

Electronic Data Interchange: Competitive Externalities and Strategic Implementation Policies

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Electronic Data Interchange (EDI) is an emerging type of standardized inter-organizational information system. We analyze the impact of EDI on the upstream suppliers' competitive position in a simple two-level hierarchical market structure where the buyer faces a linear demand curve and the competing heterogeneous suppliers have an upward-sloping marginal cost function. We show that a supplier's adoption of EDI can generate positive externalities for the buyer and negative (or competitive) externalities for other suppliers. As a result, the buyer provides a price premium to those suppliers who adopt EDI and increases their sales volume and market share. Moreover, when the benefits that the buyer can derive from implementing EDI are substantial, and the suppliers' EDI adoption costs are high, it may be in the buyer's best interest to subsidize the suppliers so as to encourage them to adopt EDI, instead of mandating them to do so. Regardless of whether the buyer employs a mandatory or a subsidizing policy, the buyer and the end consumers may be the only ones who gain from this new technology. Consequently, a partial adoption by the supplier base may be optimal for the buyer when the suppliers' adoption costs are sufficiently high. We also show that, while EDI reduces the transaction costs of the buyer, the upstream market tends to become more concentrated as a result of increased cost differentials. These results provide one economic explanation of the fact that many companies have actually reduced their supplier base after implementing EDI, despite a significant reduction in their market transaction costs.

(Electronic Data Interchange; Competitive Externalities; EDI Adoption; Implementation Policies of Interorganizational Information Systems)

1. Introduction

Information and communication technologies have shortened business transaction cycles in virtually every industry and made time factors more important than ever before. Fierce global competition has also put a premium on sharing information among product designers, manufacturers, and distributors. As a result, companies need to tie the information flow through their entire value chain, from raw materials and subassembly purchasing, R&D, and manufacturing to distribution,

marketing, and after-sales product support (Cash and Konsynski 1985, Clemons and McFarlan 1988, Gurbaxani and Whang 1991). The establishment of inter-organizational information systems (IOS) (Barrett and Konsynski 1982) enables trading parties to be more responsive to a dynamic business environment by providing timely information sharing. An organization's information system is thus no longer merely a computing device for facilitating internal information processing activities; it is emerging as a crucial means of

facilitating business strategies. Successful applications of information technology in achieving competitive gains are abundantly documented in the business press and the academic journals, including the dramatic success of American Airline's SABRE (Hopper 1990), American Hospital Supply's ASAP (Runge 1988, Corey 1985), and McKesson Drug's Economost and Econotone (Corey 1985, Clemons and Row 1988).

Electronic Data Interchange (EDI) provides the common platforms by which trading partners can perform *inter-company, computer-to-computer* exchange of business documents in standard formats (Hinge 1988). EDI systems provide such widely cited benefits as reductions in paperwork, personnel and inventory costs, order lead time, and data errors (Carter and Fredendall 1990, *Computerworld* 1986, *Datamation* 1990, Davis 1989, Emmelhainz 1990, Hinge 1988, Kelleher 1986, Sokol 1988, Stern and Kaufmann 1985). Indeed, EDI can help reduce inventory overhead and speed products to the marketplace. Consequently, establishing EDI links between trading partners may have a significant impact on firms' inventory policies and manufacturing practice (Bakos 1990, Powell and Pyke 1990). Kekre and Mukhopadhyay (1990) investigate the effects of EDI transactions on the inventory, product quality, and lead-time performance of 65 outside suppliers dealing with one of the major steel producers in America. Their findings highlight EDI's ability to synchronize manufacturing and mitigate the negative impacts of process uncertainties.

The rapid deployment of EDI and its well-documented impact on the manufacturing world raise many important managerial issues. Should a major buyer such as WalMart (Schiller 1992) mandate its suppliers to adopt EDI, or should it provide some incentives through subsidies in order to encourage its suppliers to adopt EDI voluntarily? In this paper we attempt to answer these questions through a simple two-level hierarchical model with one buyer and a number of heterogeneous competing suppliers.

The recent paper by Riggins et al. (1991) develops a novel model of network externalities with competing participants. The authors model the users' willingness to pay for participating in the network by a U-shaped willingness-to-pay function that depends on the number of other network participants. This approach extends

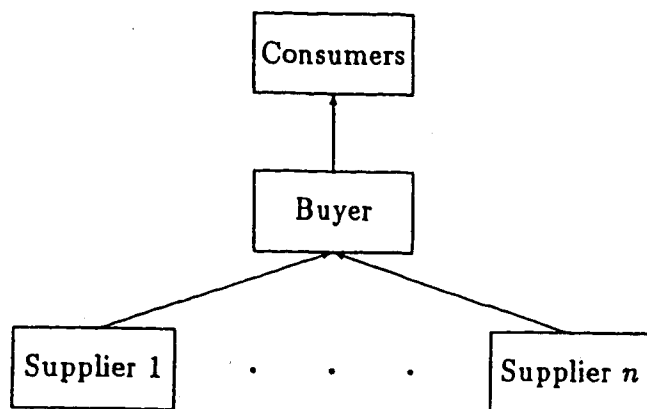
the line of research exploring the "critical mass" and "start-up" problems of networks (see, e.g., Markus 1990; Oren and Smith 1981; Rohlfs 1974). All these studies assume that the identity of a particular user has no impact on other users' willingness to join a communication network; only the total number of participants matters, and typically an individual's willingness to join is increasing in proportion to the number of participants (i.e., the system exhibits positive externalities). For many EDI networks, however, the participants are either trading partners or competitors, and therefore the identity of the participants plays a critical role in determining any individual firm's willingness to join. In our model we explicitly recognize the possible heterogeneity of suppliers due to both productivity and the sophistication of their in-house information systems. Thus the suppliers' willingness to pay for participation is endogenous and depends on trading quantities and prices, EDI implementation costs, and the number and identity of participants. In our model each supplier's willingness to join is explicitly derived from its net gains in doing so, given the structure of the new competitive environment it would enter. As a result, we are able to examine how the buyer should optimally recruit its electronic trading partners as well as the impact of EDI on suppliers' market share and profitability.

The plan of our paper is as follows. We formulate our model in §2 and derive the suppliers' initial upstream market structure in the absence of EDI technology in §3. Using this initial market structure as a benchmark enables us to examine the effects of EDI technology. The positive and negative effects of EDI on the trading partners are studied in §4. Section 5 evaluates two policy options for the buyer, namely financial subsidies and mandatory adoption of EDI. In §6, we summarize our main research results and discuss potential extensions. Appendix A summarizes the major notations, and Appendix B contains all the proofs of the theorems.

2. The Hierarchical EDI Model

In this section we introduce our model and use it to evaluate potential externalities caused by the introduction of EDI. We focus on a hierarchical model consisting of one buyer and n suppliers, S_i , $i \in N = \{1, \dots, n\}$. These n suppliers produce a homogeneous intermediate

Figure 1 The Basic Industry Structure Studied



product used by the buyer to produce a final product for sale in the market; see Figure 1. We assume the buyer is the sole buyer of the intermediate product produced by these n upstream suppliers.¹

The buyer may be a monopolist possessing a patented technology that is essential in producing the final product, or a regional monopolist offering a differentiated product in an oligopolistic market. For simplicity, we assume that the buyer is a monopolist with no short-term threat of entry into its market and faces a linear (inverse) demand function.²

ASSUMPTION 1. *The consumers of the final product have an aggregate inverse demand function: $w(x) = a - bx$, where x is the number of units consumed and a and b are some positive real numbers.*

Prior to the introduction of EDI, the buyer and the set of n suppliers are assumed to have a well-established buyer-supplier relationship. This condition is typical in industries such as automobile and computer hardware manufacturing, which rely on a large number of subcontractors. Although we assume the buyer plays a dominant role in this buyer-supplier relationship and knows each supplier's cost function, we do not assume

¹ Even if the buyer is not the suppliers' sole buyer, it may be their most important customer, and it therefore would have most of the bargaining power. This phenomenon is not unusual, for example, in the retail industry (Schiller 1992).

² The reasons for the buyer's ability to persist in its monopolistic power through R&D and the patent system are beyond the scope of our paper. Readers interested in this aspect should consult Leininger (1991) and the references therein.

it possesses all the bargaining power required to extract all the suppliers' profits. For simplicity, we restrict the buyer's bargaining power by assuming that it can only quote a linear purchase price for the intermediate product to each supplier.³ Given the prices quoted by the buyer, each supplier determines the quantity it is willing to supply. That is, the buyer can only offer a fixed unit price, p_i , which is the same for all units purchased from supplier S_i . Of course, p_i can be different from p_j for $j \neq i$.

We assume that the quality of the intermediate product delivered and the timeliness in fulfilling the buyer's orders are the same across all suppliers. For expositional convenience, we make the following simplifying assumption regarding the suppliers' production cost functions:⁴

ASSUMPTION 2. *Each supplier S_i has a common knowledge cost function, $c(x_i, v_i) = \phi(v_i)x_i^2 + \gamma x_i$, with $\phi(v_i) > 0$ for all $i \in N$, where x_i is the quantity of intermediate product produced by S_i , $\phi(v_i)$ is a strictly increasing function with v_i parameterizing supplier S_i 's productivity, and $\gamma =$ some nonnegative real number characterizing the suppliers' basic technology. Without loss of generality, we index the suppliers in ascending order of v_i 's (i.e., $v_1 \leq v_2 \leq \dots \leq v_n$).*

The suppliers are assumed to have the same production technology exhibiting diseconomies of scale, but they are heterogeneous with respect to their productivity. The diseconomies of scale in producing the intermediate product incorporate the suppliers' limited

³ Our pre-EDI solution represents the "quasi-competitive" equilibrium in an oligopolistic supplier market (Henderson and Quandt 1980, p. 200). Moreover, if the buyer is able to offer nonlinear price schedules, it can extract all the suppliers' profits. In this circumstance, the only feasible policy for the buyer is to subsidize all the adoption costs of its electronic trading partners. For this case, we can nevertheless analyze the impact of EDI on the suppliers' market shares.

