PRIVATE NETWORKS PUBLIC OBJECTIVES
E. Noam and A. NíShúilleabháin (Editors)

Information Technology, Private Networks, and Productivity

Steven S. Wildman

1. INTRODUCTION

There has been a widespread belief in the inevitability of a coming information age, at least since the publication of Daniel Bell's *The Coming of Post-Industrial Society: A Venture in Social Forecasting*, in 1973. Just as the widespread application of industrial technology leads to a many fold increase in the productivity of economic activities, and thereby to a dramatic improvement in the quality of life for members of industrial societies, so it was prophesized that pervasive applications of information technologies (IT) would take us to a yet higher plane of economic and social well-being.

Today, few would question that the pervasiveness part of that prophesy has come true -- at least for the world's advanced economies, where information technologies have become vital to the facilitation and coordination of economic activity. The growing centrality of information technology and information services to economic activity in general is reflected in the growth of information workers as a percentage of the total workforce in the United States (now well over fifty percent) and in the dramatic growth in the percentage of capital investments going to information technology. From 1972 to 1989, U.S. service sector spending on IT increased from about three percent of total investments in durable equipment to about forty percent. In the manufacturing sector the increase was from three percent to about twenty-five percent over the same period.[1]

Given the degree to which the transformation toward an information society has been documented, it does not seem too early to be looking for empirical evidence of the economic benefits that are supposed to accompany the information revolution. At the very least we might expect some solid theoretical work to tell us whether these expectations are justified. If measured by volume, the research community has been more than obliging. In what he characterized as a selective review of this literature, Brynjolfson[2] surveyed over 150 articles, books, and research reports on IT productivity. The results were disquieting. The overwhelming majority of studies found no significant payoffs to IT investments, although Brynolfson's own more recent econometric study[3] does find significant benefits. The inability of researchers to consistently document significant returns on IT investments, combined with disillusionment by many business leaders whose firms have not experienced sustained increases in profitability following major IT projects, have lead many to question the business wisdom of past IT investments and public policies that promote them.

This chapter looks at the productivity contributions of private networks. The linking of varied information processing devices to create networks with functional capabilities vastly exceeding the stand-alone capabilities of their components is a development that was not widely anticipated by the early prophets of the information age. In fact, researchers' recognition of the significance of networks as functional entities providing services other than transmission is too recent to have been the subject of much empirical investigation.

Private networks may contribute to productivity in two ways: (1) They may provide the same services as public networks but at lower cost. The comparative benefits of public and private networks, when private networks are viewed as alternatives for performing the same basic transmission-related services as the public switched network, are examined by other authors.[4] (2) Private networks may also contribute to productivity by making it possible to produce other goods and services more efficiently, which is the subject of this chapter. The empirical literature on IT productivity is briefly reviewed in the next section. I will argue that, for the most part, the empirical studies of IT reported to date have placed the empirical cart a considerable distance ahead of the theoretical horse. In part this situation reflects the inadequacy of current theory for addressing certain problems raised by IT, including private networks; but it also reflects the fact that in our rush to measure we have made inadequate use of the theoretical tools at hand.

Theoretical work that has been done on modeling the social welfare consequences of investments in new technologies shows that a wide variety of outcomes are possible.[5] Results are highly context specific, with both welfare gains and welfare losses possible. This suggests that further progress in developing a broader understanding of the benefits of IT investments will depend to a large extent on a succession of application-by-application and industry-by-industry studies. The productivity implications of several services and benefits associated with certain types of private networks are examined in Section III.

2. EMPIRICAL ASSESSMENTS OF INFORMATION TECHNOLOGY BENEFITS

Most of the attempts to empirically assess the benefits of information technology have lumped various types of information technology together. While private networks are components of the larger whole being examined, it is not possible to disentangle their contributions to productivity from the contributions of other IT investments. The fact that networks add capabilities not present in their component pieces alone is further complication. Nevertheless, at the conceptual level the same issues must be dealt with in assessing private network benefits as for assessments of IT benefits generally. Empirical studies of the benefits of information technology fall into four broad groupings: (1) Studies of the profitability of business investments in information technology; (2) Studies employing Bureau of Labor Statistics (BLS) productivity measures; (3) Production function studies; and (4) Studies of the economic surplus generated by information technology investments. The preponderance of these studies fall in the first two categories.

Profitability studies come in several varieties. For example, there are comparisons of the profits of firms employing different IT strategies across industries[6] and work comparing the profits of firms with different IT strategies in the same industry.[7] Whatever approach is used, however, the search is always for correlations between firm profitability and IT investments. Strassman's conclusion that there is no clear correspondence between IT investments and profitability at the firm level characterizes the findings of this branch of the literature in general.

While less numerous, studies employing BLS measures of productivity, have received by far the most attention, especially a series of studies by Stephen Roach.[8] In his widely cited reports, Roach compares trends in productivity indices for manufacturing industries and for service industries during the period, from the early 1970s to the late 1980s, when IT investments in both sectors rose dramatically. BLS measures of manufacturing productivity rose through most of this period while measures of service sector productivity were basically flat. This, Roach argues, showed that investments in IT in manufacturing industries had been reasonably productive, while the return on IT investments in service industries was been woefully inadequate.

