of earlier economic models. They are particularly interested in comparing the rivalry solutions with cooperation. They examine conditions under which it is profitable to form a consortium to develop new technology instead of competing.

Most of the early writers were concerned with spending on research to develop new

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products, which might or might not be protected by patents. The firms were considered to be in a race to develop the product first (or cooperatively). This approach led them to claim that total costs were a function of the development time. To produce an innovation earlier, firms would have to spend exponentially more money. Benefits vary by author, including decreased operating costs, additional sales arising from patent protection or license revenue, and sales during the small time frame before the rival firm imitates the product.

The early works provide a useful introduction and excellent mathematical foundations. However, there are some important differences between spending for research and development versus spending for potentially strategic applications of IT. As noted by Clemons and Knez [9], unique characteristics of IT include (1) a large fixed cost and low variable costs, and (2) it is difficult to prevent imitators. They used these observations to note the value of cooperation.

In fact, the structure of IT development shows that we can make an even stronger statement: the costs to developing a new IT are lower to the second and successive adopters of the technology. Scherer [36] foresaw this possibility but concluded that it was not important to the situation of developing products that could be protected by patents.

Banks

Although a general model can be applied to any industry, more detailed results can be obtained by tailoring the model to a specific industry. The banking industry is often used as an illustration since it depends heavily on IT. Within the banking industry literature, there have been subjective discussions on the valuation of IT investment, but little research and only limited conclusions regarding how to measure IT effectiveness. A survey concerning the evaluation of an integrated DBMS is presented by Smith et al. [37]. On the other hand, there is a substantial discussion of marketing issues and consumer attitudes.

Detailed examination of the strategic effects requires a model that can measure the impact of the effects on the firm. Numerous papers contribute to understanding the consumer model used here. Cox and Lasley [11] studied consumer attitudes toward new products, illustrating the use of consumer utility functions. Parker and Coulter [28] analyzed consumer attitudes toward large and small banks, demonstrating the importance of treating the two bank types separately. Hannan and McDowell [14] statistically determined that services from electronic banking can influence the market positions of the bank participants, and that offerings are related to the initial size of the bank.

A good introduction to the topic of bank modeling can be found in Santomero [34]. More sophisticated models have been posed, such as that by Sprenkle [38] incorporating different levels of uncertainty on liabilities and assets. More recently, Alpar and Moshe [2] examined banks in the context of a static cost model pertaining to IT valuation.

Two strategic IT decisions that banks have faced in recent years are the expanded account offerings (e.g., "sweep accounts") that required substantial upgrades in IT,

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and automated teller machines. Today, bankers are facing similar IT-related questions with respect to the implementation of point-of-sale terminals (POS) and debit cards, as well as electronic data interchange (EDI) and automatic monitoring of commercial loans.

Recent developments in the banking sector have placed a renewed emphasis on the use of technology and information systems. Electronic payment systems are discussed by Lordan [22], and credit card systems by Mitchell [25], while automated clearing house issues are examined by Nikbakht et al. [26]. Bansal et al. [5] explored issues of IT involved in managing risk. General issues in banking IT and the effect on consumers are discussed by Saunders [35] and Steinborn [39]. The Banker and Kauffman [3] study notes the importance of examining benefits across the organization and the difficulty in quantifying those benefits.

The Model

THE STRATEGIC ASPECTS OF THE MODEL ARE DERIVED from Porter's [30] discussion of strategic advantage. Parsons's [29] elaboration identifies strategic categories in products and services, operating costs, and effects on consumers and suppliers. McFarlan's [24] research further identified switching costs, and barriers to entry as important strategic variables. The goal is to build a model that can evaluate these effects, as summarized in Table 2.

To capture the strategic effects as well as the more traditional operating benefits and costs, it is necessary to model the actions of the various market participants. These entities are modeled as interdependent objects, where the entities follow a rational objective strategy. *Consumers* play the role of both suppliers and customers, as they save or borrow money at a given financial institution. *Financial institutions* make money based on the difference between lending and saving rates and from various service charges. Firm profits are directly related to the number of customers. In the banking *market*, consumers have to make choices between banks, and the banks compete with each other to make profits. This rivalry leads the individual banks to search for a competitive advantage.

Development of the model proceeds through five steps: (1) examination of consumers; (2) the aggregation of consumers into a market force; (3) operational costs and costs of technology; (4) profits of individual firms over time; and (5) evaluation of market solutions involving rivals and implementation of decisions over time.

Consumers

Most of the prior work on innovation and rivalry ignored the role of consumers, assuming only that the innovation would lead to some predetermined increase in sales. With IT in banking, we cannot be so complacent. The consumer acceptance of the new services might play a strong role in the level of benefits and decisions of the firm. To measure and control for consumer acceptance, it needs to be explicitly modeled. Second, IT might have a strategic effect through switching costs. This effect can be

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Table 2 Strategic Capabilities of Model

	Suppliers / Customers[1]	Competitors
Product	Direct attraction	Timing response and new products
Cost	Operations cost savings	Implementation costs
Prices	Deposit rates and loan rates	Compete with technology
Market expansion	Growth rates[2]	Local versus regional
Switching costs	Utility function constants[2]	Barriers to entry

[1] For banks, suppliers and customers are the same (deposits and loans).
[2] Variables are in the model, but not examined in this paper.

incorporated through a model of consumer behavior.

Customers make decisions on the basis of their economic utility functions. In a given market, deterministic utility is denoted: ${}_kV_{i,j}(t)$, which represents the utility of consumer k for switching from bank$_i$ to bank$_j$ at time t. The utility function depends on three factors: (1) a switching cost (${}_kC_{i,j}$), (2) interest rates on loans and deposits ($r_i^L(t)$, $r_i^d(t)$), and (3) the variety and quality of services provided by the competing banks at time t.

The switching cost represents the cost of switching from bank$_i$ to bank$_j$. This parameter is used to indicate customer loyalty to a given bank. In particular, ${}_kC_{i,i}$ (note same bank subscripts) indicates the value of a particular customer staying at bank$_i$. As noted in the literature on strategy, some types of technology can alter the switching costs. As shown in equation (4) below, increases in the cost of switching from i to j ($C_{i,j}$) encourage consumers to stay at bank i. Similarly, increases in $C_{i,i}$ result in having less loyal customers at bank i, which will expand the customers propensity to switch to another bank.