⁴ Although the assumed cost function seems to be restrictive, it can approximate a wide range of production technologies. For example, by setting $\gamma = 0$, we can consider the suppliers' production cost function as a result derived from the generalized Cobb-Douglas production technology; see, e.g., Varian (1984). Assumptions 1 and 2 together allow us to give a fuller exploration of the problem analytically. After performing many numerical experiments, we expect most of our main results to hold with more general demand and production cost functions.

capacity, since it is not unusual for a manufacturing system to yield a higher defect rate and experience excessive queueing delays or inventory buildup as the production rate approaches its capacity.

The buyer is assumed to have a constant return to scale technology to transform one unit of the intermediate product into one unit of the final product; without further loss of generality, this production cost is normalized to zero. Implementing EDI can provide the buyer with many operational benefits. These include higher processing speeds for issuing orders, integration of time-critical business processes, reduced safety stocks, and an increase in the accuracy and efficiency of logistical operations (Kreuwels 1992).

ASSUMPTION 3. *By installing an EDI system, the buyer realizes an operational savings of θ for every unit of the intermediate product purchased.*

All other production-related costs of the buyer are normalized to zero without further loss of generality. This assumption implies that the *direct* benefits of implementing EDI accrue solely to the buyer. Suppliers' adoption of EDI will thus generate *positive externalities* to the buyer. This approximates the fact that the benefit from implementing EDI increases with transaction volume (Hinge 1988). As will be shown later, the suppliers installing EDI can also benefit *indirectly* from it. Their benefits include a larger quantity purchased and a higher unit price paid by the buyer.

Moreover, if supplier S_i adopts EDI, we assume that it will incur an EDI adoption cost of e_i for each period. This cost includes security and syntax control, network services, file translation from the EDI to the in-house format, etc. Depending on the capability of their in-house information system function, the suppliers' EDI adoption costs can vary greatly. The buyer will also incur some costs from implementing EDI, since the development and maintenance of special translation software to interface with a trading partner's proprietary format can be costly (Kelleher 1986; Leinfuss 1990). Yet the complexity of managing and maintaining an additional protocol is roughly the same regardless of the volume of the traffic supported by that protocol. As a result, we assume that the buyer's EDI implementation cost is an increasing, weakly convex function of the number of EDI-linked suppliers but independent of the

identity of the suppliers. Let $e_b(m)$ denote the buyer's cost per period for implementing EDI when there are m suppliers transacting electronically with it through EDI. The following assumption summarizes the costs related to implementing EDI.

ASSUMPTION 4. *The cost associated with adopting EDI for supplier S_i is e_i , $i \in N$, per period. The buyer's cost function for supporting electronic trading with m suppliers through EDI is $e_b(m)$, which is assumed to be increasing and weakly convex.*

3. The Pre-EDI Supplier Base

This section derives the economically optimal pre-EDI supplier base, given our restriction on the buyer's bargaining power. The resulting market structure serves as a benchmark for facilitating our later analysis of the effects of EDI. The buyer's initial supplier base, N , is assumed to be a result of the buyer's optimization.

In our model, there are two levels in the hierarchy of decision making—one leader, the buyer, and a set N of followers, the n competing suppliers. Since the buyer plays a dominant role in this buyer-supplier relationship, we derive the initial supplier base in the Stackelberg fashion. That is, the buyer has the market power to commit to a certain procurement rule and the suppliers can only respond to it. (See Basar and Olsder 1982 for more details on solution concepts of a hierarchical nature.) Recall that the buyer can only offer a linear price schedule. Given p_i , the price offered by the buyer, supplier S_i is in fact facing a constant marginal revenue function p_i , and thus S_i 's profit is:

$$\pi_i(p_i, v_i) = \max_{x_i \geq 0} \{ p_i x_i - c(x_i, v_i) \}. \quad (3.1)$$

From the first-order condition, it is clear that supplier S_i 's supply function

$$x_i(p_i, v_i) = \frac{p_i - \gamma}{2\phi(v_i)},$$

and thus

$$\pi_i(p_i, v_i) = \frac{(p_i - \gamma)^2}{4\phi(v_i)}.$$

Given the n supply functions, $x_i(p_i, v_i)$, and the consumers' (inverse) demand function, $w(x)$, the buyer

determines the optimal prices to quote, or equivalently the quantities to purchase. Thus, the buyer's profit is

$$\Pi^0(V) \equiv \max_{x_i \geq 0, i \in N} \left\{ xw(x) - \sum_{i=1}^n \{ [p_i(x_i, v_i) + \theta]x_i \} \right\}, \quad (3.2)$$

where $V \equiv (v_1, \dots, v_n)$ is the suppliers' productivity profile, and $x \equiv \sum_{i=1}^n x_i$. It is clear that from Assumptions 1 and 2 an interior solution to (3.2) exists if $a - \gamma - \theta > 0$, or if the demand for the final product is strong enough. Assume this is the case; then the following first-order conditions are necessary and sufficient to characterize the buyer's optimal quantity purchased from each of its suppliers:

$$\begin{aligned} 0 &\equiv w(x^0) + x^0 \frac{dw(x^0)}{dx^0} \\ &\quad - \frac{\partial p_i(x_i^0, v_i)}{\partial x_i^0} x_i^0 - p_i(x_i^0, v_i) - \gamma - \theta \\ &= a - 2bx^0 - 4\phi(v_i)x_i^0 - \gamma - \theta \quad \forall i \in N, \end{aligned} \quad (3.3)$$

where $x^0 \equiv \sum_{i=1}^n x_i^0$. Since $x_i = (p_i - \gamma)/2\phi(v_i)$, the optimal prices quoted by the buyer are identical across suppliers:

$$p_i^0(x^0) = p^0(x^0) \equiv \frac{a + \gamma - \theta - 2bx^0}{2}$$

for all $i \in N$. At the optimum, the buyer's marginal rates of substitution among quantities supplied by all suppliers must be the same. Although the prices are the same across all suppliers, the higher the v_i , the smaller the quantity S_i will supply. Since

$$x = \sum_{i=1}^n \frac{p^0(x) - \gamma}{2\phi(v_i)} = \frac{(p^0(x) - \gamma)\Phi}{2}, \quad (3.4)$$

where $\Phi \equiv \sum_{i=1}^n \phi(v_i)^{-1}$, the price that can support the quantity x is $p^0(x) = 2x/\Phi + \gamma$, and then from (3.3) we can write the buyer's marginal cost function as a function of x :

$$MC^0(x) = 4\phi(v_i)x_i^0 + \gamma + \theta = 4x/\Phi + \gamma + \theta. \quad (3.5)$$

Because of the typical (short-run) diseconomies of scale in the suppliers' production technology (Varian 1984), the unit price of the intermediate product will be higher if the buyer wants to purchase more, and therefore both

$p(x)$ and $MC^0(x)$ are upward-sloping as shown in Figure 2. Letting $MR(x)$ denote the buyer's marginal revenue function: $a - 2bx$, then (3.3) reduces to the simple optimality condition: $MR(x) = MC^0(x)$, or

$$a - 2bx = \frac{4x}{\Phi} + \gamma + \theta. \quad (3.6)$$

So the total amount purchased by the buyer is

$$x^0 = \frac{\Phi(a - \gamma - \theta)}{2(2 + b\Phi)} \quad (3.7)$$

and the optimal quantity purchased from supplier S_i is

$$x_i^0 = \frac{a - \gamma - \theta}{2\phi(v_i)(2 + b\Phi)}. \quad (3.8)$$

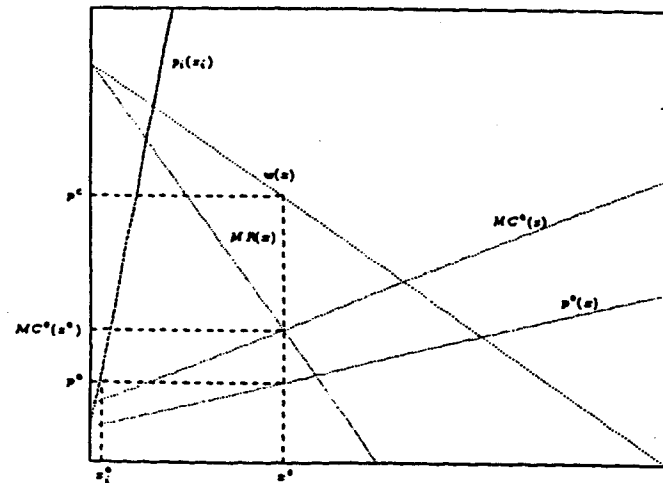
Figure 2 shows the interaction among $MR(x)$, $MC^0(x)$, $p^0(x)$, and $p_i(x_i)$.

Note that x_i^0 depends on the shape parameters of the consumers' demand function, a and b , on the buyer's potential savings, θ , and on the supplier's productivity function, $\phi(v_i)$. However, the suppliers' market share

$$MS_i^0 \equiv \frac{x_i^0}{x^0} = \frac{\phi(v_i)^{-1}}{\Phi} \quad (3.9)$$

depends solely on the suppliers' productivity profile, V . Thus, if we view $\phi(v_i)^{-1}$ as the index of S_i 's productivity, the market share of S_i is simply the fraction of the aggregate productivity of all suppliers. Furthermore, we can show that the profits of S_i and the buyer are

Figure 2 Schematic of the Pre-EDI Stackelberg Equilibrium



$$\pi_i^0 = \frac{(a - \gamma - \theta)^2}{4\phi(v_i)(2 + b\Phi)^2} \quad \text{and} \quad (3.10)$$

$$\Pi^0 = \frac{\Phi(a - \gamma - \theta)^2}{4(2 + b\Phi)} \quad (3.11)$$

respectively.

