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Information Technology, Productivity, and Trade Implications

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Introduction

There has been a wide-spread 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. To many, the anticipation was for a transformation of the economic and social fabric of society as complete as the transformation wrought by the industrial revolution. Just as the widespread application of industrial technology lead to a many fold increase in the productiveness 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, I doubt that many would question the pervasiveness part of that prophesy. While we clearly are still in the early phases of transformation, information technologies have become vital components of economic activities in all advanced economies. In fact, many activities and services that are now so commonplace as to be taken for granted, such as faxing, e-mail and on-line access to data bases, would not be possible without an advanced information infrastructure.

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. (Roach 1992)

Given the degree to which the transformation toward an information society has been documented, it does not seem to be 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 (1991) surveyed over 150 articles and research reports on this subject. The results are disquieting. The benefits of information technologies have proven to be elusive, at least in the empirical research reported on this subject to date. The failure of researchers to provide solid empirical evidence for IT benefits, 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.

Our failure to document general and widespread benefits from IT also poses a dilemma for policy makers. Given the massive investments in IT that have already been made in both the private and public sectors, and even more massive investments that are planned, the consequences of low payouts on these investments are not a trivial issue. If IT is not the most productive use of scarce resources, then we are all the poorer for IT investments made in the past and we would be wise to scale back our IT ambitions for the future.

This paper is organized as follows. In the next section I briefly review and criticize the empirical literature on IT benefits. My conclusion is that, with one notable exception, the empirical studies reported in the literature to date have all placed the empirical cart a considerable distance ahead of the theoretical horse. For the most part the methods employed have been inappropriate to the assessment of the benefits of information technologies. This reflects to some extent the inadequacy of current theory for addressing certain problems raised by IT; but it also reflects the fact that in our rush to measure we have done little to apply the theoretical tools at hand to the problems for which they are relevant.

Tim Bresnahan's (1985) study of the benefits of computer investments in the financial services industry is the one empirical study to date to employ measures of benefits of IT explicitly based on theoretical considerations. He also provides the useful theoretical proposition that competitive industries make welfare optimal IT investment decisions. I explore the range of circumstances to which Bresnahan's model can be applied in Section III. My conclusion is that the basic assumptions underlying his approach cannot be assumed to hold generally, even for the class of competitive industries he was modelling. His optimality result no longer holds if information spillovers are introduced to the model or if his narrow implicit restrictions on cost functions are relaxed.

Bresnahan's model does provide an excellent starting point for the analysis of a wider range of situations, however. From the perspective of the formal modelling exercise, his work and a related model presented in this paper fall squarely within the tradition of work on the economics of R&D spending. So it should be possible to apply some of the modelling techniques and empirical methods developed in that literature to capture the effects of information spillovers which are implicitly assumed away in Bresnahan's model.

However, the little work that has been done on modelling the social welfare consequences of IT investments shows that a wide variety of outcomes are possible. 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 case-by-case and industry-by-industry studies.

II. Empirical Assessments of IT benefits

At some risk of being overly general, studies seeking empirical evidence on the benefits of information technology can be classified as falling 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 proponderance of these studies fall in the first two categories. I am aware of only one study each in categories (3) and (4).

Profitability studies come in several varieties. There are case studies of individual firms (add cites), comparisons of the profits of firms employing different IT strategies across industries (e.g., Strassman 1990) and work comparing the profits of firms with different IT strategies in the same industry (e.g., Dos Santos and Peffers, 1991). Whichever 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 (1987, 1989, 1991, 1992). 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, indicates that investments in IT in manufacturing industries have been reasonably productive, while the return on IT investments in service industries has been woefully inadequate.

In a widely cited working paper, Loveman (1988) estimated 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 concluded that funds invested in information technologies would have yielded higher returns had they been invested in more traditional forms of capital instead.

Bresnahan's (1985) 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 to have been five times the cost of the technology.