The variety and quality of bank services is a function of the IT offerings and the effective ness of this technology. The base model can accommodate multiple technologies by defining consumer k's perception of IT services as:

$$(1) \qquad {}_kIT_i(t) = \sum_m {}_kb_{i,m}\, x_{i,m}(t)\,,$$

which is summed over the number of different technologies. The $X_{i,m}(t)$ are binary variables representing the presence of the m^{th} technology in bank$_i$ at time t. The b coefficients represent the consumer perception of the relative usefulness of each technology.

Writing the deterministic utility as a function of the three variables discussed above,

$$(2) \qquad {}_kV_{i,j}(t) = {}_kf_{i,j}\,[\, C_{i,j} r_i^d(t), r_j^d(t), r_j^L(t), IT_i(t) IT_j(IT)\,]\,.$$

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In the general form, the total switching utility (${}_kU_{i,j}(t)$) is a function of deterministic utility (observable) and the stochastic utility (nonobservable):

(3) $$ {}_kU_{i,j} = {}_kV_{i,j}(t)\,{}_k\varepsilon_{i,j}(t)\,. $$

To operationalize the model, $V_{i,j}$ is specified as:

(4)
$$ {}_kV_{i,j}(t) = \tau_j^d r_j^d(t) - \tau_j^L r_j^L(t) + \delta_j IT_j(t) + 1/C_{ij} $$
$$ + h_{ij}^d [r_j^d(t) - r_i^d(t)] - h_{ij}^L [r_j^L(t) - r_i^L(t)] + g_{ij}[IT_j(t) - IT_i(t)]\,. $$

These equations can accommodate more diversity by defining groups of consumers that possess similar characteristics. Some consumers could be highly responsive to technology-oriented services, while others may not care. This model can use more detailed utility functions that incorporate additional variables that reflect the availability of additional market information.

Given these utility functions, it is possible to examine the probability that customers will switch banks—for example, because of a change in technology. By imposing a distribution on the utility functions and examining an "average" consumer, the utility functions for all firms in the market can be aggregated to yield the market probability function that consumers will switch banks. Let ${}_kP_{i,j}(t)$ be the probability that consumer$_k$ switches from bank$_i$ to bank$_j$ at time t. That is,

(5) $$ {}_kP_{i,j}(t) = Prob\,({}_kU_{i,j}(t) > {}_kU_{i,b}(t)),\ \supset\ b \neq j\,. $$

In accordance with McFadden's [24] derivation of the logit model, assume that the stochastic utility ($\log_k(\in_{i,j}(t))$ follows the type I extreme value distribution to get:

(6) $$ P_{i,j}(t) = {}_kV_{i,j}(t)/\sum_b {}_kV_{i,b}(t)\,, $$

where the denominator is summed over the total number of banks in the given market.

Customers are heterogeneous in terms of their utility parameters. Assuming that

(7) $$ {}_kV_{i,j} \approx Gamma\,(\mu, \mu V_{i,j})\,, $$

where μ is the scale parameter of the gamma distribution, and $\mu V_{i,j}$ is the shape parameter, then $V_{i,j} = E_k({}_kV_{i,j})$ is the average deterministic utility for all customers in the market. Then,

(8) $$ {}_kP_{i,j} - Beta\,(\mu V_{i,j}, \mu \sum_{h \neq j} V_{i,j})\,. $$

Although it is known (see [15]) that the logit model imposes some constraints on the covariance structure between the alternatives, it is commonly used for fixed-

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alternative models because of its tractability. With minimal changes in the theory, the probability determination could be replaced with the probit model. However, the estimation and computation burdens increase exponentially.

Either way, the average switching probability for all customers is given by:

(9)
$$P_{i,j}(t) = E_k\,[{}_kP_{i,j}(t)\,] = V_{i,j}/\sum_b V_{i,b}\,.$$

This probability represents the primary observable consumer response to technology (and interest rates). It will directly affect the market share of the firms involved in the market.

Market

A useful general approach is to consider a dual market structure. In the United States, there are loosely two bank markets: dominant and local. Since at least the 1960s, a small but increasing number of large banks serve customers across a large region. Yet, limitations on interstate banking have supported local markets served by smaller "local" banks. To simplify the analysis, this situation will be modeled with two dominant banks and two local banks. The primary rivalry in the local market is between the two local firms. For the large banks, any given local market represents a small portion of profits, so they perceive each other as the primary competition. The goal of attracting consumers can be measured with market share. Small banks compete largely against each other—and assume that the large banks will not directly respond to their actions. Customers in the local market can choose either type of bank.

Given an initial market share, the new market share for bank$_b$ can be found by:

(10)
$$M_b(t) = \sum_i [P_{i,b}(t)\,M_i(t-1)]\,,$$

where $b = (0, 1)$ in the regional market and $b = (0, 1, 2, 3)$ in the local market.

Costs

Technology costs form a crucial part of the model. Historically, the costs of IT behave differently from other business costs. The most important aspect of technology costs is that they decrease over time. Accordingly, initial implementors of IT have to develop the system from scratch, which translates into higher costs, while later implementors would benefit from some of the knowledge gained by the leading edge competitors, generating lower costs.

Consider hardware and software costs at the introduction of new IT. If the firm uses state-of-the-art equipment, they will undoubtedly pay a premium for initial versions of the equipment. Also, this hardware may be more susceptible to failures, ongoing modifications, or increased maintenance expenses. Even for mainstream technology, costs will decline over time. In addition, a new system may require additional support

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personnel, especially if interfacing with existing equipment (interoperability) is required. Software costs at this stage will also tend to be relatively high. In particular, the system will usually have to be custom designed and developed. That means paying the expenses of the analysis and design team, increased hardware use during the development phase, debugging and testing costs, and the cost of management time to aid in the overall design phase.

Earlier writers investigating rivalry and innovation also perceived costs as declining over time. Scherer [36] espoused this position by noting that for a given project, decreasing the development time results in exponentially higher costs due to diminishing returns. Although this same argument might apply to IT development, a stronger case can be made for an exogenous decline in hardware and software costs due to improvements in technology. Although the final functional form of the cost curves are similar, the Scherer argument implies that firms begin incurring development costs in time zero. Our new model generalizes the problem and development costs are incurred when the project is undertaken.

An additional important distinction of IT development is that once the initial application has been designed and introduced by some other firm, costs will be different for later adopters. There will be decreases in the cost of the hardware as a result of the nature of the hardware industry. The technology may no longer be state of the art, implying that the technology has reached production economies of scale, and improved quality control. Also, the technology has likely achieved substantial market presence so that interconnections and interoperability issues are supported by more vendors. If a bank chooses to build the application at this time, the firm still faces a custom development effort. However, many of the design features will already be in place. That is, the bank could "reverse engineer" the existing system, thereby saving a portion of the design costs. Eventually, as enough banks adopt the technology, the hardware becomes standardized and competition in manufacturing causes the price to decline further. In addition, the software is available in packaged form, significantly decreasing development, implementation, and switching costs. It also becomes possible to hire employees away from the original firms, saving training costs and speeding development.