4. The Effects of EDI

We seek in this section to derive the optimal set of suppliers that the buyer should request (or possibly force) to adopt EDI. However, before doing that, we first study the impact of EDI in a case with m suppliers who have already adopted EDI. We then define the subset of suppliers who have adopted EDI as the *adopters* and the remaining suppliers as the *non-adopters*. Our analysis of the effects of EDI is done in two stages. The first stage (§4.1) ignores the EDI costs of both the buyer and the suppliers and analyzes a network having m arbitrary adopters, $m \in \{1, \dots, n - 1\}$. This stage serves as a benchmark case for facilitating our study of the impact of EDI adoption costs. In the second stage (§4.2), we reintroduce the EDI adoption costs and investigate the buyer's two EDI implementation policies, namely the *mandatory policy* and the *subsidizing policy*, for selecting the optimal subset of suppliers to participate in its EDI program.

4.1. Partial Adoption with m Arbitrary Suppliers

Letting the subset of suppliers $M \subset N$ be an arbitrary set of adopters, and letting the complementary set, $J = N \setminus M$, be the set of nonadopters, then the buyer's profit from production is:

$$\Pi(M, V) = \max_{\substack{x_i, i \in M \\ x_j, j \in J}} \left\{ xv(x) - \sum_{i \in M} p_i(x_i, v_i)x_i - \sum_{j \in J} [p_j(x_j, v_j) + \theta]x_j \right\}, \quad (4.1)$$

where again $p_i(x_i, v_i) = 2\phi(v_i)x_i + \gamma$. For expositional simplicity, we assume that a is sufficiently large that the buyer will still be willing to buy from a supplier even when it is the only non-adopter (unless the buyer employs a mandatory policy, as will be discussed in §4.2). Formally, we make the following assumption:

ASSUMPTION 5. $2(a - \gamma - \theta) - b\theta\Phi > 0$.

Given Assumption 5, the buyer's problem (4.1) has a unique interior solution given by the following first-order conditions:

$$0 \equiv a - 2bx^N - 4\phi(v_i)x_i^e - \gamma \quad \forall i \in M, \quad (4.2)$$

$$0 \equiv a - 2bx^N - 4\phi(v_j)x_j^n - \gamma - \theta \quad \forall j \in J, \quad (4.3)$$

where the superscripts "e" and "ne" denote adopters and non-adopters, respectively. The first-order conditions (4.2) and (4.3) imply that the same price p^e should be paid by the buyer to all the adopters, that the same price p^n should be paid to all the non-adopters, and that $p^e - p^n = \theta/2$. Thus, following the introduction of EDI, the buyer is willing to offer a price premium of $\theta/2$ to the suppliers who adopt EDI.

Expressing p^e as a function of x :

$$p^e(x) = \frac{2x}{\Phi} + \frac{\theta\Phi^I}{2\Phi} + \gamma,$$

we get the buyer's aggregate marginal cost function:

$$MC^N(x; M, V) = \frac{4x + \theta\Phi^I}{\Phi} + \gamma, \quad (4.4)$$

where $\Phi^I \equiv \sum_{j \in J} \phi(v_j)^{-1}$. From (4.4) and (3.5), we get the optimality condition:

$$\begin{aligned} MR(x) &= MC^N(x; M, V) \\ &= MC^0(x) - \frac{\theta(\Phi - \Phi^I)}{\Phi}. \end{aligned} \quad (4.5)$$

Thus $\theta(\Phi - \Phi^I)/\Phi$ is the positive externality effect of EDI on the buyer's marginal cost. Figure 3 gives the pictorial representation of the current case. It is easy to show that the total quantity purchased by the buyer is

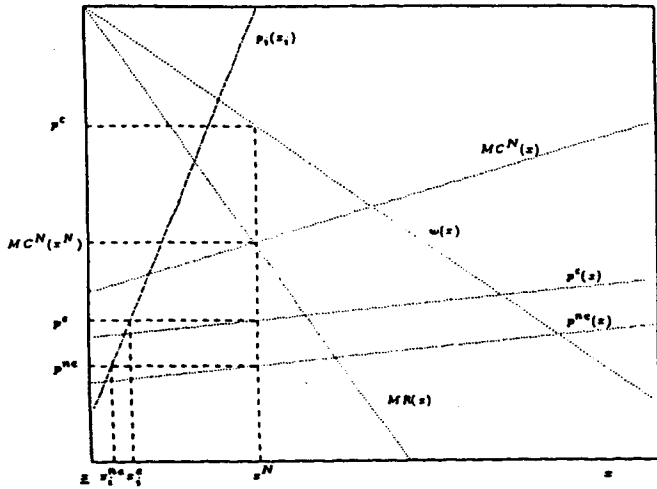
$$x^N(M, V) = \frac{(a - \gamma)\Phi - \theta\Phi^I}{2(2 + b\Phi)}, \quad (4.6)$$

so the optimal quantities purchased from an adopter S_i and from a nonadopter S_j are

$$x_i^e(M, V) = \frac{2(a - \gamma) + b\theta\Phi^I}{4\phi(v_i)(2 + b\Phi)}, \quad (4.7)$$

$$x_j^n(M, V) = \frac{2(a - \gamma - \theta) - b\theta(\Phi - \Phi^I)}{4\phi(v_j)(2 + b\Phi)}, \quad (4.8)$$

Figure 3 The Case of Partial Adoption with m Arbitrary Suppliers, Where x is the Smallest Total Quantity Purchased by the Buyer Such That $x_j^{nc} > 0, \forall j \in J$ if $x > x$



respectively. These results show that both the total quantity purchased by the buyer and the quantity supplied by an adopter increase while the quantity supplied by a non-adopter decreases. As a result, the market share of every non-adopter is unambiguously reduced. Further notice that the purchase prices from both subsets of suppliers, and the quantities purchased, decrease as more and more suppliers adopt EDI. However, the following theorem shows that the incremental quantity purchased from a supplier who adopts EDI is independent of the number of adopters existing in the network.

THEOREM 1. *The incremental quantity that the buyer will purchase from an arbitrary supplier, S_i , if it adopts EDI, is independent of the number of existing EDI adopters. Furthermore, the incremental quantity is decreasing and convex in v_i . (All proofs can be found in Appendix B.)*

From the second part of the theorem, we see that the adoption of EDI has a greater impact on the quantity sold by a supplier if the supplier is more productive. From (4.6)–(4.8), it is easy to see that the relative market share between the adopters and the non-adopters now depends not only on their relative productivity but on the number of EDI adopters as well. As the number of adopters increases (i.e., as Φ^I becomes smaller), non-adopters need more efficient production to keep pace with the adopters.

The profit from production for the adopter S_i is:

$$\pi_i^c(M, V) = \frac{[2(a - \gamma) + b\theta\Phi^I]^2}{16\phi(v_i)(2 + b\Phi)^2}, \quad (4.9)$$

and the profit from production for the nonadopter S_j is:

$$\pi_j^{nc}(M, V) = \frac{[2(a - \gamma - \theta) - b\theta(\Phi - \Phi^I)]^2}{16\phi(v_j)(2 + b\Phi)^2}. \quad (4.10)$$

Clearly $\pi_i^c(M, V)$ is increasing and convex in θ , and $\pi_j^{nc}(M, V)$ is decreasing and convex in θ . We also see from (4.9) and (4.10) that, for any supplier $S_i, i \in M$, its profit decreases as more suppliers adopt EDI, since Φ^I decreases with M . Similarly, for any supplier $S_j, j \in J$, its profit also decreases as more suppliers adopt EDI. Thus, regardless of whether a supplier is an adopter or not, its profitability depends critically on its relative productivity as well as on the number of adopters. In particular, if a supplier adopts EDI, it inflicts some external penalties on all other suppliers in terms of profit reduction. We call this type of externalities “competitive externalities” caused by the suppliers’ adoption of EDI. The following theorem characterizes the effect of competitive externalities on the suppliers’ profit.

THEOREM 2. *The production profit of an arbitrary adopter decreases monotonically with respect to the number of adopters; similarly, the production profit of an arbitrary non-adopter also decreases monotonically with respect to the number of adopters. However, the production profit for an arbitrary supplier when no suppliers adopt will be smaller than that when every supplier adopts.*

Let

$$\{\pi_i^c(M, V), \pi_j^{nc}(M, V) : M \in 2^N\}$$

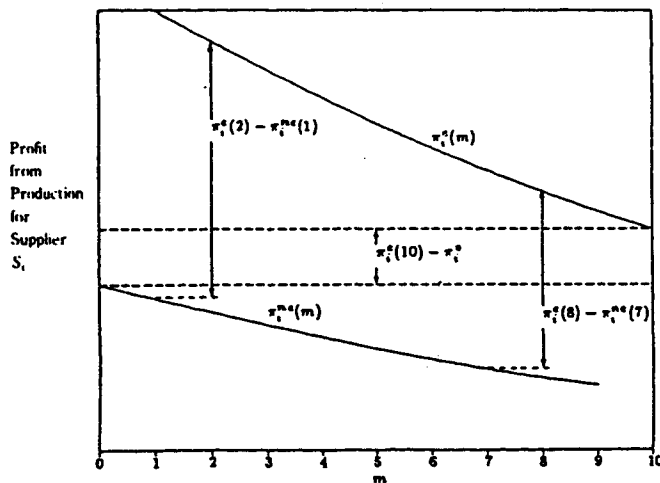
be the “production profit structure” of the upstream industry. Of course, if all the suppliers have the same productivity, the profit structure only depends on the number of adopters and is decreasing and convex in the number of adopters. This type of profit structure arises naturally in the environment that we study. It is similar to the profit structure typically assumed in the literature studying externalities of information goods (see, e.g., Muto 1986, Muto and Nakayama 1988, Nakayama and Quintas 1988a, 1988b).

Our results show that the non-adopters lose their competitive position very rapidly if: (a) there is a large

set of adopters (a large M), (b) the consumers' demand is very elastic (a large b), or (c) the EDI results in a significant reduction of the buyer's cost (a large savings, θ). Figure 4 illustrates the differential effect of competitive externalities on a supplier's profit when it is an adopter and when it is a non-adopter. Apparently, in the costless adoption case, the supplier's profit from production with full adoption ($m = 10$) is greater than that with no adoption ($m = 0$). Thus, if adopting EDI is costless, full adoption is the unique equilibrium. However, as we discussed earlier, adopting EDI may involve a substantial amount of investment on an ongoing basis. Furthermore, a supplier should also consider the competitive externalities caused by other suppliers' adoption of EDI. Each supplier thus faces a situation where the tradeoff between the cost associated with adopting EDI and the competitive position it may lose by not adopting EDI must be evaluated. In the following theorem we show that, as more and more suppliers adopt EDI, the incentive for a non-adopter to adopt reduces, and that adoption by a supplier with low production costs will have a larger negative impact on other suppliers' willingness to adopt.