In a widely cited working paper, Loveman[9] estimates a Cobb-Douglass production function for manufacturing firms that included information capital as a factor of production. On the basis of comparisons of output elasticities, he concludes that funds invested in information technologies would have yielded higher returns had they been invested in more traditional forms of capital instead. Brynolfson[10] applies this technique to a larger and more recent sample of firms and found significantly higher returns to IT investments than for other capital investments.

Bresnahan's[11] econometric study of investments in computer technology in the financial services industry measured benefits as the area under the industry's derived demand curve for information services. He estimated benefits at five times the cost of the technology. Hitt and Brynolfson[12] applied Bresnahan's methodology to a larger and more diverse data set covering the years 1988 through 1992 and estimated the surplus created by computer investments for their sample of 367 large (Fortune 500) firms to have been $4.1 billion per year.

Each of these empirical approaches is either theoretically flawed or based on theoretical assumptions that make their use for estimating IT productivity benefits highly suspect. The profitability studies can be dismissed on purely theoretical grounds. While long-term, supracompetitive profits are the objective of the business strategist, to the policy maker they are often taken as evidence of less than vigorous competition. In dynamic competitive markets technology innovators are often quickly imitated or leap-frogged by new innovators. This competition forces prices down toward costs and transfers the surplus made possible through productivity gains to consumers. Therefore, the complaint that the profits from IT strategies are not sustainable in the long run is really a complaint about the vigor of competition. As long as early IT adopters realize at least short term profits, the transient nature of these profits is evidence that productivity benefits are passed on to their customers in the end.[13]

Long recognized problems with the measurement of the outputs of various service activities have been the basis for criticisms of BLS measures of service sector productivity, and, because service industries have invested heavily in IT, criticisms of arguments like those advanced by Roach that IT investments have not been productive.[14] If businesses use IT to provide new services, for which there is no explicit charge, in conjunction with their traditional products or services, the value of the additional service does not show up in BLS measures of productivity. For example, a number of document and package shipping companies now use specialized networks to track the progress of shipments throughout the delivery process and let their customers use these network as a "free" add-on to their service. Because there is no explicit charge attributed to the tracking service, BLS productivity measures don't pick up the full contribution of private networks to these shippers' outputs. Similarly, the productivity benefits of a financial services firm using computer applications to create more sophisticated financial instruments for its clients may not be counted as a productivity gain, given the way that financial services are measured. IT advocates point out that with the severity of the measurement problems in the BLS indices of services productivity, substantial IT productivity contributions may be going unmeasured.

Denison[15] points out that when there are unmeasured productivity gains in intermediate products and services, they may show up as measured productivity gains in an industry purchasing these inputs. Much of the output of the service sector is purchased by manufacturers. Therefore, a portion of the measured productivity gains in manufacturing may actually reflect IT contributions to service sector productivity.

Loveman's econometric production function study of the benefits of IT in manufacturing has been criticized by Baily and Chakrabarti[16] for relying on comparisons of estimated output elasticities, rather than on more meaningful marginal product estimates. It should also be noted that some of the output measurement problems inherent in the BLS productivity measures are also problems for the production function approach to measuring IT benefits, because customer benefits not captured by sellers will not be picked up. However, output measurement problems are less severe for manufacturing sector outputs, so these criticisms have less force when applied to the Loveman and Brynolfson empirical studies.

The theoretical basis for these production function studies merits further examination, however. Profit maximizing businesses should equate returns at the margin on all types of investment. Therefore, productivity studies should find higher returns for IT investments than for other capital investments only if the stock of IT capital is less than optimal. In other words, higher than normal returns to IT should be a disequilibrium phenomenon that can't persist in the long-run. As such, higher than normal returns on IT capital are a measure of prior ignorance regarding the true benefits of IT. Even the disequilibrium interpretation of production function estimates of IT productivity must be viewed cautiously, however. If we really are going through a period of disequilibrium and transition to a more IT intensive system of production, then the assumption underlying these estimates that production function coefficients are stable over time is hard to justify.

Bresnahan[17] developed a model of a perfectly competitive market in IT services to address the measurement problems just discussed. He used the model to show that there are conditions under which an industry's inverse demand function (derived from consumer demands) for information services can be used to estimate the benefits to consumers of investments in IT. In the process he provided the theoretically useful result that in some circumstances competitive markets can be relied upon to make social benefit-maximizing investments in information technologies.