The rate of decline due to the general structure of the industry can be written:

(11)

$$ {}_1C_i(t) = C_0 \exp(-\beta_0 t) . $$

This equation states that the cost to the first firm (bank_i) adopting the technology will decline at the rate indicated by β_0. The decline due to learning effects means the second firm to adopt the technology (bank_j) will pay a lower rate, as long as bank_j adopts the technology at a later time period than bank_i. Accounting for both types of declines yields a cost of:

(12) $$ {}_2C_j(t) = C_0 \exp(-\beta_1 / t_1 - \beta_0 t) , $$

where t_1 is the time period in which the information technology was first adopted. The

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equation can be generalized to analyze a situation with more than two banks. In addition, adoption by additional banks will affect the base rate of decline (β_0). For example, the value for β_0 in equation (12) may not be the same as that in equation (11). This change is indicated by adding a subscript on the betas to show the number of prior implementors.

Costs are computed on the basis of the declining rate and charged to the bank as a net present value at the time of adoption. Costs are zero in other time periods. Any maintenance or ongoing costs are discounted to the present value at the time of adoption.

Technology might also affect the operating costs of the firm. Implementation of the technology causes operating costs to decline by some percentage. For example, Alpar and Moshe [2] estimated that a 10 percent increase in IT spending resulted in a 1.9 percent decrease in total operating costs for banks between 1979 and 1986. Since this model evaluates all costs and benefits at discounted present value, the effect on operating costs can be incorporated by discounting the operating cost savings back to the proposed implementation time and applying these savings to the cost of the equipment. That is,

(13)
$$Net\_Cost(t) = Cost(t) - \int_t^{\infty} [\exp(-\varphi t)\, Savings(t)]\, dt .$$

In some cases, the net cost will be negative, representing a net benefit. Those cases represent the basic benefit cost problem that has been studied extensively. It is more interesting to concentrate on situations where the benefits arise from increased sales instead of reduced operating costs.

Profits

Profits are calculated on the basis of the balance sheet of a given bank. The primary effect of changing the number of customers to a bank is on the deposits and loans. For clarity, deposits are treated as a homogeneous entity. By regulation, the amount of money a bank can lend is a function of the amount of deposits and capital available. Hence, loans are:

(14)
$$L_i(t) = \alpha_i [N \cdot D \cdot M_i(t)] + K_i(t) ,$$

where N is the number of customers in the market and D is the average deposit size for those customers. Profits can be expressed as:

(15)
$$\pi_i(t) = r^L(t)\, L_i(t) - r_i^d(t)\, N \cdot D \cdot M_i(t) - Cost(t) ,$$

where the r_i terms represent the interest rates on loans and deposits as indicated by the superscript. Cost(t) is zero in a given time period if the firm does not implement the technology at that time, otherwise it is given by equation (12), depending on the number of prior implementors. Recently, some banks have concentrated on accumu-

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lating revenue through service fees. This case can be represented by an additional term in equation (13), where fees = $\pi N M_i(t)$.

Note that profits must be computed for each time period. As pointed out by Clemons [6], and reiterated by many others, it is likely that any gain in market share (hence profits) due to the implementation of technology will last only until the rival introduces the technology. By recomputing consumer response, costs, market share, and profits in each time period for each bank, the model captures all of these reactions. Any profits obtained in one time period will affect the capital (K) available for the next period; therefore,

$$K_i(t+1) = K_i(t) + \pi_i(t) . \tag{16}$$

Finally, annual profits are discounted (by ϕ) back to time zero as given by:

$$S_i = \int [\exp(-\varphi t)\, \pi_i(t)]\, dt , \tag{17}$$

to allow comparison of the choices over time. The goal of each firm is to maximize profit by choosing when (or if) to implement each technology-oriented service.

Market Solutions

As shown in figure 1, there are two markets (regional and local) and the model can be treated as a two-stage game. The two banks in the regional market make their decision about when to implement the new technology and ignore the effects in the local market. Next, the two local firms make their implementation timing decisions assuming that the regional firm's choices are fixed. Thus, each market is represented as a duopoly. The duopoly model has been used successfully for many years to model the effects of firm rivalry. Even if there are more than two firms in the market, the model can usually be applied by reinterpreting what is meant by "rival." For example, when one bank is trying to judge the reaction of its rivals, it may not matter which one of the other firms responds, only that there is at least one reaction.

Duopoly Games

There are many ways to model firm rivalry. The most common methods include: competitive, joint optimization, collusion, and a Stackleberg leader/follower relationship. Sometimes firms can be examined with greater degrees of foresight where each firm models reaction functions to determine how the other will react. Many of these models are intractable in general form, and corresponding results depend highly on market-specific assumptions. In any case, a competitive situation is a good starting point.

A competitive model, typically represented by a Nash equilibrium, is characterized by the Cournot assumption that each firm believes the rival will not respond to changes. The resulting equilibrium has many properties of the economic competitive solution. In this solution method, the first firm chooses the optimal value of the control

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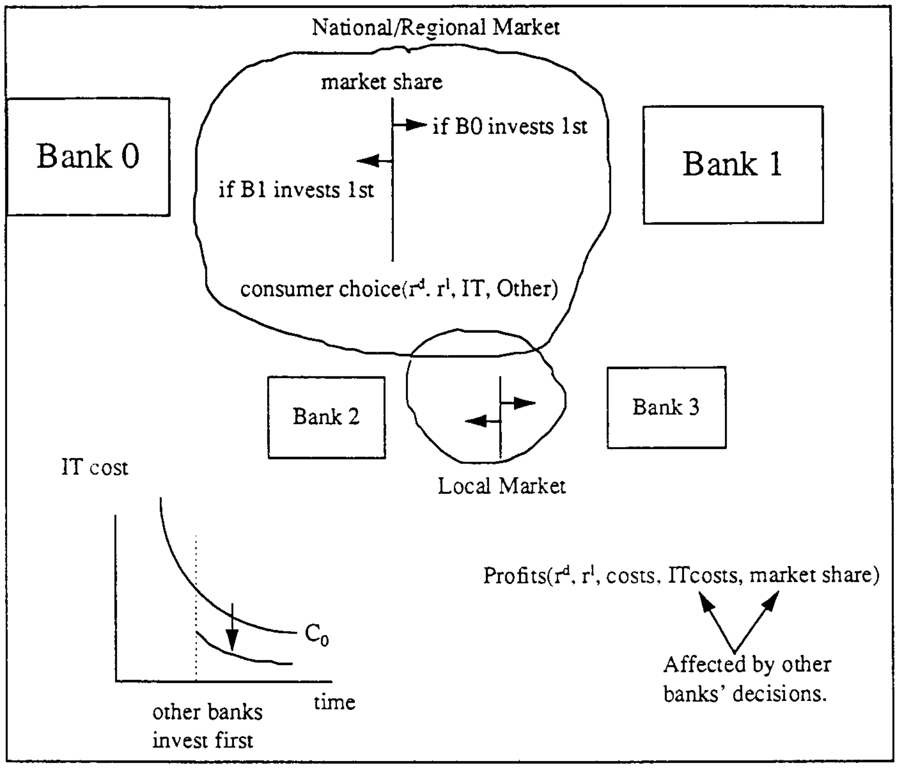