From a policy perspective, the profitability studies are easiest to dismiss 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. The 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 and, as long as IT innovators do realize at least short term profits, may be a taken by policy makers as evidence that consumers benefit from IT investments. (Egan and Wildman, 1992)

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. (Panko, 1991; Baily and Chakrabarti, 1988) 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, if a shipper uses telecommunications to allow a customer to track the progress of a package in the process of delivery, and offers this as a "free" service, the full contribution of IT to the firm's output is likely to be underestimated by the BLS. 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.

This line of reasoning can be extended to argue that some portion of the measured productivity gains in manufacturing are actually a reflection of IT contributions to service sector productivity. Denison (1989) points out that when there are unmeasured productivity gains in intermediate products and services, these will often show up as measured productivity gains at the stage of an industry purchasing these inputs. Over half of the output of the service sector is purchased by manufacturers.

Loveman's econometric production function study of the benefits of IT in manufacturing has been criticized by Baily and Chakrabarti (1988) for relying on comparisons of estimated output elasticities rather than more meaningful marginal product estimates. It should also be noted that the output measurement problems that are the basis of the BLS productivity measures also apply to this production function study. However, because output measurement problems are less severe for manufacturing sector outputs, these criticisms have less force, when applied to Loveman's study.

Bresnahan (1985) uses a model of a competitive market to address the measurement problems just discussed. He uses 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 provides the theoretically useful result that in some circumstances competitive markets can be relied upon to make social benefit-maximizing investments in information technologies. Given these assumptions, his econometric estimates show that benefits to consumers of IT investments by financial services firms were five times IT expenditures. I rederive Bresnahan's optimality result in the next section and elaborate on it to get some feel for the range of circumstances in which it is likely to hold and also to evaluate the sensitivity of his estimate of the benefits of IT in the financial services industry.

III. Modelling the benefits to IT investments

The focus in this section is on modelling IT investment strategies rather than constructing benefits measures that might be estimated. However, it should become clear that modelling exercises of this sort are a necessary prerequisite to reliable empirical assessments of IT benefits.

A closer look at Bresnahan's optimality result

The model developed in this subsection differs from Bresnahan's in its particulars, but not in its essentials. Specifically, the particular representation of the demand function employed was chosen to facilitate the application of the model to cycle time competition that is developed below. The model follows Bresnahan in assuming that the productivity benefits of IT are manifest in direct consumer benefits rather in lower production costs.[1] However, the particular

[1] Spence (1984) shows for a R&D investment model, which is similar to the IT expenditure model developed here, that a cost reduction

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,...,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 $\phi(d_i)$ such that $\phi(0) = 1$, $\phi(\infty) \geq$, and $\phi' < 0$. And define $X = \sum_i \phi(d_i) x_i$.

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 $U'' < 0$. $\phi' < 0$ 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 that 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 that $\phi(d_i) = .6$ and $\phi(d_k) = .3$ and that $x_i = x_k$. Then, even though firms i and k have the same (measured) outputs, i's output is valued at twice k's (as long as the loss of neither has a significant impact on U'). Finally, define p_i to be the price for representative firm i, define I_i to be information

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formulation is isomorphic with a consumer benefits formulation over a wide variety of circumstances.

services purchased on a per period basis by firm i, and represent by c(x,I) be the costs incurred by a firm with output x and information services purchases of 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 for designing its next 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 affect 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. Granted this leeway and the further assumption of symmetry, the problem can be written as

$$\max_{x,I,n} U - ncx - nI,$$

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.

$$U'\phi(d) - c_1 = 0. \quad (1)$$

$$U'\phi'd'x - c_2 = 0. \quad (2)$$

$$U'\phi(d)x - cx - I = 0. \quad (3)$$

Where c_1 and c_2 are the derivatives of c with respect to x and I respectively. Let Π_i be the profit of firm i.

$$\Pi_i = P_i x_i - c(x_i, I_i).$$

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 firms 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 (4) and (5).

$$p_i - c_1 = 0 \tag{4}$$

$$(\partial p_i/\partial l_i)x_i - c_2 = 0 \tag{5}$$

The zero profit condition for a free entry equilibrium is

$$p_i x_i - c_i = 0. \tag{6}$$

Substituting the utility function equivalents for the price expressions in equations (4), (5), and (6) shows them to be the same as (1), (2), and (3), 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.