In contrast with the production function studies, the recent findings of which make sense only if firms don't fully appreciate the benefits of information technology, Bresnahan's approach produces reliable estimates of IT benefits only if firms do fully understand the benefits of the information technologies they invest in. Because it estimates the area under a downward sloping demand curve, a finding of positive benefits is inevitable. Only the magnitude is in doubt. In other words, Breshnahan's approach doesn't allow for mistaken IT investments. If applied to U.S. nuclear power facilities, most of which are now known to have been mistakes, it would still show positive net benefits. Nevertheless, Bresnahan's model provides a useful benchmark for examining the extent to which the *understood* benefits of IT are likely to be internalized in market transactions.

The message of this brief review of the IT productivity literature is clear. The empirical techniques employed to date to estimate the productivity consequences of investments in information technology are not up to the task. Many of the claimed benefits of IT are intangible, which means they are not captured, or are captured imperfectly, in BLS productivity statistics. Bresnahan's approach is elegant and theoretically defensible, but only if the nature of the benefits is well-understood by firms investing in information technology. Brynolfson's estimates of substantial benefits, which imply that investments in information technology are not well-informed, and the fact that the "productivity paradox" is still a subject of intense discussion, suggest that for most industries Bresnahan's assumption, that firms fully anticipate the benefits IT will provide, is not satisfied. To make further progress in estimating the return on IT investments, we need to do a better job of modeling IT's benefits.

IT has many applications and the nature of the benefits should be specific to these applications. While less exciting than producing global estimates, clearly specifying and modeling the economic implications of the benefits that can reasonably be expected in specific IT applications seems to be the only way to make further progress. The next section of this chapter uses an economic perspective to examine the productivity implications of several of the observed consequences of certain types of private networks. Central to this analysis is the assumption that private networks provide services that are primarily facilitative. That is, they make it possible to carry out more primary economic activities more rapidly, or more accurately, or at lower cost, etc., than would be possible without them. Previously undervalued and/or unanticipated benefits of private networks are revealed. Once these benefits are better understood, the job of estimating their magnitude will be much easier. Besides making possible more accurate estimates of private networks' productivity contributions, this type of careful modeling of prospective benefits should lead to wiser and more productive investments in private networks and IT generally.

3. SEARCH FACILITATION: ANALYSIS OF AN APPLICATION OF PRIVATE NETWORKS

Economic actors often commit considerable resources to the gathering of information about their options before committing themselves to a course of action. In these situations, the net benefit associated with search is the realized (expected) increase in the value of the option taken relative to the value of the option that likely would have been taken with no (or less) search minus the value of the resources committed to the search processs. Private networks affect the cost side of this tradeoff by lowering the cost of search and they affect the benefits side to the extent that the quality of the option selected is affected. This is most obvious in the case of private networks used to facilitate buyer search, such as a real estate multiple listing service (MLS) or an airline computer reservation service (CRS). However, similar processes and consequences are to be observed in the manufacturers' and service providers' attempts to improve production practices and in the search for the inspirations for new products and services.

Consider the case of a private network used to facilitate buyer search. An optimal search strategy requires that the buyer continue examining new alternatives until the value of the best alternative examined so far is high enough that the expected improvement over that value from one more search is not large enough to justify the cost of the search.[15] The major attraction of certain private networks, such as MLS's and CRS's, is that they lower search costs. In both cases, buyers' direct costs of searching are reduced because they can compare significant attributes of different purchase options on-line. In the case of a CRS, enough information is provided to make a final selection -- at which point the CRS is also used to process the transaction. While the final selection of houses and other real estate properties are seldom made on a MLS, use of a MLS to screen options can significantly reduce the number of properties a buyer actually visits before making a selection.

The savings in buyer search costs are an obvious productivity gain from these networks, and one that may be recouped at least in part in buyer fees. However, the bigger benefit, especially in real estate markets, is likely to come from a better matching of buyer preferences with the options offered by sellers. An obvious implication of the search rule stated above is that buyers will examine more options if the cost of search is reduced. The benefit to the individual buyer of screening more options is that the best of the larger number of options considered with network search facilitation is likely to be better than the best of the smaller number of options that would be examined otherwise. In the aggregate, the benefit of search facilitation comes from a better matching of heterogeneous products with buyers with heterogeneous tastes.

To illustrate the nature of the benefits of buyer search facilitation, suppose that in the absence of network search facilitation home buyer A would end up with house 1, which she values at \$100,000, and buyer B would settle for house 2, which he values at \$100,000. With the aid of a MLS, A would find house 2, for which she would be willing to pay \$110,000 and B would discover house 1, for which he would be willing to pay up to \$110,000. In this case, network search facilitation would produce a reallocation of the existing housing stock among existing buyers worth \$20,000 to the buyers.

Under a wide variety of circumstances, much of this gain would not show up in the prices reflected in BLS productivity statistics. As I showed in an earlier effort to model network search facilitation,[19] some of the benefits of better choices by buyers may be picked up by sellers who raise their prices when they realize that the prospective buyers who approach them are the ones who value their properties most highly. Prices could also fall, however, because buyers are now examining more options. In either case, the additional surplus retained by buyers does not show up in BLS-type productivity calculations because it is over and above the purchase price. Furthermore, because the same stock of houses is being sold, price increases due to better buyer-seller matches are likely to be discounted as price inflation in BLS statistics.