Figure 1. Market Structure

variable while assuming the second firm will not change. Then the second firm makes a similar assumption and chooses its optimal position. This process continues until an equilibrium position is attained. Equilibrium may be either a single point, or it may represent a set of choices that the firms cycle through.

Other rivalry assumptions can be utilized, but an exhaustive examination is beyond the scope of a single paper. For comparison purposes, a cooperative case, where competing firms choose to maximize joint profits, is examined. In particular, the local banks may find it advantageous to form a joint venture with respect to new technology. In today's banking environment, this cooperation may take the form of one bank buying out the local competitor to gain a stronger position against the regional banks.

In the context of one market, only one game is played to determine implementation time of a single technology. In practice, if many different technologies arise over time, the firms might find themselves playing similar games, with different parameters. In this "repeating game" environment, it is possible that a firm might eventually detect a reaction pattern of its rival that is different from the Nash assumptions. At the extreme, each firm might gain perfect foresight and be able to completely predict the other's actions. This situation is likely to be rare in practice, and typically does not have a single solution, so it is beyond the scope of this work. However, note that a

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single Nash equilibrium point does represent a perfect foresight solution.

Cooperation could be useful if there are major capital costs that can be shared, such as telecommunications equipment, ATMs, or a central database. In general, it is cheaper to work together and split the remaining profits, assuming that antitrust laws are not violated.

Questions to Examine

THE MODEL IS GENERAL IN THE SENSE THAT IT CAN BE USED to evaluate almost any technology-driven services. For example, it could be applied in retail banking to evaluate the introduction of debit cards, on-line banking, digital mortgage loan applications and processing, or advanced credit-card processing. In commercial lending, bankers are facing questions regarding on-line monitoring of borrowers, implementation of local EDI services, and additional support for international transactions. In each case, bankers are faced with difficult decisions.

Small Banks

Consider a hypothetical situation for a small bank. Intuitively, it seems that a small conservative bank that primarily markets to local customers might be reluctant to be the initial firm to implement a new information system. First, this bank would have to pay substantial design and development costs to create the system. Second, their customers are not likely to demand the services provided by the new technology—in part because the other local competitors will also be reluctant to invest the large sums of money. However, at some point, the new services may be offered by the larger banks competing in the broader market (possibly at a low price). At this time, it will become necessary for the local banks to upgrade their IT to provide the needed services.

According to traditional cost–benefit evaluation of static costs and benefits, it does not pay for the small bank to be an early implementor of technology. At first glance, it is tempting to chastise the local banker for being extremely conservative (risk-averse). It appears to be a classic opportunity to attempt to use IT for competitive advantage—the bank just needs to upgrade the IT to increase market share against local competition. Yet the issue hinges on the valuation of the increase in customers. If a bank faces a certain increase in costs but only an estimate of the benefits, a manager may not want to risk the bank's financial position on highly subjective estimates. Even more important, in the IT area, costs will eventually decrease—especially if the bank is not the initial implementor. Yet, even if it is true that the bank should not implement first, exactly when should the small bank implement the new technology? How many benefits (customers) will the bank lose while waiting for the costs to decrease?

Large Banks

Consider the same problem from the perspective of a large regional bank. High development costs are still applicable, but these costs are a much smaller share of the bank's total budget. The large bank also faces uncertainty about the effect of new

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technology on existing customers and hence profits. However, there are four direct consequences of the bank addressing larger, more sophisticated customers. First, more money is involved, so small increases translate to larger profits. Similarly, the larger scale gives the regional banks a lower cost per transaction for implementing technology. Second, the customer is more likely to demand added innovative services. Third, there is a higher probability that the rivals will also be developing a similar system. Fourth, the larger bank has a more extensive capital base that can absorb higher development costs and potential losses.

Even if it seems likely that regional banks should implement the technology earlier than the smaller banks, they are still faced with two major questions. First, exactly when should the technology be implemented? Second, if a bank chooses not to implement before the competitors, how many customers and how much profit will be lost? In other words, which technologies and services will make a difference, and which ones could be avoided or deferred until costs decline?

Estimation

THE FIRST STEP IN THE USE OF THIS MODEL is to estimate as many of the parameters as possible. In many cases, estimation is accomplished by obtaining current values of balance sheet and income statement items. In other cases, it may be difficult to obtain statistical estimates of some of the parameters—notably customer sensitivity to technology. In these situations, it is best to select wide ranges of the variables and evaluate the choices at different values. This sensitivity analysis approach yields important results.

The first step in applying the model is to estimate the coefficients. Three sets of data need to be acquired or estimated: (1) cost behavior or decline over time; (2) consumer response to technology; (3) balance sheet data. Equations (11) and (12) are estimated via regression. Consider an example with total implementation costs for the large banks of $10 million. The estimates for the base coefficients are shown in Table 3.

Since consumer responses will always be difficult to estimate, it is wise to begin with coefficients that are deliberately biased against the technology—reflecting inertia on the part of customers. As we show below, an important property of this method is that it is easy to alter these assumptions and evaluate their effect on the decision. For the example, consider a base case where customers are assumed to be ten times more responsive to interest rate shifts and twenty times more responsive to miscellaneous service features (convenience, etc.) than they are to technology changes.

Miscellaneous operating parameters (e.g., market size, deposits, and other balance sheet data) will be readily available to each firm. For the illustration, consider "average" large banks with approximately $1 billion in assets versus smaller banks with $50 million in assets. Other values can be derived from competitive reports, or from average industry ratios.