(4) in combination with (6) 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.[2] 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.

Policy Applications of the Model

If the number of firms is taken as fixed, and we allow for positive spillovers from one firm's IT expenditures to

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2 This would also apply to informative advertising.

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 (1984). 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 extention, these results would also apply to expenditures on information technologies. 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.

The fact that many of the policy problems posed by R&D and IT investments are formally equivalent suggests that researchers interested in information policy could profitably mine the extensive theoretical and empirical literature on R&D productivity.

Unfortunately it probably is not safe to assume that the conclusions derived with models, like this one, of atomistic competition in markets for homogeneous good generalize to other types of markets with different rules governing investments in IT. For example, in an earlier paper

(Wildman, 1991) I examined the economics of information services collectively funded by members of an industry that make it easier for buyers to search among the differentiated offerings of different sellers by comparing product attributes on-line. Real estate multiple listing services are an example. Airline computer reservation services and on-line mortgage shopping services serve similar functions, although the collective nature of the ownership and management relationships may differ from those of MLS's. I found that both over investment and under investment in seach-facilitating networks is possible, depending on the search algorithm employed and the elasticity of demand for the product. In fact, in some circumstances expenditures on IT will exceed the benefits of reduced search costs to buyers, which reduces social welfare.[3] In this situation, IT investments make a negative contribution to social welfare. The variety of welfare results that are possible even in the small number of IT investment models discussed here suggest attempts to provide economy-wide assessments of the benefits

[3] This can happen when buyers employ a two-stage search procedure, using an information service to identify a select pool of sellers most likely to have products well-suited to their tastes, who are then searched again to make a final product selection. When buyers search in this manner, the fact a buyer approaches a particular seller tells the seller that the buyer is likely to place a high value on her product. The seller rationally responds by raising price. This type of search mechanism transfers surplus from buyers to sellers. The amount of surplus redistributed to sellers may exceed the surplus gained by buyers from reduced search costs. In this situation, the net benefits of an industry's expenditures on a search facilitating network may be negative.

of IT are not likely to produce results in which one can have much confidence.

IT and R&D

Extending this model to include R&D along with IT expenditures is fairly straight forward, although I have not had time to complete this part of the analysis. However, it is clear that the Bresnahan's optimality result generalizes to a market with both R&D and IT expenditures, although caveats about cost functions restricting the applicability of this result apply here just as they do to Bresnahan's optimality result.

What becomes obvious when IT and R&D are included in the same model is that for many purposes the two cannot be treated independently. Take the case of product R&D and a broadband network used to facilitate coordination among geographically dispersed members of an R&D team. IT may complement or substitute for expenditures on other R&D inputs, such as personnel. If IT and other inputs are complements, policies to promote IT investments may simultaneously encourage more non IT spending on R&D. Alternatively, if IT substitutes for R&D, policies promoting IT investments, such as IT investment subsidies, may be partially offset by reductions in spending on non IT R&D inputs. Of course policies promoting R&D would have analogous effects on R&D related IT investments.

Cycle time competition: An application of the model with domestic policy and trade implications

Assume that the unmeasured service to which IT contributes is made possible by an increase in the speed with which a firm can respond to market information. This can be interpreted in either of two ways, depending on the planning horizon one wants to analyze. One interpretation would use the product cycle, the amount of time that elapses from the conception of a new product until it is actually brought to market, as the measure of the firm's planning horizon. One of the claimed benefits of IT is that it facilitates coordination between product designers and manufacturing engineers, enabling companies to reduce the time required to bring new products (or new models of their products) to market. For example, suppose that before the application of advanced IT to product design and engineering, it took an automobile manufacturer 5 years to bring a new car model to market and that after IT adoption it took 2 years.