While not as easy to model, there are analogous benefits from the use of private networks to facilitate the search for solutions to the types of problems, which, while perhaps infrequent or even non recurring for the individual enterprise, must be dealt with by all enterprises engaged in similar activities. Typically there are a number of ways to address a given production problem or design problem, some of which are immediately apparent, others of which are not. The comparative advantages of alternatives are often hard to assess. Private networks are increasingly being used to facilitate the formation and operation of personal networks of experts and other interested parties who share information, perspectives, and the benefits of experience in dealing these kinds of problems. Examples are the bulletin boards that have emerged on the major on-line services, such as CompuServe, America On-Line, and Prodigy, on which computer experts post problems they are having difficulty solving and offer solutions to problems posted by others, and computer networks for physicians that post information about new medicines and procedures.

4. CYCLE-TIME REDUCTION: ANALYSIS OF AN OBSERVED EFFECT OF PRIVATE NETWORKS

Electronic data interchange (EDI) is probably the private network application that has received the most attention in the business press. EDI networks connecting buyers and sellers have made it possible for firms to dramatically reduce paperwork and implement just-in-time (JIT) inventory programs which, by making it possible for firms to place orders and receive shipments from suppliers on an as-needed basis, have dramatically reduced paperwork and the lapsed time from the placement of an order to the delivery of a part or product. Reduced order times, or order cycles, make possible smaller inventory holdings because the risks associated with stock outages are reduced. The savings from reduced inventories are obvious. Inventory has an opportunity cost equal to the cost of the financial capital tied up and there are the additional savings in storage costs and the costs of keeping track of inventory holdings. Substantial staff reductions are also often realized as various clerical functions are automated and the amount of paperwork falls.

With flexible manufacturing processes, the just-in-time philosophy is also being applied to production, which makes possible further savings in inventory holdings, paperwork, and personnel. Private networks have also been used to speed the flow of information between executive suites and the shop floor and to facilitate communication between product designers and product engineers and between product engineers and manufacturing operations. The aggregate effect of these applications of private networks has been an often dramatic reduction in the time required to move a new product or service from concept through design and into production.

The focus on inventory and paperwork reductions from JIT systems has obscured the fact that even without these benefits, there would probably be substantial, though more subtle, productivity benefits from the reduction in the time required to carry out various economic activities. Some of these are realized at the level of the firm while others reflect changes in entire production (or value) systems, the set of vertical relationships among firms at different stages in a production process. I want to examine two largely overlooked benefits of shorter cycle times: reduced opportunity costs associated with resource commitments and better matches of products and plans with market conditions.

One part of the resource commitments I am referring to is the expenditures on labor and other inputs that must be made at each stage of a product's transformation from raw materials and labor inputs to a finished final good in the hands of a buyer. Since the payoff to these expenditures is not realized until the end product is purchased by its ultimate buyer, the final cost of the product must include the opportunity cost of the expenditures on all inputs employed in the processes of producing, distributing, marketing, and selling of a product up to the moment it is actually sold. I will refer to this sequence of activities as the product provision cycle, or the provision cycle. The more drawn out are the processes making up the provision cycle, the greater the opportunity cost. Another way of looking at this is that the payments to labor and other inputs used to produce, distribute, market, or sell, the final product must be lower the longer is the product provision cycle, because the opportunity cost of funds tied-up must also be covered in the product's price, and price is constrained by the location of the product's demand function. In other words, longer production cycles reduce factor productivity.

In one respect this claim is pretty obvious. The length of the production cycle is partially determined by the speed with which labor works. Clearly productivity varies inversely with the pace at which the individual worker works. However, much of the delay in production processes is due to communication delays -- time required for acquiring, transmitting, and processing information. These delays occur independent of the rate at which individual workers (other than information workers) carry out their tasks. Therefore, using information technology to reduce these delays increases labor productivity even if the ratios of physically measured labor inputs to outputs stay the same, because consumption of the final product occurs much closer to the date the work was performed, and less opportunity cost of funds is included in the final price. Of course, this is also true for non labor inputs. The following example shows the magnitude of the productivity gains that might be realized from using information technology to shorten production cycles.

Consider a product that can be produced with an expenditure of $400 in direct payments for the labor and other inputs used in its production. Once produced, the product is purchased off the factory floor with no extra expenditures on distribution, marketing or sales. Suppose production takes place over a four year period, input expenditures are constant at the rate of $100 per year, and the annual interest rate is 10 percent. Then, at the end of the four year period the sum of direct payments to factors plus the opportunity cost of the funds tied up would come to approximately $487.31.

If the time required to move the product through all its stages of production is reduced to two years due to more efficient communication, the total of the opportunity cost of funds plus $400 in factor payments would be reduced to $441.00, a reduction of 9.5 percent from the four year cost. Halving the provision cycle again to a year would reduce the total cost to $420, a reduction of 4.8 percent from the $441 and a 13.8 percent reduction from the $487.31 four year cost.[20] Clearly the potential savings from shortening product provision cycles are quite substantial.