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Table 3 Estimated Base Parameters

Name	Notation	Value	Comments/description
Cost base	C_0	10.0	Million dollars, scaled down for local banks based on asset size
Cost rate	$\beta_{.1}$	0.09	Decline after one adopter
Cost rate	$\beta_{.2}$	0.3	Decline after two adopters
Cost rate	$\beta_{.3}$	0.3	Decline after three adopters
Utility deposit int—absolute	τ^d	10.0	See equation (4)
Utility loan interest—absolute	τ^l	10.0	See equation (4)
Utility technology—absolute	δ	0.10	See equation (4)
Utility constant—relative	$C_{i,j}$	0.5	Inverse of switching cost from i to j
Utility deposit int—relative	$h^d_{i,j}$	5.0	Deposit interest rate differential
Utility loan int—relative	$h^l_{i,j}$	5.0	Loan interest rate differential
Utility technology—relative	$g_{i,j}$	0.1	Technology index differential
Index weight	$b_{i,m}$	1.0	See equation (1)
Total customers	N	800,000*	In the regional market
Total customers	N	50,000*	In the local market
Average deposits	D	0.0025	0.0020 in the local market ($ million)
Discount factor	ϕ	0.085	See equation (13)
Initial capital	K	50	In the regional market ($ million)
Initial capital	K	3	In the local market ($ million)
Required reserves	$1-\alpha$	0.12	Set by Federal Reserve
Deposit interest	r^d	0.06	Interest paid on deposits
Loan interest	r^l	0.10	Interest charged on loans
Market share (regional)	M	0.5	Split the regional market
Market share	M_0	0.15	Big bank share in local market
Market share	M_2	0.35	Small bank share in local market

*The customers and average deposits were chosen so that the regional banks each have assets of about $1 billion, while the local banks have about $50 million in assets. See the modeling section for details on sources and use of the parameters. The estimation section explains how the parameters were estimated.

Results

Large Banks

ACCORDING TO THE BASE SET OF PARAMETERS, THE RESULTS indicate that in a competitive market (Nash equilibrium), the regional bank will implement the new technology at time period 2, and the two local banks will implement no earlier than time period 11. For almost all parameter values examined, the Nash solution converged to a single equilibrium point. In a few cases, one firm will gain a "first mover"

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Observe that the early implementation by the large banks is different from the result of Katz and Shapiro [17], who concluded that "industry leaders will tend to develop minor innovations, but will develop major innovations only if imitation is difficult." The Katz and Shapiro model focused on innovations that reduced costs. Bringing in market share benefits (and avoiding linearity) shows that the large banks do have an incentive to innovate, even though there is no way to prevent the rival from duplicating the innovation.

Large Bank Cooperation

One point worth examining is determining what happens if the large banks are allowed to form a joint venture. The conclusion from this model is that they will defer implementation until the last possible time period. In a noncompetitive environment, it is most profitable for large firms to avoid implementing the technology. This conclusion is an indication of two concepts. First, by the traditional cost–benefit approach, large firms would have avoided implementing the new technology. Second, the conclusion agrees with traditional antitrust comments regarding the effect of collusion on the consumer. Kamien and Schwartz [16] showed that R&D expenditures for cooperating firms could be higher or lower rates than for noncooperating firms, depending on the circumstances and underlying parameters.

As Clemons and Knez [9] note, it can be more profitable for firms to cooperate in the development of ATM networks than to compete directly. Our model reaches the basic conclusion, but adds the additional information that if the regional banks had agreed to cooperate, implementation would have been delayed for many years. Since the banks accumulated positive profits in both situations, the cooperative approach (with delayed implementation) would be looked on unfavorably by antitrust regulators, as indicated by Grimm [12].

Strategy

An important conclusion from these results is that the regional banks are "forced" to implement earlier because of rivalry, even though it would be cheaper for them to delay implementation. Also, it is clear that once one firm adopts the technology, the other has no choice and must adopt within the next period. That is, the model effectively captures the notion of technology becoming a "strategic necessity."

From the perspective of the manager of a large bank, in many cases, forming cooperative agreements with rivals would seem to be the "ideal" solution to the IT dilemma. However, this solution would severely delay the implementation of many technologies. In addition, the firm runs the risk of encouraging the introduction of noncooperating rivals. The situation would be similar to that encountered in the 1970s when banks were forced by legislation to cooperate on interest rate payments. Although the large interest rate spread was profitable for the banks, it enabled Merrill-Lynch to utilize technology to enter the industry with its Cash Management Account. As Scherer [36] points out, "R&D projects are typically so complex, and intelligence information on rival strategies so imperfect, that the mutual coordination

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and trust required for joint profit maximization cannot easily be maintained." This risk of new entry (or "cheating" on an agreement) is not incorporated directly in this model. However, the model does allow the manager to compare the profit levels of the cooperative strategy and the Nash rivalry with the lower profits received if a rival is the sole implementor of the technology.

Consider two situations: (1) there are only slight differences in profitability between the three options, (2) there is a risk of major gains or losses if a noncooperating firm implements. In the first case, there is little incentive for a firm to "cheat." However, at the same time, there is little to be lost by being an early implementer, and there might be additional "image" benefits to implementing before anyone else. The second case is more risky. Although managers might reap substantial gains by cooperating and delaying implementation, there is a stronger incentive for noncooperating firms to implement before anyone else. The question of cooperation hinges on how effectively firms can force the agreements and prevent other entrants.

Small Banks

According to the base coefficients, a small bank's optimal implementation (Nash solution) occurs at time period 11 or 12. If the large firms change their implementation time to period 20, the smaller firms delay only slightly, choosing to implement technology at period 16, which is now earlier than the implementation time of the large firms. This result indicates that the smaller firms are highly cost-dependent; in other words, they wait until the cost drops far enough to allow them to recover the costs in a shorter time frame. In particular, sensitivity analysis indicates that these banks are dependent on the base rate of cost decline. It also shows that if the regional banks choose to cooperate, they would have to ensure the participation of all of the local banks, to minimize the threat of competition.

In terms of cooperation, consider the situation of total cooperation where the local banks make their decisions through joint optimization. In this case, the small firms find it profitable to implement around time period 18. This result varies only slightly in response to changes by the large regional firms. Even when the large banks delay implementation to time 20, the small local banks will implement around time period 18. However, in virtually all cases, the cooperation enables the smaller firms to gain market share over the larger regional banks—especially if the regional banks delay implementation. When the large banks implement early, the cooperating smaller banks still defer implementing the technology. Although they lose some customers to the larger rivals, the smaller banks gain by keeping costs down and by not competing with each other. When the smaller banks do finally implement the technology, they regain their lost customers by being able to charge lower prices. Note that if the small bank customers are less loyal, then the local banks are forced to implement technology earlier—whether they are competing or cooperating. In a limited way, customer loyalty protects the smaller banks from the effects of technology-based services of the larger banks. If this loyalty is reduced, the smaller banks must implement technology much earlier, and at a higher cost.