THEOREM 3. *For a particular supplier S_i , its production profit increment from adopting EDI decreases as the number of adopters increases.*

Figure 4 An Example of Theorems 2 and 3 with Ten Suppliers ($|N| = 10$). Where the Supplier's Profit Functions Are Parameterized by the Number of Adopters m



The incremental profit from adoption is delineated by the vertical lines in Figure 4. These lines get shorter as m increases. In other words, a supplier's marginal incentive for adoption decreases as more and more other suppliers adopt EDI. Although many firms view EDI as a service and productivity-enhancing tool, these advantages can be rapidly eroded by others offering similar services (Stern and Kaufmann 1985).

We next examine the impact of suppliers' adoption on the buyer's profit. The following theorem shows that the buyer's profit $\Pi(M, V)$ increases as more suppliers adopt EDI; however, the marginal increment in the buyer's profit from adding a particular supplier is diminishing.

THEOREM 4. *The marginal contribution to the buyer's profit for a particular supplier's adoption is decreasing in the number of adopters. Consequently, if the buyer adds the suppliers into its EDI program in descending order of their productivity (i.e., increasing in v_i 's), its profit is increasing and concave in the number of adopters.*

Theorem 4 states that it is best for the buyer to have all suppliers participate in its EDI program. However, when the buyer will incur some costs for each additional EDI adopter, it may not be in the buyer's best interest to have all suppliers participate in its program. Furthermore, we have shown above that adoption by a supplier with low production costs can have a larger impact on the buyer's profit, so that the buyer will prefer EDI adoption by the most productive suppliers. On the other hand, it may not be in the best interest of a high productivity supplier to participate if its cost of adopting EDI is sufficiently large. Given these complex interplays, we need to further investigate the buyer's potential implementation policies.

4.2. Recruiting Electronic Trading Partners: The Buyer's Decision Problem

We know from Theorem 4 that the buyer's gross profit will monotonically increase as more and more suppliers are recruited, and that the buyer would prefer recruiting the most productive suppliers. Letting $M(m) = \{1, \dots, m\}$, the following theorem gives the necessary and sufficient conditions for maximizing the buyer's profit without accounting for the suppliers' adoption costs.

THEOREM 5. *The buyer's maximum profit is achieved if and only if the set of adopters is $M(m^*)$, where*

$$m^* \equiv \arg \max_{0 \leq m \leq n} \{ \Pi(M(m), V) - e_r(m) \}.$$

We call $\Pi(M(m^*), V)$ the buyer's *unconstrained maximum* profit. This theorem simply states that the buyer prefers to add the suppliers into its network in ascending order of $\phi(v_i)$'s until the marginal benefit exceeds the marginal EDI implementation cost. However, $\Pi(M(m^*), V)$ may not be achievable in general, since it may not be in the best interest of the suppliers S_i , $i \leq m^*$, to adopt if their adoption costs are sufficiently large. For example, a recent industrial survey found that recruiting electronic trading partners is often the most costly element when a company begins instituting an EDI program (Clark 1990).

To help evaluate the buyer's recruiting policies, we assume the following sequence of actions by the buyer and the suppliers:

1. The buyer commits itself to an EDI implementation policy and determines its new supplier base and the set of suppliers who should adopt EDI based on that policy.
2. The buyer announces its policy and the adoption decision that each supplier remaining in its supplier base should make.
3. Each supplier remaining in the supplier base then decides individually whether or not to adopt EDI.
4. Following on the suppliers' adoption decisions, the buyer determines the optimal quantity to be purchased from each supplier and the corresponding price.

The suppliers make their adoption decisions individually. Also note that the buyer makes its purchase decisions based on the realized adoption decisions of the suppliers remaining in its supplier base. Consequently, in order for any policy to be effective, the buyer must present a self-enforcing policy for all the selected electronic trading partners, so that a supplier will have no incentive to deviate from the buyer's recommendation if all other suppliers do not. It is reasonable to assume that the buyer can refuse a supplier's voluntary adoption if it is not among the set of selected suppliers. For expositional convenience, we normalize all the suppliers' opportunity costs to be zero; suppliers will drop out of the buyer's supplier base if and only if they will incur a loss.

We first analyze a mandatory adoption policy. Here the buyer simply mandates that all suppliers wishing to remain in its supplier base adopt EDI. Of course, a supplier who cannot make a positive profit after adoption will voluntarily drop out of the buyer's supplier base. We then study the subsidizing adoption policy. In this case the buyer provides subsidies to certain suppliers to offset part of their adoption costs.

4.2.1. Mandatory Policy. The mandatory policy can be effective only if the buyer refuses to purchase from the suppliers who are unwilling to adopt EDI. For example, assume that N is the supplier base determined by the buyer and that all suppliers have decided to conform to the buyer's decision to adopt EDI except S_r . Then, if

$$\pi_r^f(N, V) - e_r < \pi_r^{**}(N \setminus \{r\}, V),$$

S_r will not adopt EDI unless the buyer can refuse to trade with S_r .

Under the mandatory policy, the buyer's net profit is:

$$\max_{M \subseteq N} \{ \Pi^f(M, V^M) - e_r(|M|) \} \quad (4.11)$$

subject to

$$\pi_i^f(M, V^M) - e_i \geq 0 \quad \forall i \in M, \quad (4.12)$$

where the superscript "f" denotes the mandatory policy, V^M is the productivity profile of the set of M adopters, and $\Pi^f(M, V^M)$ and $\pi_i^f(M, V^M)$, respectively, are the buyer's and supplier S_i 's gross profits when the buyer's supplier base consists of a set of M adopters. Constraints (4.12) keep suppliers from incurring a loss after adoption.

A mandatory adoption policy can be effective if the suppliers' profits are sufficiently high and/or their adoption costs are sufficiently low. When the suppliers' EDI adoption costs are substantial, they may completely offset the profit of these suppliers, and the buyer may be forced either to give up its EDI plan or to provide subsidies to reduce the suppliers' adoption costs.

4.2.2. Subsidizing Policy. In this subsection, we will show that, even when the buyer has the ability to make a credible commitment not to purchase from those suppliers who refuse to adopt EDI, it may not be in the

buyer's best interest to mandate adoption. Instead, the buyer may be better off providing sufficient incentives (or subsidies) to attract certain suppliers. In reality, we find cases where large firms subsidize their small trading partners for the cost of implementing EDI, at least at the pilot phase (Kelleher 1986; Klein 1992).

We denote by $s_r(M, V)$ the buyer's subsidy to S_r when the set of adopters is M . To successfully employ a subsidizing policy, the buyer must make the selected suppliers at least as well off as when they do not adopt (i.e., the subsidizing structure must be "incentive compatible"). For any supplier S_r that belongs to the set of selected suppliers, M ,

$$\pi_r^s(M, V) - e_r + s_r(M, V) \geq \pi_r^{nc}(M \setminus \{r\}, V);$$

the suppliers' adoption decisions must be "self-enforcing." Thus, with the adopters' profits decreasing in the number of adopters, if the buyer provides a subsidy to a particular supplier, say, S_r , $r \in M$, the profit of all suppliers, S_i , $\forall i \in M$, will be reduced from $\pi_i^s(M, V)$ to $\pi_i^s(M \cup \{r\}, V)$. Consequently, in maintaining "incentive equity" when providing subsidies to the suppliers with high adoption costs, the buyer must assure that all other selected suppliers will not drop off because of the competitive externalities. Therefore, when using a subsidizing policy, the buyer's problem in recruiting its electronic trading partners is:

$$\max_{M \in 2^N} \left\{ \Pi(M, V) - e_b(|M|) - \sum_{i \in M} s_i(M, V) \right\} \quad (4.13)$$

subject to

$$\begin{aligned} \pi_r^s(M, V) - \pi_r^{nc}(M \setminus \{r\}, V) \\ - e_r + s_r(M, V) \geq 0 \quad \forall r \in M. \end{aligned} \quad (4.14)$$

Letting M^s be the optimal set of adopters under this policy, the buyer's selection of the suppliers for implementing EDI is *subsidy-free* if and only if

$$\pi_i^s(M^s, V) - \pi_i^{nc}(M^s \setminus \{i\}, V) - e_i \geq 0$$

for all $i \in M^s$, i.e., if and only if it is in the best interest of all the selected suppliers to adopt even without being subsidized. When full selection is subsidy-free, the buyer can simply request all its suppliers to participate in its EDI program, and conforming to the buyer's re-

quest is also the best response for every supplier if all other suppliers conform. This situation is more likely if the EDI costs ($e_b(\cdot)$ and e_i 's) are small or the benefits to be derived from EDI are sufficiently large.

For the partial selection case, subsidy-free implementation requires:

$$\begin{aligned} \Pi(M^s, V) - \Pi(M^s \setminus \{i\}, V) \\ \geq e_b(|M^s|) - e_b(|M^s| - 1) \quad \forall i \in M^s, \end{aligned} \quad (4.15)$$

$$\begin{aligned} \Pi(M^s \cup \{j\}, V) - \Pi(M^s, V) \\ < e_b(|M^s| + 1) - e_b(|M^s|) \quad \forall j \in N \setminus M^s, \end{aligned} \quad (4.16)$$

$$\pi_i^s(M^s, V) - \pi_i^{nc}(M^s \setminus \{i\}, V) \geq e_i \quad \forall i \in M^s. \quad (4.17)$$

The inequalities (4.15) and (4.16) simply say that the set of selected suppliers, M^s , gives the buyer its unconstrained maximum profit if the implementation is subsidy-free, while the inequalities (4.17) say that the implementation is indeed subsidy-free. This situation is likely to occur when the buyer's marginal implementation cost is very large and the suppliers' adoption costs are very small, so that, even though there are some suppliers who are willing to adopt EDI without being subsidized, the buyer does not want them to adopt because of its high marginal cost to add them. When partial selection is subsidy-free, the buyer may have to restrain certain suppliers from adoption if there is some unselected supplier $S_j \notin M^s$ such that

$$\pi_j^s(M^s \cup \{j\}, V) - \pi_j^{nc}(M^s, V) > e_j, \quad (4.18)$$

$$\begin{aligned} \Pi(M^s \cup \{j\}, V) - \Pi(M^s, V) \\ < e_b(|M^s| + 1) - e_b(|M^s|). \end{aligned} \quad (4.19)$$

Although supplier S_j is willing to adopt EDI without being subsidized, due to the supplier's high marginal cost, the buyer is better off omitting S_j from its EDI program.