Ignored in the preceding discussion of product (or service) provision cycles were the costs of conceptualizing and developing new products and services and the costs of designing and setting up the facilities for producing them. New products and services are often years in development and in major industries like automobiles and prescription drugs, development costs may run to the hundreds of millions or billions of dollars. Private networks are now being used shorten product development costs by facilitating the flow of information among teams of marketing experts, design engineers, and the managers of manufacturing facilities. Given the financial sums involved, the potential opportunity cost savings from shorter planning cycles are clearly quite large.

Other benefits of reduced cycle times are similar in some ways to the benefits of better matching of buyers and existing products attributable to search facilitation, only the analogous benefits of shorter cycle times are reflected in smaller forecast errors and better matches of seller plans and buyer demands. Demand forecasts are always uncertain, and the magnitude of uncertainty grows the further into the future that demand must be forecast. Therefore a benefit of shorter cycle times is a better match of products available with buyer preferences. This applies to all three types of cycle times discusses. Shorter order cycles (often referred to as inventory cycles) mean a better match of goods retailers hold in stock with contemporaneous buyer preferences, given the range of options actually produced by manufacturers. Shorter provision cycles give retailers a better set of options (product options that more closely mirror buyer preferences) from which to choose than would be available otherwise. Finally, shorter planning cycles make a better range of production options available to manufacturers. Shorter planning and provision cycles also reduce costs by making it possible for manufacturers to incorporate more recent advances in production techniques and to select input ratios that more closely reflect factors prices at the time of production.

5. A MODEL OF CYCLE TIME COMPETITION

The model developed in this subsection is similar in many respects to that developed by Bresnahan.[21] An important difference is that the representation of the demand function employed here was chosen for its usefulness in modeling cycle time competition. The model follows Bresnahan in assuming that the productivity benefits of IT are manifest in direct consumer benefits rather in lower production costs.[22] However, the particular form of the model employed has little effect on the generality of the analysis.

We will consider an industry with n firms, indexed by $i = 1,\dots,n$ and employ the following definitions. Let x_i be the measured output of representative firm i and let d_i be i's cycle time (either product cycle or inventory cycle). Define $ø(d_i)$ such that $ø(0) = 1$, $ø(\infty) \geq 0$, and $ø' < 0$. $X = \Sigma ø(d_i)x_i$.

Consumers' utility gross of expenditures on the industry's product is given by U(X), with marginal utility increasing in X, but at a decreasing rate. That is, $U' > 0$ and $U'' < 0$. $ø' < 0$ means that a longer cycle time reduces the value of a firm's output to consumers. (For example, longer product development cycles could result in product designs more out of date relative to current consumer preferences.) To illustrate what this assumption about the effect of differences in cycle times on preferences means in terms of the model being developed, suppose for firms i and k that $ø(d_i) = .6$, $ø(d_k) = .3$, and that $x_i = x_k$. Then, even though the unit measures of output for the two firms are the same, i's output contributes twice as much to consumer utility as k's (as long as the loss of neither has a significant impact on U'). Finally, let p_i be the price for representative firm i, define I_i to be per period expenditures on information services by firm i. Included in I are the rental value of investments in information technology and the ongoing costs of operating and maintaining the technology. The costs incurred by a firm with output x and information services purchases of I are given by c(x,I).

We assume d_i to be a decreasing function of I_i only. This assumption, which is implicit in Bresnahan's model, is not totally innocuous, especially for the product cycle interpretation of the model. For example, it is not unreasonable to expect some of the market intelligence gathered by firm i in designing the next product model to be leaked to other firms in the market and vice versa. Nor is it unreasonable to expect that information acquired in this manner might be used to improve the "fit" of a firm's design to consumer tastes at the time of its release. Similarly, knowledge of advances in design techniques at one firm may eventually become common knowledge throughout an industry.

Our first task is to describe the configuration of the industry that maximizes consumer utility net of production and information services costs. In doing this we make the simplifying assumption that firms are selecting steady state values for all choice variables and that the discount rate is sufficiently low that we can ignore the fact that the effects of changes in a firm's level of I do not affect demand for its product until d(I) amount of time has passed. These assumptions should have no effect on the comparative static results while saving the notational clutter of discount factors that would appear in some first order conditions but not in others. With symmetry among firms, the problem can be written as:

$$\mathrm{Max}_{x,I,n}\ U - nc(x,I), \tag{1}$$

where the unsubscripted x and I are values for these variables common to all firms. This gives us the following first order conditions for a welfare optimum, where c_1 and c_2 are the derivatives of c with respect to x and I respectively.

$$U'\phi(d) - c_1 = 0 \tag{2}$$

$$U'\phi'd'x - c_2 = 0 \tag{3}$$

$$U'\phi(d)x - c = 0 \tag{4}$$

Let Π_i be the profit of firm i.