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Sensitivity to Technology

Many different situations can be examined. Of particular interest is the case of customer sensitivity to technology. Remember that customer sensitivity to technology was deliberately minimized. If this sensitivity is increased slightly (from 0.10 to 0.30, which is still only one-third the value for an interest rate change), then the regional banks will implement at time 1 and the local banks will implement at time 2 or 3. This pattern is reflected for higher levels of sensitivity as well.

Estimates of customer sensitivity to technology are crucial in timing the introduction to technology. In credit card processing, four or five large banks dominate the market—because they emphasize the use of technology to keep costs low. On the other hand, in retail banking, customers proved to be relatively insensitive to services provided by ATMs and debit cards. In mortgage banking, there is minimal customer loyalty, indicating a potential use for technology. The point is that customers evaluate each innovation or service differently. Any strategic model must evaluate customer sensitivity and allow managers to examine outcomes based on different assumptions.

Evaluating Alternatives

In practice, creating a model and estimating the coefficients are only the beginning. To be useful, the model must be capable of evaluating different situations. In any realistic setting, some of the coefficients will be difficult to estimate, or will have a large variance. The model can be used to evaluate results for varying levels of the coefficients. Sensitivity analysis is also useful to determine which variables have the strongest effect on the outcome, similar to Rockart's [32] critical success factors. Review the model parameters in Table 4 to see that there are many possible combinations that could be examined.

One coefficient that is difficult to estimate is the degree of customer loyalty, especially relative to technological sensitivity. A useful approach to the problem is to examine each of the dominant regional firms from the standpoint of four levels of customer loyalty: neutral (N), medium (M), high (H), and very high (V). These descriptive terms were chosen simply to make the results and discussion easier to follow. The correspondence between the terms and the actual parameter values is arbitrary. The coefficients were chosen to represent a fairly wide range to highlight the differences. As an example, the parameter for "very high" is 0.3 whereas for "neutral" it is 2.0, which is over six times larger. The four levels yield ten distinct cases when applied to the two firms (V-N, V-M, V-H, V-V, H-N, H-M, H-H, M-N, M-M, and N-N).

Symmetric Regional Banks

In the four cases where customer loyalty is the same for both firms, banks tend to implement at the same time and accrue similar profits. However, there are often substantial differences between the four cases in terms of implementation time and

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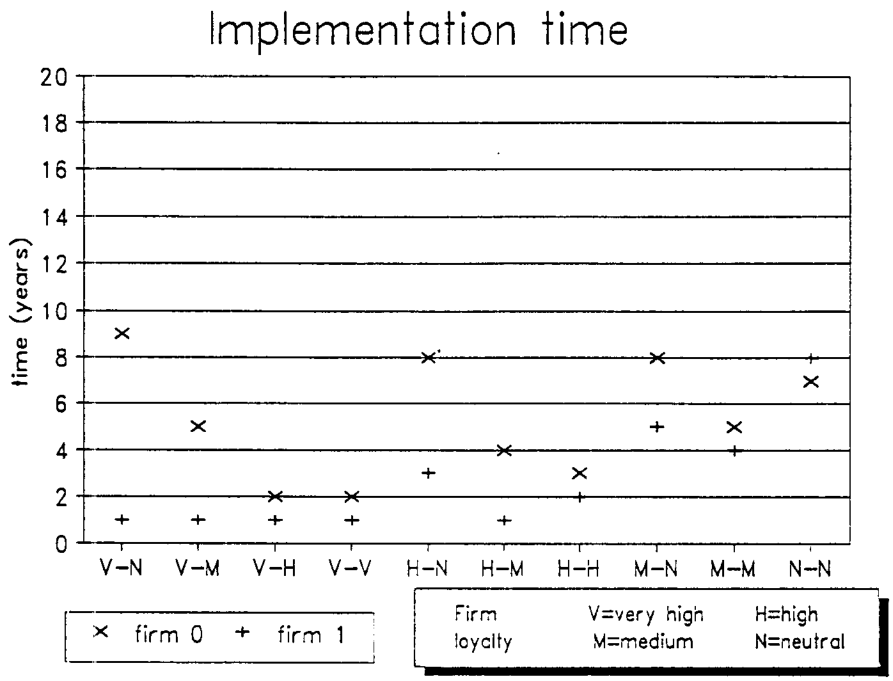

Figure 2. Implementation Times as Loyalty Changes

profits. Figures 2 and 3 illustrate this situation. In particular, observe the differences at the four points where the banks face the same consumer loyalty (V-V, H-H, M-M, and N-N). Specifically, note that there appears to be a tendency for a later implementation time as the consumers become more neutral in their loyalty. As customers become less likely to switch banks, it is necessary to implement technology earlier. However, note that there is virtually no difference in profit. By controlling the implementation time, the banks are able to compensate for different levels of customer loyalty and still maintain profit levels.

A plausible explanation of the effect is that when customers are relatively loyal, an early implementation attracts them to a bank quickly, and then they tend to stay. If customers are less loyal, it may be advisable for the bank to wait for costs to drop since the attraction of technology may not be sufficient to retain the customers.

Asymmetric Regional Banks

Beginning with Scherer [36] and Kamien and Schwartz [16] and continuing through the other analyses of innovation and rivalry, authors have relied on treating the firms as identical. This assumption is traditionally imposed to make the mathematics tractable, and most writers acknowledge that the case of asymmetric firms should be examined "in the future." In our model, numerical solutions for asymmetric firms are no more difficult than for symmetric firms, so the results are included here.