There are at least three types of benefits that the auto maker might realize from a shorter product cycle. (1) product designs could be altered to take advantage of advances in manufacturing techniques and technologies that occur closer to the date of a new car's release; (2) more frequent introduction of new models would enable the firm's product designers and engineers to move down the learning curve for new product development more rapidly; and (3) if tastes change over time and predictions of tastes at any given future date become more accurate the closer one approaches that date, then design specifications will be a closer match to consumer tastes at the time a product is released if cycle times are shorter. It is the third (demand matching) source of benefits that will be explored here because this is a difficult to measure intangible unlikely to be picked up in standard productivity measures.

Alternatively, we might use the inventory cycle, the minimum amount of lead time required to make a unit of the product available to a firm's retail customers at any prespecified date, as a measure of a planning horizon. Here the problem addressed is the speed with which the firm is able to adjust its supply of a given model of its product in response to variation in consumer demand. At least two benefits might be realized from applications of IT to shorten inventory cycle times. (1) With shorter inventory cycles, the amount of inventory that must be held in stock to provide a given amount of insurance against being unable to satisfy customer demands at the time they are expressed is reduced. The reduced opportunity cost of inventory is a savings to the firm, and in a competitive market this would be passed along to customers. (2) With a shorter inventory cycle the firm's retail arm can rely on more current predictions of the level of demand in adjusting its inventory levels, and this could translate into a reduced likelihood that the firm's customers will find its product out of stock when they want it and shorter wait times when it is out of stock. Thus shorter inventory cycles may provide direct benefits to consumers. If the inventory interpretation of the model, the benefits considered will be the intangible benefits to customers just described.

We can employ the model developed above to examine the the effects of a policy promoting IT investments on output levels, prices, information investments, and seller and consumer surplus. 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 (4') and (5'), which are variants of the firm first order conditions, (4) and (5).. The addition of the second term in (1'), which is not in (1), allows for the possibility that firms are not price takers.

$$U'\phi(d) + U''[\phi(d)]^2x - k = 0. \qquad (4')$$

$$U'\phi'd'x - 1 + s = 0. \qquad (5')$$

Taking the total derivatives of (4') and (5') 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, however.[4]

We can take the analysis a few steps further if we are willing to accept the seemingly reasonable assumptions that firms will always increase their investments in IT in response to an increase in the subsidy, s, and that if different firms' IT investments are subsidized to differing degrees, the firms receiving the largest subsidies will always have the largest levels of IT spending. These assumptions are reflected in Figure 1. (Note that while linear inverse demand functions are depicted in Figure 1, the results illustrated do not depend on linearity.)

The three demand functions shown in Figure 1 are all residual demand functions for are representative firm's product. This means that they take as given the levels of output and expenditures on IT for all other firms in the market. Output is represented in physically measurable units—e.g., the number of cars produced and sold—that are not quality-adjusted to reflect the effects on customer satisfaction of differences in product or inventory cycle times. Similarly, price is the price paid per physically measurable unit of output.