$$\Pi_i = P_i x_i - c(x_i, I_i). \tag{5}$$

For firm i, $P_i = U'\phi(d_i)$. In a standard competitive model, firms take price as parametric. In this model, it is U' that is taken as given. That is, each firm's output is a sufficiently small fraction of the market total that the effect of small variations in any x_i on marginal utility is trivial. However, each firm can affect the price of its own product through its choice of I. The first order conditions for a Cournot competitor taking U' and the values of its competitors' information services purchases and outputs as fixed are given by (6) and (7).

$$P_i - c_1 = 0 \tag{6}$$

$$(\partial P_i/\partial I_i)x_i - c_2 = 0 \tag{7}$$

The zero profit condition for a free entry equilibrium is

$$P_i x_i - c_i = 0. \tag{8}$$

Substituting the utility function equivalents for the price expressions in equations (6), (7) and (8) shows them to be the same as (2), (3), and (4), which is Bresnahan's optimality result. What is not obvious are the cost function restrictions implied by a sustainable competitive equilibrium. The cost functions in turn imply restrictions on the types of information services that are compatible with a competitive equilibrium.

(6) in combination with (8) rules out cost functions in which I has a fixed cost component unless marginal cost is rising, since at most only variable costs could be covered otherwise. Thus, for example, a cost function of the form $c(x,I) = kx + I$, where I might be expenditures on a common information service available to all of a firm's customers is ruled out.[23] It is hard to envision a data base type service that would not be ruled out by this restriction.

For a firm's information expenditures to increase buyers' valuation of its product without adding a fixed cost component to a constant cost production function, the cost function would have to be of the form $c(x,I) = v(I)x$. This requires a separate expenditure on information inputs on the firm's part for each unit of the product sold, which seems unlikely. This possibility aside, for industries that do not have rising marginal costs, spending on information technology is incompatible with a classical competitive equilibrium. If IT spending adds a fixed cost component to an otherwise constant cost industry, a stable equilibrium requires that eventually enough firms exit the industry so that those remaining are sensitive to the effect of their output decisions on price. In general, it seems unwise to invoke Bresnahan's optimality result to justify IT investments in competitive industries unless careful attention is given to the nature of the contribution of IT to the value of the industry's product and the role of IT in firms' cost functions.

If the number of firms is taken as fixed, and we allow for positive spillovers from one firm's IT expenditures to other firms--perhaps the results of IT facilitated market research are leaked to competitors--then the model is formally identical to a model of R&D investments developed by Spence.[24] Such spillover benefits to competitors reduce the incentive to invest in R&D. Spence showed that in the presence of R&D spillovers an optimal policy would be to subsidize firms' investments in R&D. In fact, Spence shows that subsidies can be set to generate the optimal level of expenditure on R&D when the number of firms in an industry is fixed. By extension, these results would also apply to expenditures on information technologies such as private networks.

The fact that the spillover benefits of a firm's IT investments to other firms are not internalized in its derived demand for IT suggests that Bresnahan-type derived demand function estimates of benefits from IT investments might be used as lower bound estimates for actual benefits when firms understand the benefits of information technology and act as atomistic competitors. Dropping the assumption of atomistic competition in IT services can produce radically different results, as illustrated by the discussion of industry-sponsored search facilitation above.

The model still produces interesting insights into the nature of competition in information services and the implications of government technology policy, however, if we drop the restrictive assumptions that firms view price (or marginal utility) as constant and that competition proceeds to the point of pushing profits to zero; even though we lose the ability to make clean cut, comparative static welfare comparisons.

For example, assume a domestic market with the number of firms fixed at n, let s be the fraction of every dollar spent on IT that is rebated to IT purchasers by the government, and let $c(x,I) = kx+I$. These assumptions are reflected in equations (9) and (10), which are variants of the firm first order conditions, (6) and (7). The addition of the second term in (9), which is not in (2), allows for the possibility that firms are not price takers.

$$U'\o(d) + U''[\o(d)]^2 x - k = 0. \tag{9}$$

$$U'\o'd'x - 1 + s = 0. \tag{10}$$

Taking the total derivatives of (9) and (10) with respect to s, it can be shown that for a linear demand curve (which implies $U'''=0$), dI/ds and dx/ds are both positive. That is, IT investments and output both increase in response to an increase in the subsidy, which is intuitively plausible. These results do not generalize to all possible specifications of consumer demand functions,[25] but intuition suggests that they are likely to characterize most real-world situations. Given a fixed number of firms, dI/ds > 0 means that the industry as a whole increases its purchases of IT services if its own contribution to the cost of those services is reduced, which seems reasonable. dx/ds > 0 means that the physical measure of industry output increases as its cost for purchasing the IT inputs that make its product more appealing to consumers declines. This also seems reasonable.