It is likely that the regional firms face different levels of customer loyalty. Generally

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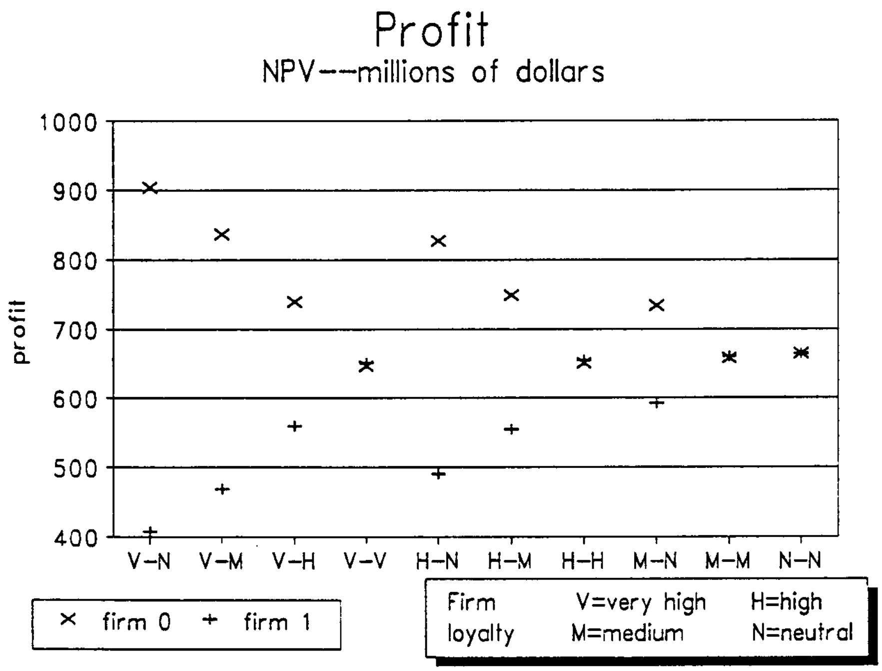

Figure 3. Profitability as Loyalty Changes

the bank faced with more loyal customers will tend to make greater profits than the other firm (which will also have a smaller market share). Figures 2 and 3 show that the profit differential is greatest when there is a large difference between customer loyalty in the competing firms (V-N). Likewise, as indicated by the downward trend in figure 2 (e.g., V-N, V-M, V-H, V-V), both firms tend to implement earlier as they face increasingly similar customer loyalties. For example, when $bank_0$ has very loyal customers, it will delay implementation if the competing bank has less loyal customers. As customer loyalty increases for the second firm, it gains market share, and $bank_0$ is forced to implement technology earlier. Somewhat surprisingly, when loyalty in $bank_1$ is increased to the point where it matches that of $firm_0$, then both firms will delay implementation (e.g., H-H). A possible explanation is that $bank_1$ no longer needs to be as aggressive in order to maintain market share.

Strategic Implications

A DIFFICULT QUESTION TO ANSWER REGARDING IT IS ESTIMATING its value as a strategic weapon. Some of its value has been demonstrated in the prior sections; many other questions can be examined with the model. For example, if one firm ($firm_0$) attempts to attract customers through price cuts (interest rates), is it better for $firm_1$ to match the prices, or is it better to compete on the basis of improved services available through new IT? Although this is not a new question (for example, see the marketing examples of Onkvisit and Show [27]), its examination demonstrates the power of the underlying model.

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Table 4 Implement Technology versus Follow Loan Rate Decrease

	Both firms change rates				$Firm_0$ alone			
$Firm_0$ loan rate	$Firm_0$ time	$Firm_1$ time	$Firm_0$ profit	$Firm_1$ profit	$Firm_0$ time	$Firm_1$ time	$Firm_0$ profit	$Firm_1$ profit
0.08	15	15	244	244	14	2	252	626
0.10	2	3	654	651	2	3	654	651

The second row contains the solution to the base case. If $firm_0$ decreases the loan rate (price) from 10% to 8%, $firm_1$ can also cut price (profit = 244) or not cut price but implement technology earlier (profit = 626).

In theory, the answer to the basic question must depend on the circumstances. It is possible that customers care about only prices and nothing else. With more typical customers, where loyalty exists, the question might not have such an obvious solution. As shown in Table 4, the model was used to consider the case where $bank_0$ changes prices and $bank_1$ has to choose a market response.

Consider the case of loans. If the first bank drops the interest rate on loans (price), then the rival bank has a choice of following the rate drop or of changing their IT implementation strategy. Start at the bottom row (interest rate = 0.10). If $bank_1$ follows a rate decrease (to 0.08), then $bank_1$ will have an NPV profit of $244 which is a drop of $407. On the other hand, if $bank_1$ maintains a 10 percent interest rate and implements the new technology one period earlier (2 instead of 3), then it receives a profit of $626, which is a drop of only $25. On the other hand, by not following the price cut, $bank_1$ tends to lose at least two points of market share. Similar results exist with deposit rates, which are analogous to a purchase from a vendor. The basic conclusion is that it is better to respond to a price change with an earlier implementation of technology.

Obviously, this result depends on the actual values of the coefficients, but how sensitive is the conclusion to customer sensitivity to technology? To examine this question, results were computed for values of technology sensitivity that ranged from 0.001 to 10.0. These values represent a range of four orders of magnitude, where the end-point values forced the model solutions to extremes. At one end the firms implement at time 1; at the other end they implement at time 20.

For all of the values examined in this range, the overall conclusion remained constant: a firm is wiser to counter a price change with IT implementation than to follow the price change. Although the levels of customer sensitivity to technology did not alter this conclusion, the technology sensitivity did affect profits, implementation time, and market share.

Limitations and Future Work

THIS MODEL IS CAPABLE OF EXAMINING COMPLEX RELATIONSHIPS in the strategic implementation of IT. As suggested in the model section, it can be expanded in several

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aspects. The model can be applied to many different situations by estimating new values for the coefficients. In addition, the equations can be tailored to specific industries or firms.

Other Industries

A major difference between the banking industry and other service sector industries is that customers and suppliers can be treated the same in the banking industry. In other industries, they consist of different sets of people or firms with slightly different motivations. Hence, the utility equations have to be modified.

The objective is to create two groups: consumers and suppliers. First, remove all of the "supplier" information from equation (4), which involves the deposit terms. Second, create a "preference" function for suppliers that is based on prices and any other characteristics of the industry that may be relevant. This function represents the suppliers' willingness to deal with this firm, so increases in prices increase utility to the suppliers. A switching cost term should be incorporated for the supplier, and it could be affected by the IT implementation. Other relationships such as payment schedules and EDI availability may also be included. There will now be two equations similar to equation (4)—one for customers and one for suppliers. Finally, modify the profit function so that it accurately reflects all revenues and costs.

Additional Strategic Effects

As illustrated here, the primary strategic effect used is the ability to attract customers with new services. As noted in the introduction, the strategic use of technology can have many other effects, and they can be evaluated using this model, as shown in Table 2. For example, it is straightforward to allow the technology to increase the probability that a customer stays with the firm by altering the switching costs.