When partial or full selection is not subsidy-free and the buyer's marginal profit that can be derived from a particular supplier's adoption is sufficiently high, the buyer will be better off providing explicit or implicit subsidization to that supplier in order to encourage its adoption. For instance, when

$$\pi_j^s(\{j\}, V) - \pi_j^0(V) - e_j < 0 \quad \forall j \in N, \quad (4.20)$$

but there is a supplier S_i such that

$$\begin{aligned} \Pi(\{i\}, V) - \Pi^0 - e_b(1) \\ > e_i - (\pi_i^r(\{i\}, V) - \pi_i^0), \end{aligned} \quad (4.21)$$

the buyer can get a strictly positive improvement on its profit by subsidizing S_i by an amount $e_i - (\pi_i^r(\{i\}, V) - \pi_i^0)$ to encourage adoption.

As we can see, deriving the optimal solution for either the mandatory policy or the subsidizing policy involves solving a nonlinear 0-1 integer programming problem, and therefore the problems are intractable in general. For purposes of exposition we focus in the next section on a special case, where all suppliers have the same productivity.

5. A Special Case: Suppliers with Identical Productivity

In this section we study a case where $\phi = \phi(v^*) = \phi(v_i)$ for all $i \in N$. Since all suppliers have the same productivity and $\Phi = n\phi^{-1}$, we can parameterize all the variables by the number of adopters, m . From Theorem 4, $\Pi(m)$ is strictly increasing and concave. We first consider the case where the buyer employs a subsidizing policy, and then turn to the case where the buyer uses a mandatory policy.

Subsidizing Policy. Since all the suppliers have the same productivity, we can omit the subscripts from the suppliers' profit functions and, without loss of generality, index the suppliers by adoption costs in ascending order, i.e., $e_1 \leq e_2 \leq \dots \leq e_n$. Letting $\Delta\pi(m) = \pi^r(m) - \pi^{m-1}(m-1)$, then if $\Delta\pi(m) - e_r \geq 0$, $\Delta\pi(m) - e_i \geq 0$ for all $i \leq r$. Note that the price offered by the buyer to (and therefore the quantities purchased from) S_i , depends on the total number of adopters and whether or not S_i is among these adopters, but is independent of the subsidies. Further observe that if the buyer wants to induce a "marginal" supplier, say S_{m+1} , to adopt, it is optimal for the buyer to subsidize S_{m+1} by an amount $e_{m+1} - \Delta\pi(m+1)$. Of course, the buyer also must subsidize S_i by an amount $e_i - \Delta\pi(m+1)$ for all $i \leq m$ if $\Delta\pi(m+1) - e_i$ ever becomes negative. Consequently, when there are m selected participants, the subsidy to supplier S_i is:

$$s_i(m) = \max\{0, e_m - \Delta\pi(m)\}, \quad (5.1)$$

and the total subsidy equals $s(m) = \sum_{i=1}^m s_i(m)$. Then the buyer's optimal subsidizing policy can be obtained by solving:

$$\max_{m \in N} \{ \Pi(m) - s(m) - e_b(m) \}. \quad (5.2)$$

Because $\Pi(m)$ is increasing, concave, and $e_b(m)$ is increasing, weakly convex, (5.2) is concave if $s(m)$ is increasing, weakly convex. The following theorem shows that $s(m)$ is indeed increasing and weakly convex.

THEOREM 6. *If all suppliers have the same productivity, the total required subsidy $s(m)$ is increasing and weakly convex in m , the number of adopters.*

From Theorem 6 we know that (5.2) is concave in m , and therefore solving the buyer selection problem amounts to finding the largest index $m_1 \leq n$ such that

$$\Delta\Pi(m_1) - \Delta e_b(m_1) \geq \Delta s(m_1), \quad (5.3)$$

where

$$\Delta\Pi(m_1) = \Pi(m_1) - \Pi(m_1 - 1),$$

$$\Delta e_b(m_1) = e_b(m_1) - e_b(m_1 - 1), \quad \text{and}$$

$$\Delta s(m_1) = s(m_1) - s(m_1 - 1).$$

Hence the optimal set of adopters that the buyer should select is $m^s = \min\{m_1, n\}$.

Mandatory Policy. If the buyer uses the mandatory policy, only the suppliers who are willing to participate in EDI can remain in its supplier base. Under a mandatory policy with a supplier base of size m , it is readily verified that the suppliers' and the buyer's profits are

$$\pi^f(m) = \frac{(a - \gamma)^2}{4\phi(2 + bm\phi^{-1})^2}, \quad (5.4)$$

$$\Pi^f(m) = \frac{m(a - \gamma)^2}{4(2\phi + bm)}, \quad (5.5)$$

respectively. It is obvious that $\pi^f(m)$ is strictly decreasing, convex, and that $\Pi^f(m)$ is strictly increasing, concave. Again, since we index the suppliers by their adoption costs in ascending order, supplier S_m would not drop out of the buyer's supplier base if and only if

$$\frac{(a - \gamma)^2}{4\phi(2 + bm\phi^{-1})^2} \geq e_m.$$

Letting m_1 denote the largest index such that the above inequality holds and letting m_2 denote the largest index such that $\Delta\Pi^f(m) > \Delta e_b(m)$, then the buyer's optimal mandatory policy is to force all suppliers $S_i, i \leq m^f$, to adopt EDI, where $m^f = \min\{m_1, m_2\}$.

5.1. A Numerical Example

To illustrate this special case, we present a case of seven competing suppliers ($n = 7$) with: $w(x) = 20 - x$, $\phi = \frac{1}{2}$, $\gamma = 0$, $\theta = 2$, and $e_b(m) = m$. The sorted vector of suppliers' adoption costs (e_i 's) is:

$$(1, 1.2, 1.4, 1.4, 1.6, 1.8, 2). \quad (5.6)$$

The relevant decision quantities as a function of the number of adopters m are shown in Table 1.

It is clear that $\pi^c(7) > \pi^{nc}(m)$ for all m and that $\Pi(m)$ is increasing and concave. Thus, if all the suppliers' adoption costs are less than $\Delta\pi(7)$, full adoption will occur and this outcome is beneficial to all the parties, since $\Delta\Pi(7) < 1$. When the suppliers' adoption cost profile equals (5.6), full adoption will not occur unless all the suppliers are subsidized by an amount at least as large as $s_c(7)$. However, as will be shown later, full adoption will not be optimal from the buyer's standpoint. To study the impact of adoption costs on the buyer's recruitment of its electronic trading partners and

on the suppliers' decisions to adopt EDI, we first investigate the case where the buyer employs the subsidizing policy.

Subsidizing Policy. From Table 1, we know that the quantities purchased by the buyer from the adopters and from the non-adopters decrease linearly as the number of adopters increases, while the difference between $x^c(m)$ and $x^{nc}(m)$ remains constant. However, the total quantity purchased by the buyer, $x^N(m)$, increases linearly.

Observe that both $\Delta\Pi(m)$ and $\Delta\pi(m)$ are strictly decreasing. As a result, both the marginal incentive for the buyer to include additional suppliers in its EDI network and the marginal incentive for the suppliers to adopt EDI are diminishing. Since $\Delta e_b(m) = 1$ and $\Delta\Pi(7) = 1.625$, the buyer would prefer all suppliers to participate in its EDI program if all the suppliers' adoption costs are sufficiently low that no subsidy is necessary. Under this circumstance, introducing EDI enables the buyer to increase its net profit by $\Pi(7) - 7 - \Pi(0) = 9.625$. However, since $\Delta\pi(7) \approx 0.71094 < e_c$ for all S_i , no supplier has the incentive to adopt EDI if the buyer requests all of them to adopt without subsidies.