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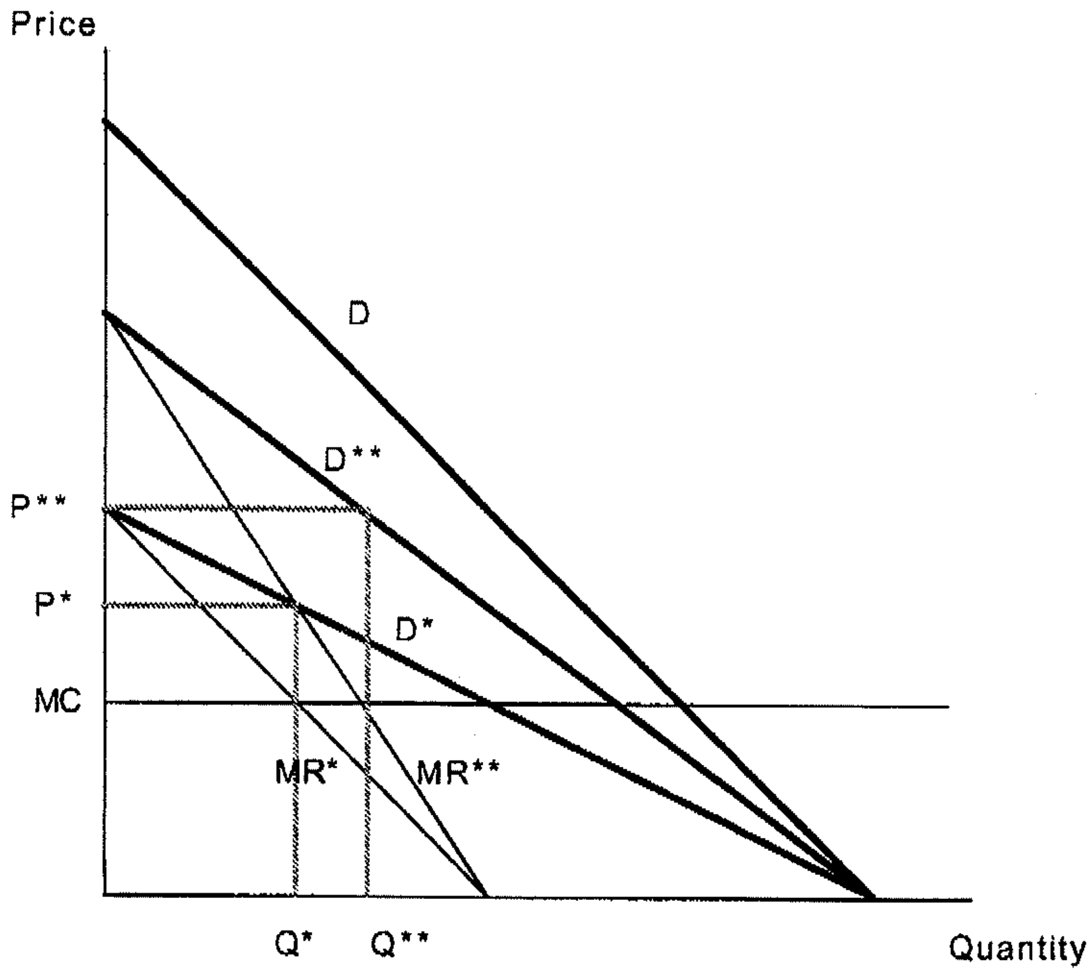
[4] This is because U''', the third derivative of the demand function, appears in the expressions for dI/ds and dx/ds, and this term cannot be signed on purely theoretical grounds.

Figure 1



The specification of the demand function employed for this analysis dictates that as its cycle time increases, the inverse demand function for a firm's product shifts downward, rotating about its intercept on the horizontal axis. If cycle time is reduced by increased IT spending, and if IT spending increases in response to an increase in the subsidy offered this firm, then difference between D** and D* may be interpreted as the demand response to quality improvements (increased customer satisfaction due to reduced cycle time) induced by an increase in the firms IT subsidy from an initial level of s* to the higher level of s**.

Alternatively, we might assume that instead of representing alternative potential inverse demand functions for a single firm, D* and D** are representative of the situations of two classes of firms, with the firms in the two classes assumed identical in every respect except for the level of their IT subsidies.[5] Firms receiving the larger subsidy, s**, will maximize profits with respect to D**. Firms receiving s* will maximize profits with respect to D*. Q**,P** and Q*,P* are the associated profit maximizing prices and quantities. The firms receiving the larger subsidies will both sell more and charge higher prices than the firms with the lower subsidies.

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[5] This graphical characterization of this situation is reasonably accurate if the number of firms is relatively large.

The trade implications of this analysis are quite obvious. s* and s** could represent the IT investment subsidies of two countries whose firms compete in an open international market. Firms from the country with the larger subsidy will have higher unit sales and be able to command higher prices than the firms from the country with the lower subsidy. The difference between s** and s* shifts unit sales and revenues to the country with the higher subsidy. Of course in this analysis the variable s could be used to reflect the influence of policies other than direct IT subsidies that increase the returns to firms' IT investments. The creation of a public telecommunications infrastructure that complements private IT investments is one possibility.

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