In a firm that uses physical products as inputs, it is important not only to consider the costs of the inputs but the quality and timeliness of delivery. These factors can be incorporated into the supplier and profit functions. The factors are often strategic variables that can be affected by the implementation of technology.

Parsons [29] discusses more subtle strategic effects. For example, IT may change the structure or size of the market. Market growth rates can be added to the model, and they can be linked to the implementation of the technology. It is considerably more difficult to evaluate changes in market structure—largely because these changes may be unpredictable. The most likely change to the model is that the profit function would change when technology is implemented. In other words, the model would require two profit functions: (1) the calculation of current profits, and (2) a formula to calculate profits (and costs) if the entire production process is changed.

Operating costs can also be included in the model to further reflect the cost structure of the firm. The model can include the effect of technology on these costs, so that as new technology is introduced, operating costs might be reduced. Examination of the results indicates that making these changes leads to a basic rule that as IT causes

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costs to drop faster, firms will tend to implement earlier. There do not appear to be any dramatic (or strategic) effects, but not all cases were considered. When the implementation of IT causes a 10 percent or more decline in operating costs, the regional firms will move implementation to time 1. This result is dependent on the size of the costs and the other parameters, but it does provide an indication of the basic results.

As mentioned in the discussion of duopoly, the model can be applied to situations involving more than two firms. For example, the model was evaluated for approximately twenty local banks divided into two sets of ten firms. The market size was scaled up to compensate for the increased number of firms. The basic result is that because there are now more firms implementing the technology, the costs will drop faster. Therefore, the local banks implement the technology earlier. On the other hand, if there is a simple increase in local banks, without an increase in market share, there will be less incentive to implement technology because none of the small banks will be able to afford it. Again, it is possible to consider more complex interactions, such as a scenario involving an increase in the number of local banks while customer sensitivity to technology decreases.

In summary, the advantage of this technique is that it can be modified to incorporate a wide variety of market structures and interactions between the variables. The only constraint is that the modeler must know the structure of the new system. For example, deciding that IT would create new products is not sufficient: the researcher needs to have some idea of how those products will be produced, and how profits will be affected.

Conclusions

THIS PAPER HAS DISCUSSED THE DEVELOPMENT OF A DYNAMIC MODEL used to evaluate information technology, particularly the strategic uses. The model is illustrated in the banking industry, but it can be modified to examine other industries. Although the results may depend on the specific situation examined, there are several interesting findings. First, larger regional banks will tend to implement new technology before smaller local banks. The optimal strategy is for smaller banks to focus on costs instead of the strategic uses of IT.

Complex and realistic problems involving the evaluation of information technology can be handled with this model. One innovative contribution of the model is its proficiency in evaluating the strategic effects of IT on customers and competitors over time. The ability to examine these complex interactions makes it a useful tool for many existing problems in managing IT resources. The importance to many firms is that relying on cost–benefit studies is not sufficient. The value of the technology (future profit stream) and implementation time change considerably when considering the strategic effects. This method provides a mechanism to evaluate those effects and choose the best implementation strategy.

The issue of cost reduction versus strategic positioning in regard to IT implementation is explored, with many small firms opting for a cost-reduction strategy while

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larger market players choose a competitive strategy. This difference may be explained in the capital requirements for an IT implementation, which can be a barrier to entry for smaller firms. However, estimation of the model shows that there are situations where smaller firms can gain strategic advantage from early implementation of IT. The model gives decision makers the ability to identify those situations more precisely.

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APPENDIX: Outline of Solution Procedure

1. Estimate parameters for all model equations.
2. In the regional market, evaluate the net discounted profit for each firm at all possible implementation times. The result will be a $T \times T$ matrix with two entries: discounted profits accruing to each firm if they both implement at the indicated time and not earlier. At each time-pair,
   a. Evaluate the switching probabilities.
   b. Compute market shares.
   c. Compute present value of costs and profits.
   d. Maintain dynamic profiles of capital and market shares.
3. Use Nash equilibrium (or alternative techniques, e.g., Stackelberg leader-follower, cooperation) to find optimal implementation times. Beware of "cycling" solutions that do not center on a single time. The Nash solution process

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Table A1 Nash Equilibrium Example

	Firm$_1$ implementation times		
Firm$_0$ implements	10 / 12	7 / 8	12 / 15
	7 / 10	9 / 7	16 / 16
	8 / 15	14 / 12	9 / 10
	Firm$_0$ / firm$_1$ profits		

is illustrated by Table A1. The Nash solution begins with the Cournot assumption that each firm assumes its rival does not respond to changes.

Let firm$_0$ begin the process. Assume that firm$_1$ starts at column (time) 1, then firm$_0$ chooses row 1, since it produces the highest profit (10). Firm$_1$ then assumes that firm$_0$ will not change, so it chooses column 3 (profit = 15). Firm$_0$ then chooses row 2. Since firm$_1$ has no reason to change, the game has reached equilibrium. The final solution (t_0 = 2, t_1 = 3) represents the intersection of the Cournot reaction functions. In this case, there is a single point. In practice, there might be several intersections, resulting in a "cycling" between the points. Last, to test the assumption that firm$_1$ started at time 1, repeat the analysis for each of the T possible starting points. In all cases examined in this paper, the final intersection did not change.

Note that the firms do not actually attempt to implement each of the individual (Cournot) steps. Instead, they evaluate the reactions and choose the final equilibrium point as the single solution to the game. As summarized by Reinganum [31], a point is a Nash equilibrium if it meets three conditions:

a. The strategy $((t_0^*, t_1^*)$ is feasible for both participants.
b. $P^0 (t_0^*, t_1^*) \geq P^0 (t_0^*, t_1^*)$. The payoff for firm$_0$ at the equilibrium is higher than for other feasible choices of t_0 when t_1 is not changed.
c. $P^1 (t_0^*, t_1^*) \geq P^1 (t_0^*, t_1^*)$. The payoff for firm$_1$ at the equilibrium is higher than for other feasible choices of t_1 when t_0 is not changed.

Although the Nash/Cournot assumption might seem naive, it ends up being a stable solution with the assumption of nonresponse proved true when the equilibrium exists. The Nash approach is often used to represent a competitive market. As Scherer [36] notes, "If only one firm proceeds in this manner, it can pull all its rivals along into a series of Cournot reactions."

4. In the local market, given the large firm implementation times, evaluate the net discounted profit for each local firm at all implementation times ($T \times T$).
5. Use Nash equilibrium (or alternatives) to find optimal implementation times.
6. If some parameters cannot be estimated accurately, choose a range of values and repeat steps (2) through (4) for those values to examine the results.

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