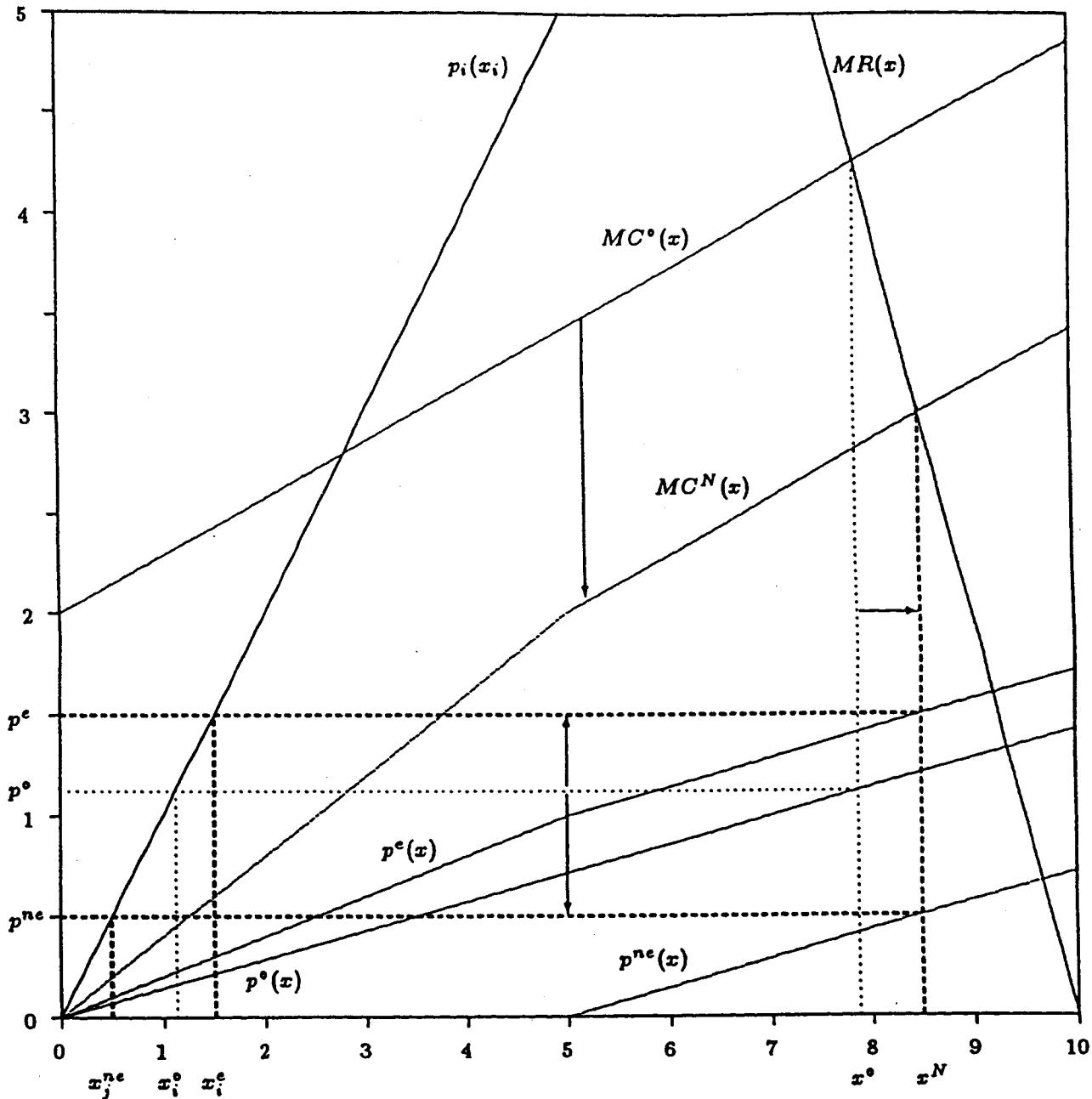
In Figure 5, we compare the no adoption case with the optimal case under the subsidizing policy ($m = 5$). This figure clearly demonstrates the impact of EDI on

Table 1 The Case of Seven Competing Suppliers with Identical Productivity

| m | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|----------------|----------|----------|----------|----------|----------|----------|----------|----------|
| $x^N(m)$ | 7.87500 | 8.00000 | 8.12500 | 8.25000 | 8.37500 | 8.50000 | 8.62500 | 8.75000 |
| $x^c(m)$ | - | 2.00000 | 1.87500 | 1.75000 | 1.62500 | 1.50000 | 1.37500 | 1.25000 |
| $x^{nc}(m)$ | 1.12500 | 1.00000 | 0.87500 | 0.75000 | 0.62500 | 0.50000 | 0.37500 | - |
| $p^c(m)$ | - | 2.00000 | 1.87500 | 1.75000 | 1.62500 | 1.50000 | 1.37500 | 1.25000 |
| $p^{nc}(m)$ | 1.12500 | 1.00000 | 0.87500 | 0.75000 | 0.62500 | 0.50000 | 0.37500 | - |
| $\Pi(m)$ | 70.87500 | 74.00000 | 76.87500 | 79.50000 | 81.87500 | 84.00000 | 85.87500 | 87.50000 |
| $\pi^c(m)$ | - | 2.00000 | 1.75781 | 1.53125 | 1.32031 | 1.12500 | 0.94531 | 0.78125 |
| $\pi^{nc}(m)$ | 0.63281 | 0.50000 | 0.38281 | 0.28125 | 0.19531 | 0.12500 | 0.07031 | - |
| $\Delta\Pi(m)$ | - | 3.12500 | 2.87500 | 2.62500 | 2.37500 | 2.12500 | 1.87500 | 1.62500 |
| $\Delta\pi(m)$ | - | 1.36719 | 1.25781 | 1.14844 | 1.03906 | 0.92969 | 0.82031 | 0.71094 |
| $s(m)$ | - | 0.00000 | 0.00000 | 0.30313 | 0.88281 | 1.95156 | 3.47813 | 5.42344 |
| $\Pi^*(m)$ | 70.87500 | 73.00000 | 74.87500 | 76.19688 | 76.99219 | 77.04844 | 76.39688 | 75.07653 |

m : the number of adopters, $x^N(m)$: the total quantity purchased by the buyer, $x^c(m)$: the quantity sold by an adopter, $x^{nc}(m)$: the quantity sold by a nonadopter, $p^c(m)$: the price offered by the buyer to an adopter, $p^{nc}(m)$: the price offered by the buyer to a nonadopter, $\Pi(m)$: the buyer's profit from production, $\pi^c(m)$: the adopter's profit from production, $\pi^{nc}(m)$: the non-adopter's profit from production, $s(m)$: the total subsidy paid by the buyer, $\Delta\Pi(m) = \Pi(m) - \Pi(m-1)$: the buyer's marginal benefit from incremental adoption, $\Delta\pi(m) = \pi^c(m) - \pi^{nc}(m-1)$: the marginal benefit of a supplier from adoption, $\Pi^*(m) = \Pi(m) - m - s(m)$: the buyer's net profit.

Figure 5 No Adoption vs. the Optimal Adoption ($m = 5$) Under the Subsidizing Policy



the buyer's decision variables. The total quantity purchased increases from x^o to x^N ; the price offered to an adopter increases from p^o to p^e while the price offered to a non-adopter decreases from p^o to p^{ne} . Note the downward shift in the buyer's aggregate marginal cost function and the "kink" at $MC^N(5)$ for $m = 5$. The kink

arises because the two non-adopters will be dropped from the supplier base when the buyer's optimal total quantity purchased is less than 5. From Table 1, it is clear that the total subsidy $s(m)$ is indeed increasing and weakly convex, as asserted by Theorem 6. For a given number of adopters, the subsidy increases in the

order of their adoption costs. In addition, note that S_1 and S_2 get no subsidy if $m = 1$ or 2 . As m increases, so does the subsidy, in order to compensate for reduced profits. From the last row of Table 1, it is obvious that the optimal set of adopters under the subsidizing policy consists of the five suppliers with the lowest adoption costs. In this case, the buyer's net profit is

$$\Pi^*(5) = \Pi(5) - 5 - s(5) = 77.04844.$$

Note that if all five selected suppliers are subsidized, their net profits will be the same:

$$\pi^i(5) - e_i + s_i(5) = \pi^{m^*}(4) = 0.19531$$

for all $i \leq 5$. Although the two unselected suppliers S_6 and S_7 do not have to incur EDI adoption costs, they have an even lower profit: $\pi^{m^*}(5) = 0.125$. Thus, in this particular example, only the buyer and the end consumers benefit from the introduction of EDI.

Of course, if some suppliers' adoption costs are sufficiently low, their profits may actually increase. For instance, in our example, if $e_1 < \pi^*(5) - \pi^0 = 0.49219$, it is straightforward to show that m^* will remain equal to 5, but S_1 's profit will increase. Furthermore, as a result of the introduction of EDI, the market share of each adopter is increased from $\frac{1}{7}$ to $\frac{3}{17}$, whereas the market share of each nonadopter is decreased from $\frac{1}{7}$ to $\frac{1}{17}$.

Mandatory Policy. Note that since $\pi^*(7) = 0.78125 < e_1 = 1$, if the buyer forces all the suppliers to adopt EDI, all of them will incur a loss. As a result, the mandatory policy would not work if the buyer presses all suppliers at the same time without dropping some of the suppliers from its supplier base. Thus we should examine whether or not the buyer's profit can be improved by requiring some of the suppliers to adopt EDI and at the same time dropping the others from its supplier base.

As discussed above, the buyer's implementation costs do not impose any constraint on any policy selected by the buyer. Then, from (5.4), m^f is the largest index such that all suppliers S_i , $i \leq m^f$, will not incur a loss, i.e.,

$$\frac{a^2}{8(1 + bm^f)^2} - e_{m^f} = \frac{50}{(1 + m^f)^2} - e_{m^f} \geq 0.$$

Since the suppliers have the same productivity and are indexed in ascending order of their adoption costs, the buyer should mandate all the suppliers with an index

less than or equal to m^f to participate in its EDI program and drop all other suppliers from its supplier base if $m^f < n$. It is straightforward to show that $m^f = 4$, and then from (5.5) the buyer's net profit:

$$\Pi^f(4) - e_b(4) = \frac{4a^2}{4(1 + 4b)} - 4 = 76,$$

which is smaller than the net profit that the buyer can derive if it employs the subsidizing policy. Thus it may not be optimal for the buyer to force its suppliers to adopt EDI; as shown earlier, providing a proper subsidy can increase its profit. It may be in the buyer's best interest to provide suitable incentives to offset the negative effects of competitive externalities and high adoption costs that EDI imposes on its suppliers. Of course, if the suppliers' adoption costs are such that $e_i < \pi^*(7)$ for all $i \in N$, the buyer's unconstrained maximum net profit is achieved by the mandatory policy, and no subsidization policy can outperform it. For this example, if $e_i < 0.78125$ for all $i \in N$, the buyer's net profit is $\Pi(7) - 7 = 80.5$ when it employs the mandatory policy. The subsidizing policy can achieve this level of profitability if and only if it is subsidy-free even when all seven suppliers are selected (i.e., if and only if $e_i < 0.71094$, $\forall i \in N$). If there was some e_i between 0.71094 and 0.78125, the mandatory policy could have generated a strictly larger profit for the buyer.

Furthermore, since $\pi^f(4) = 2$ for all $i \leq 4$, the adopter's net profit is $2 - e_i \geq 0.4$. Thus, under the mandatory policy, all adopters' profits and market shares are higher than when the buyer uses the subsidizing policy. This phenomenon occurs because under the mandatory policy the buyer's supplier base consists of only four suppliers who share an equal amount of the market, while under the subsidizing policy the buyer's supplier base consists of seven suppliers with five adopters.