Thus we would expect firms (or an industry) favored by IT subsidies to increase product quality and sell more units at higher prices than they would otherwise. More intriguing is the clear implication that a country providing larger IT subsidies to its domestic firms than its trading partners provide to their domestic manufactures could turn the balance of trade in the affected industries in favor of itself. This would happen because firms in the country with the largest IT subsidy would invest more in information technology and produce "higher quality" products[26] than their international competitors from other nations. While the firms with greater IT investments will also charge higher prices, their higher prices will be more than compensated for by higher quality. So their unit sales will be greater than competitors from other countries as well.

6. SUMMARY

Attempts to estimate empirically the benefits of information technology investments to date have either been theoretically flawed or have been based on theoretical assumptions (either implicit or explicit) that are hard to justify. What seems clear from the empirical evidence produced is that most firms have invested in information technology without a clear understanding of its prospective benefits. Theoretical considerations also suggest that, because both net benefits and net losses from IT investments are possible and the situations that generate benefits and losses are likely to vary among industries, attempts to directly estimate the aggregate benefits and costs of IT investments are not likely to produce useful results.

The fact that IT in general, and private networks in particular, are used primarily to facilitate the performance of more primary economic activities suggests that a careful study of the benefits of the types of facilitation provided by private networks (and information technology more generally) would be fruitful. This chapter examined the prospective productivity benefits that might be expected from the use of private networks to facilitate search and to shorten various economic cycles. The prospective benefits identified are potentially quite large and this identification lays the foundation for more meaningful productivity estimates. The clearer identification of prospective benefits itself should also further the goal of more effective IT investments.

A formal model of network-facilitated cycle time competition showed that the optimality properties of Bresnahan's[27] model are unlikely to be satisfied in most real world applications of information technology; however, his approach should be useful for calculating a conservative lower bound on the benefits of IT investments when firms are well-informed. An extension of the model showed that a country providing larger IT investment subsidies to domestic firms than its international rivals might be able to gain an advantage in international trade.

REFERENCES

Baily, M. N. and Chakrabarti, A. K., *Innovation and the Productivity Crisis*, Washington, D.C.: Brookings, 1988.

Bresnahan, T. F., "Measuring the Spillovers from Technical Advance: Mainframe Computers in Financial Services," *American Economic Review*, September 1986, 76, 742-55.

Brynjolfsson, E., "The Productivity of Information Technology: Review and Assessment," Center for Coordination Science Technical Report #126, Sloan School of Management, MIT, December 1991.

Brynjolfsson, E., "Paradox Lost? Firm-level Evidence on the Returns to Information Systems Spending," Sloan School of Management, MIT, December 1994.

Denison, E. F., *Estimates of Productivity Change by Industry*, Washington: The Brookings Institution, 1989.

Dos Santos, B. L. and K. Peffers, "Rewards to Investors in Innovative Technology Applications: A Study of First Movers and Early Followers in ATMs," Krannert Graduate School of Management, Paper no 1014, Purdue University, November 1991.

Egan, B. L. and S. S. Wildman, "Investing in the Telecommunications Infrastructure: Economics and Policy Considerations," *A National Information Network: Changing Our Lives in the 21st Century*, Institute for Information Studies, December 1992, 19-54.

Fudenberg, D. and J. Tirole, "Understanding Rent Dissipation: On the Use of Game Theory in Industrial Organization," *American Economic Review*, May 1987, 77, 177-83.

Gilbert, R. J. and Newbery, D. M. G., "Preemptive Patenting and the Persistence of Monopoly," *American Economic Review*, June 1982, 72, 514-526

Hitt, L. and Brynolfsson, E., "Creating Value and Destroying Profits? Three Measures of Information Technology's Contributions," Sloan School of Management, MIT, December 1994.

Loveman, G. W., "An Assessment of the Productivity Impact of Information Technologies," MIT Working Paper 90s: 88-054, September 1990.

Panko. R., "Is Office Productivity Stagnant?" *MIS Quarterly*, June 1991, 190-203.

Roach, S. S., "America's Technology dilemma: A Profile of the Information Economy," Special Economic Study, Morgan Stanley, April 22, 1987.

Roach, S. S., "The Technology Trap," *Economic Perspectives*, Morgan Stanley & Co., December 15, 1989.

Roach, S. S., "Services Under Siege—The Restructuring Imperative," *Harvard Business Review*, September-October 1991, 82-91.

Roach, S. S., "Policy Challenges in an Era of Restructuring," Morgan Stanley, January 8, 1992.

Spence, M., "Cost Reduction, Competition, and Industry Performance," *Econometrica*, Vol. 52, No. 1 (January, 1984), 101-121.

Strassman, P. A., *The Business Value of Computers*, New Canaan, Connecticut: Information Economics Press, 1990.

Wildman, S., "The Economics of Industry-Sponsored Search Facilitation," in M. Guerin-Calvert and S. Wildman, eds., *Electronic Services Networks: A Business and Public Policy Challenge*, New York: Praeger, 1991.

ENDNOTES

[1] Roach, "Policy Challenges in an Era of Restructuring," Morgan Stanley, January 8, 1992.

[2] Brynjolfsson, E., "The Productivity of Information Technology: Review and Assessment," Center for Coordination Science Technical Report #126, Sloan School of Management, MIT, December 1991.

[3] Brynjolfsson, E., "Paradox Lost? Firm-level Evidence on the Returns to Information Systems Spending," Sloan School of Management, MIT, December 1994.

[4] Notably in the paper "Efficiency and Productivity of Public and Private Networks of NTT" by Oniki and Stevenson, delivered at the Private Networks and Public Objectives conferences at the Columbia Institute of Tele-Information during 1991.

[5] See, e.g., Gilbert and Newbery (1982) and Fudenberg and Tirole (1987).

[6] Strassman, P. A., *The Business Value of Computers*, New Canaan, Connecticut: Information Economics Press, 1990.

[7] Dos Santos, B. L. and K. Peffers, "Rewards to Investors in Innovative Technology Applications: A Study of First Movers and Early Followers in ATMs," Krannert Graduate School of Management, Paper no 1014, Purdue University, November 1991.

[8] Roach, S. S., "America's Technology dilemma: A Profile of the Information Economy," Special Economic Study, Morgan Stanley, April 22, 1987, Roach, S. S., "The Technology Trap," *Economic Perspectives*, Morgan Stanley & Co., December 15, 1989, Roach, S. S., "Services Under Siege—The Restructuring Imperative," *Harvard Business Review*, September-October 1991, 82-91 and Roach, "Policy Challenges in an Era of Restructuring," Morgan Stanley, January 8, 1992.

[9] Loveman, G. W., "An Assessment of the Productivity Impact of Information Technologies," MIT Working Paper 90s: 88-054, September 1990.

[10] Brynjolfsson, E., "Paradox Lost? Firm-level Evidence on the Returns to Information Systems Spending," Sloan School of Management, MIT, December 1994.

[11] Bresnahan, T. F., "Measuring the Spillovers from Technical Advance: Mainframe Computers in Financial Services," *American Economic Review*, September 1986, 76, 742-55.

[12] Hitt, L. and Brynolfsson, E., "Creating Value and Destroying Profits? Three Measures of Information Technology's Contributions," Sloan School of Management, MIT, December 1994.

[13] Egan, B. L. and S. S. Wildman, "Investing in the Telecommunications Infrastructure: Economics and Policy Considerations," *A National Information Network: Changing Our Lives in the 21st Century*, Institute for Information Studies, December 1992, 19-54.

[14] Panko, R., "Is Office Productivity Stagnant?" *MIS Quarterly*, June 1991, 190-203 and Baily, M. N. and Chakrabarti, A. K., *Innovation and the Productivity Crisis*, Washington, D.C.: Brookings, 1988.

[15] Denison, E. F., *Estimates of Productivity Change by Industry*, Washington: The Brookings Institution, 1989.

[16] Baily, M. N. and Chakrabarti, A. K., *Innovation and the Productivity Crisis*, Washington, D.C.: Brookings, 1988.

[17] Bresnahan, T. F., "Measuring the Spillovers from Technical Advance: Mainframe Computers in Financial Services," *American Economic Review*, September 1986, 76, 742-55.

[18] This is description of the optimal stopping rule that is the subject of a large body of literature on the economics of search.

[19] Wildman, S., "The Economics of Industry-Sponsored Search Facilitation," in M. Guerin-Calvert and S. Wildman, eds., *Electronic Services Networks: A Business and Public Policy Challenge*, New York: Praeger, 1991.

[20] Cost for a four year cycle was approximated as:

$$\$100(1+r/2)[(1+r)^3+(1+r)^2+(1+r)+1], \quad (19.1)$$

where r is the interest rate and set equal to .10 for this example. Similarly, the cost for a two year cycle is:

$$\$200(1+r/2)[(1+r)+1] \quad (19.2)$$

and the cost for a one year cycle is $\$400(1+r/2)$.

[21] Bresnahan, T. F., "Measuring the Spillovers from Technical Advance: Mainframe Computers in Financial Services," *American Economic Review*, September 1986, 76, 742-55.

[22] Spence (1984) shows for a R&D investment model, which is similar to the IT expenditure model developed here, that a cost reduction formulation is isomorphic with a consumer benefits formulation over a wide variety of circumstances.

[23] This would also apply to informative advertising.

[24] Spence, M., "Cost Reduction, Competition, and Industry Performance," *Econometrica*, Vol. 52, No. 1 (January, 1984), 101-121.

[25] This is because U''', the third derivative of the demand function, appears in the expressions for dI/ds and dx/ds, and this term cannot be signed on purely theoretical grounds.

[26] Higher quality in this analysis can refer to the greater likelihood that firms investing more in IT will have shorter planning, provision, and purchasing cycles, and thus will have product varieties that better match consumer preferences than their competitors' products.

[27] Bresnahan, T. F., "Measuring the Spillovers from Technical Advance: Mainframe Computers in Financial Services," *American Economic Review*, September 1986, 76, 742-55.