6. Concluding Remarks

Prior research on inter-organizational communication networks has centered on developing a theory of "critical mass" (see, e.g., Markus 1990; Oren and Smith 1981; Rohlfs 1974). In these studies, a particular individual's willingness to join the network is independent of the identity of the participants and increasing in the number of participants. In contrast with these models,

we develop a simple two-level hierarchical model for evaluating the competitive externalities created by an EDI network serving a population of heterogeneous participants. Our main focus is on the structure and effects of electronic integration (Venkatraman and Zaheer 1990). Our research contributes to the strategic side of inter-organizational information systems implementation, rather than to modeling and investigating the detailed processes related to EDI.

Our analysis focuses on the potential positive and negative externalities that may be created by the suppliers' adoption of EDI. We show that the buyer's profit from production is strictly increasing in the number of suppliers who have adopted EDI, and adoption by a more productive supplier can have a greater impact on the buyer's profitability. However, the marginal profit increment from a particular supplier's adoption decreases monotonically with the number of adopters.

A supplier's adoption of EDI can increase its own profit from production while at the same time imposing some negative externalities on other suppliers in terms of profit reduction. Consequently, a supplier's incremental profit from production due to adopting EDI is decreasing in the number of EDI adopters, i.e., a supplier's incentive for adoption decreases as more and more suppliers adopt EDI. Nevertheless, if adopting EDI is costless, full adoption is the unique equilibrium. However, a high adoption cost may reduce the suppliers' incentive for adopting EDI at least partially, and a partial adoption equilibrium may result. We show that following the introduction of EDI the buyer offers a price premium to those suppliers who have adopted EDI; the price offered to the non-adopters is lower than it was before EDI. Increased cost differentials due to EDI may cause some inframarginal suppliers to supply less and at a lower price, or to exit from the market if they cannot avoid incurring a loss. As a result, the upstream market will become more concentrated. This result is consistent with the phenomena observed in the real world (Kelleher 1986). However, when the buyer's EDI implementation costs always outweigh the benefits, the presence of EDI technology would have no impact on the profitability of the buyer and its suppliers, or on the market structure. This condition is likely when, for example, the frequency of transactions is low and timely communication is not critical.

Our results also identify circumstances where it may not be optimal for a dominant buyer to mandate its suppliers to adopt EDI; instead, it may be in the buyer's best interest to subsidize its suppliers. A subsidizing policy is likely to be preferred when the buyer can derive a significant reduction of its operating expenses through the use of EDI and when the suppliers' EDI adoption costs are relatively high. We identified several cases where the buyer can reap most of the EDI benefits while leaving the suppliers with minimal profits through subsidies. For example, we reported a case where, despite the buyer's subsidization, all the suppliers' profits are reduced after adopting EDI. The increased surplus is shared by the buyer and the end consumers, at the expense of the suppliers. These results seem consistent with Clemons and McFarlan's (1986) findings in an industry with a dominant distributor.

In our current model, the buyer has perfect information about the suppliers' production and adoption costs. Relaxing the assumption of perfect information and investigating the possibility of designing a truth-revelation type of mechanism for recruiting electronic trading partners will be attempted in future research. Furthermore, since adding new participants into an EDI network generates negative externalities to the suppliers already using the system, the competing suppliers existing in a network may voluntarily provide a quantity discount to the buyer in exchange for blocking out any potential entrants to the system. A further exploration of this "backward subsidizing" and coalition formation case should be a potential research topic. Another natural extension of our model would consider a case with multiple buyers and suppliers. The impact of competition between various buyers with different value-added networks deserves further investigation.

Finally, we recognize the possibility that using general demand function and production technology may invalidate some of our results. An ill-behaved demand function or cost structure may, for example, lead to non-monotonic suppliers' marginal incentives for adopting EDI. Therefore, an adoption equilibrium may be unstable or even fail to exist. Contractual issues, such as exclusive dealing and quantity discount, left out in this paper may also affect our results. Nevertheless, our initial numerical experiments show that the above models should serve well as a starting point for future studies

of EDI with general demand and cost functions, or under more complex contractual arrangements between competing suppliers and the buyer.⁵

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Appendix A Summary of Notations

- N : The set of suppliers $\{1, \dots, n\}$.
- M : The set of suppliers who adopt EDI.
- J : The set of nonadopters $N \setminus M$.
- $\phi(v_i)$: The function that characterizes supplier S_i 's productivity.
- v_i : Supplier S_i 's productivity parameter.
- V : The suppliers' productivity profile (v_1, \dots, v_n) .
- $w(\cdot)$: The consumers' inverse demand function: $a - bx$.
- $c(\cdot)$: The suppliers' production cost function: $\phi(v_i)x^2 + \gamma x$.
- θ : The buyer's savings per unit purchased with EDI.
- c_i : Supplier S_i 's EDI adoption cost.
- $c_b(\cdot)$: The buyer's EDI implementation cost.
- p^0 : The price offered by the buyer when there is no EDI adopter.
- x_i^0 : The quantity sold by supplier S_i when there is no EDI adopter.
- x^0 : The total quantity purchased by the buyer when there is no EDI adopter.
- Π^0 : The buyer's profit from production when there is no EDI adopter.
- π_i^0 : Supplier S_i 's profit from production when there is no EDI adopter.
- Π : The buyer's profit from production.
- π_i^* : The adopter S_i 's profit from production.
- π_j^* : The nonadopter S_j 's profit from production.
- p^* : The price offered by the buyer to the adopters.
- p^{**} : The price offered by the buyer to the nonadopters.
- x_i^* : The quantity sold by the adopter S_i .
- x_j^{**} : The quantity sold by the nonadopter S_j .

Appendix B Proofs

PROOF OF THEOREM 1. It is sufficient to show that the incremental quantity purchased:

$$\begin{aligned} \pi_i^*(M, V) - \pi_i^{**}(M \setminus \{r\}, V) &= \frac{[2(a - \gamma) + b\theta\Phi^I]^2}{16\phi(v_i)(2 + b\Phi)^2} - \frac{[2(a - \gamma - \theta) - b\theta(\Phi - \Phi^I - \phi(v_i)^{-1})]^2}{16\phi(v_i)(2 + b\Phi)^2} \\ &= \frac{[2\theta + b\theta(\Phi - \phi(v_i)^{-1})][4(a - \gamma) - 2\theta - b\theta(\Phi - 2\Phi^I - \phi(v_i)^{-1})]}{16\phi(v_i)(2 + b\Phi)^2} \end{aligned}$$

$$x_i^*(M, V) - x_i^{**}(M \setminus \{r\}, V),$$

is independent of $\Phi^I = \sum_{i \in M} \phi(v_i)^{-1}$. We know that the difference

$$\begin{aligned} x_i^*(M, V) - x_i^{**}(M \setminus \{r\}, V) &= \frac{2(a - \gamma) + b\theta\Phi^I}{4\phi(v_i)(2 + b\Phi)} \\ &\quad - \frac{2(a - \gamma - \theta) - b\theta(\Phi - \Phi^I - \phi(v_i)^{-1})}{4\phi(v_i)(2 + b\Phi)} \\ &= \frac{2\theta + b\theta(\Phi - \phi(v_i)^{-1})}{4\phi(v_i)(2 + b\Phi)} \end{aligned}$$

is independent of Φ^I . Since $\phi(v_i)$ is increasing, the second part of the theorem follows directly from the last expression above. \square

PROOF OF THEOREM 2. For an arbitrary supplier S_i , we first show that the set functions $\pi_i^*(M, V)$ and $\pi_i^{**}(M, V)$ are monotonic with respect to the set of adopters M , i.e., for $M \subset K$

$$\pi_i^*(K, V) < \pi_i^*(M, V),$$

$$\pi_i^{**}(K, V) < \pi_i^{**}(M, V).$$

If $M \neq \emptyset$ and $r \in M$,

$$\pi_i^*(M, V) = \left[\frac{2(a - \gamma) + b\theta\Phi^I}{16\phi(v_i)(2 + b\Phi)} \right]^2,$$

which is decreasing in M since $\Phi^I = \sum_{i \in M} \phi(v_i)^{-1}$ is decreasing in M . Similarly, if $r \in M$,

$$\pi_i^{**}(M, V) = \frac{[2(a - \gamma - \theta) - b\theta(\Phi - \Phi^I)]^2}{16\phi(v_i)(2 + b\Phi)^2},$$

which is also decreasing in M . Furthermore, when $M = N$,

$$\begin{aligned} \pi_i^*(N, V) &= \frac{(a - \gamma)^2}{4\phi(v_i)(2 + b\Phi)^2} \\ &> \frac{(a - \gamma - \theta)^2}{4\phi(v_i)(2 + b\Phi)^2} = \pi_i^0 \end{aligned}$$

for $\theta > 0$, and when $M = \{i\}$ for some S_i ,

$$\pi_i^0 > \frac{[2(a - \gamma - \theta) - b\theta\phi(v_i)^{-1}]^2}{16\phi(v_i)(2 + b\Phi)^2} = \pi_i^{**}(\{i\}, V)$$

for $\theta > 0$, where $r \neq i$. \square

PROOF OF THEOREM 3. It is sufficient to show that

$$\pi_i^*(M, V) - \pi_i^{**}(M \setminus \{r\}, V)$$

decreases as M increases, where $r \in M$. But

Since Φ^j decreases as M increases, the last expression decreases as M increases. \square

PROOF OF THEOREM 4. Given the set of suppliers, N , and the set of adopters, $M(m)$, we can write all the quantities and prices as functions of Φ^j alone. Since

$$p^r = \frac{2x^N}{\Phi} + \frac{\theta\Phi^j}{2\Phi} + \gamma \quad \text{and} \quad p^r = p^m + \frac{\theta}{2},$$

it is straightforward to show that the buyer's profit equals:

$$\begin{aligned} \Pi(x^N(\Phi^j), \Phi^j) &= ax^N(\Phi^j) - bx^N(\Phi^j)^2 \\ &\quad - \left(\frac{4x^N(\Phi^j) + \theta\Phi^j + 2\gamma\Phi}{2\Phi} \right) \\ &\quad \times \left(x^N(\Phi^j) + \frac{\theta\Phi^j}{4} \right) - \frac{\theta\Phi^j}{4} \left(\frac{\theta}{2} + \gamma \right). \end{aligned}$$

Since the number of adopters only affects Φ^j , if we relax the discrete constraint on Φ^j , it is sufficient to show that

$$\frac{d\Pi(x^N(\Phi^j), \Phi^j)}{d\Phi^j} < 0 \quad \text{and} \quad \frac{d^2\Pi(x^N(\Phi^j), \Phi^j)}{d\Phi^j{}^2} < 0.$$

By the envelope theorem,

$$\begin{aligned} \frac{d\Pi(x^N(\Phi^j), \Phi^j)}{d\Phi^j} &= \frac{\partial\Pi(x^N(\Phi^j), \Phi^j)}{\partial\Phi^j} \\ &= -\frac{\theta x^N(\Phi^j)}{\Phi} - \frac{\theta^2\Phi^j}{4\Phi} + \frac{\theta^2}{8} \\ &= \frac{-\theta[4a - 4\gamma - 2\theta - b\theta(\Phi - 2\Phi^j)]}{8(2 + b\Phi)}. \end{aligned}$$

It is readily verified that the last expression above is negative provided Assumption 5 holds. Since

$$\frac{d^2\Pi(x^N(\Phi^j), \Phi^j)}{d\Phi^j{}^2} = \frac{-b\theta^2}{4(2 + b\Phi)} < 0,$$

$\Pi(x^N(\Phi^j), \Phi^j)$ is increasing and concave in Φ^j . \square

PROOF OF THEOREM 5. Recall that we have indexed the suppliers in ascending order of v_i 's and $\phi(\cdot)$ is increasing. Then the theorem follows directly from Theorem 4. \square

PROOF OF THEOREM 6. First, we can show that, for an arbitrary supplier S_i ,

$$\begin{aligned} \Delta\pi(m) &= \pi^r(m) - \pi^m(m-1) \\ &= \frac{\theta[2 + b\phi^{-1}(n-1)][2(2a - 2\gamma - \theta) + b\theta\phi^{-1}(n-m+1)]}{16\phi(2 + b\phi^{-1})^2}, \end{aligned}$$

which is linear in m . Thus, by adding one additional supplier into the set of adopters, the marginal benefit for a supplier to adopt decreases by:

$$\beta = \frac{2b\theta^2[2 + b\phi^{-1}(n-1)]}{[4(2\phi + b\theta)]^2}.$$

Let \bar{k} be the smallest index such that $s_i(\bar{k}) > 0$. Then $s(\bar{k}-1) = 0$. If $\bar{k} \geq n$, we are done. Now suppose that $1 \leq \bar{k} < n$. Letting k^1 be the

smallest index smaller than \bar{k} such that $s_{i+1}(k^1) > 0$, then for all $i \in \{k^1, \dots, \bar{k}\}$, $s_i(\bar{k}) > 0$. Then when $k = \bar{k} + 1$, for all $m \in \{k^1, \dots, \bar{k}\}$, $s_i(\bar{k} + 1) = s_i(\bar{k}) + \beta$ and $s_{i+1}(\bar{k} + 1) \geq s_i(\bar{k}) + \beta$ since $c_{i+1} \geq c_i$. Again, letting k^2 be the smallest index smaller than k^1 such that $s_{i+2}(k^2) > 0$, then we know that $s_i(\bar{k} + 1) \leq \beta$, $\forall i \in \{k^2, \dots, k^1\}$. Since the number of suppliers needing subsidies is increasing (including the last supplier added to the set of adopters) and

$$s_{i+r}(\bar{k} + r) < s_{i+r+1}(\bar{k} + r + 1),$$

we know that

$$s(k) - s(k-1) \leq s(k+1) - s(k)$$

for all $k \in \{1, \dots, n-1\}$. That is, $s(k)$ is increasing and weakly convex in k . \square

References

- Bakos, J. Y., "Information Channel Performance: Implications for Interorganizational Information Links," GSM Working Paper No. IS90016, University of California, Irvine, 1990.
- Barrett, S. and B. Konsynski, "Inter-Organization Information Sharing Systems," *MIS Quarterly*, Special Issue (1982), 93-105.
- Basar, T. and G. J. Olsder, *Dynamic Noncooperative Game Theory*, New York: Academic Press, 1982.
- Carter, J. R. and L. D. Fredendall, "The Dollars and Sense of Electronic Data Interchange," *Production and Inventory Management Journal*, Second Quarter, (1990) 22-25.
- Cash, J. and B. Konsynski, "IS Redraws Competitive Boundaries," *Harvard Business Review*, 63, 2 (1985) 134-142.
- Clark, S., "How to Recruit Trading Partners," *Datamation*, November 1 (1990) 75-76.
- Clemons, E. K. and F. W. McFarlan, "Telecom: Hook Up or Lose Up," *Harvard Business Review*, 64, 4 (1986) 91-97.
- Clemons, E. K. and M. Row, "McKesson Drug Company: A Case Study of Economost—A Strategic Information System," *Journal of Management Information Systems*, 5, 1 (1988) 36-50.
- Computerworld, "EDI Linked to Just-in-time Manufacturing at Navistar," Interview, September 22, 1986.
- Corey, E. R., "The Role of Information and Communications Technology in Industrial Distribution," in *Marketing in an Electronic Age*, Buzzell, R. D. (ed.), Harvard Business School Press, 1985, 29-51.
- Datamation, "Why EDI?" March 26 1990, 82.
- Davis, L., "Retailers Go Shopping for EDI," *Datamation*, March 1989, 53-55.
- Emmelhainz, M. A., *Electronic Data Interchange: A Total Management Guide*, New York: Van Nostrand Reinhold, 1990.
- Gurbaxani, V. and S. Whang, "The Impact of Information Systems on Organizations and Markets," *Communication of ACM*, 34, 1 (1991) 59-73.
- Henderson, J. and R. Quandt, *Microeconomic Theory: A Mathematical Approach*, 3rd Ed., McGraw-Hill, New York, 1980.
- Hinge, K. C., *Electronic Data Interchange: From Understanding to Implementation*, American Management Association, 1988.

- Hopper, M. D., "Rattling SABRE—New Ways to Compete on Information," *Harvard Business Review*, May–June 1990, 118–125.
- Kekre, S. and T. Mukhopadhyay, "Impacts of Electronic Data Interchange on Inventory, Quality and Performance," Manuscript, GSIA Carnegie Mellon University, 1990.
- Kelleher, J., "Electronic Data Interchange: Standard's Momentum Grows as Users Realize Benefits," *Computerworld*, September 22, 1986.
- Klein, S., "Technical, Organizational and Managerial Aspects of Implementing EDI: Results and Experiences of 12 EDI Pilot Projects," Evaluation Report to the Commission of the European Communities, 1992.
- Kreuwels, C. M. A., "Electronic Data Interchange: An Introduction and Examples of its Structural Impact," *Production Planning & Control*, 3, 4 (1992) 381–392.
- Leinfuss, E., "Digital's EDI Remedy," *Datamation*, October 1 1990, 63–73.
- Leininger, W., "Patent Competition, Rent Dissipation, and the Persistence of Monopoly: The Role of Research Budgets," *Journal of Economic Theory*, 53, 1 (1991) 146–172.
- Markus, M. L., "Toward a 'Critical Mass' Theory of Interactive Media," in *Organizations and Communication Technology*, J. Fulk and C. Steinfield (Eds.), Sage Publications, 1990, 194–218.
- Muto, S., "An Information Good Market with Symmetric Externalities," *Econometrica*, 54, 2 (March 1986) 295–312.
- Muto, S. and M. Nakayama, "A Cooperative Game of Information Trading: The Core and the Nucleolus," MEDS Discussion Paper No. 757, Northwestern University, 1988.
- Nakayama, M. and L. Quintas, "The Core of Resale-Proof Information Trades," MEDS Discussion Paper No. 740, Northwestern University, 1988a.
- Nakayama, M. and L. Quintas, "Resale-Proof Trades of Information," MEDS Discussion Paper No. 763, Northwestern University, 1988b.
- Oren, S. S. and S. A. Smith, "Critical Mass and Tariff Structure in Electronic Communications Markets," *The Bell Journal of Economics*, 12, 2 (1981) 467–487.
- Powell, S. G. and D. F. Pyke, "Effects of Electronic Data Interchange on Inventory Policies," Working Paper, The Amos Tuck School Business Administration, Dartmouth College, Hanover, NH, 1990.
- Riggins, F. J., C. H. Kriebel and T. Mukhopadhyay, "The Growth of Interorganizational Systems in the Presence of Demand Externalities," Working Paper, Carnegie Mellon University, 1991.
- Rohlf's, J., "A Theory of Interdependent Demand for a Communication Service," *Bell Journal of Economics and Management Science*, 5 (1974) 16–37.
- Runge, D. A., *Winning with Telecommunications: An Approach for Corporate Strategists*, ICIT Press, 1988.
- Schiller, Z., "Clout: More and More, Retail Giants Rule the Marketplace," *Business Week*, December 21 1992, 66–73.
- Sokol, P. K., *EDI: The Competitive Edge*, Intertext Publications, McGraw-Hill Book Company, 1988.
- Stern, L. W. and P. J. Kaufmann, "Electronic Data Interchange in Selected Consumer Goods Industries: An Interorganizational Perspective," in *Marketing in an Electronic Age*, R. D. Buzzell (Ed.), Harvard Business School Press, (1985), 52–73.
- Varian, H. R., *Microeconomic Analysis*, 2nd edition, New York: W. W. Norton, 1984.
- Venkatraman, N. and Akbar Zaheer, "Electronic Integration and Strategic Advantage: A Quasi-Experimental Study in the Insurance Industry," *Information Systems Research*, 1, 4 (1990) 377–393.

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