The Effects of Compatibility on Buyer Behavior

in the Market for Computer Networking Equipment

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Abstract

This paper examines the importance of compatibility on buyer behavior in the market for computer networking equipment over the period 1996-1998. One finding is that firm establishments are more likely to purchase networking gear from an incumbent vendor. Among some classes of networking equipment, incumbency affects vendor choice both when it occurs at the same establishment and/or at other establishments within the same firm. Another finding is that compatibility across different product lines within the same vendor also influences vendor choice. These theses are explored in data on purchases of computer networking equipment utilizing open standards such as the Ethernet networking protocol, and represent the first econometric measurement of compatibility effects within products utilizing open standards. These findings show that there are strong economic incentives to offer broad product lines, and provide one potential explanation for high concentration levels in the market for computer networking equipment.

1. Introduction

This article examines how product compatibility affects vendor choice in the market for routers and switches, two major classes of computer networking equipment. Analyzing the market for routers and switches over 1996-1998, I examine whether incumbency may affect vendor choice. In particular, I test whether the presence of an installed base increases the likelihood that a buyer will purchase from a particular vendor. As noted in Klemperer (1995) and David and Greenstein (1990), compatibility between an existing generation of equipment and potential replacements can create switching costs for buyers who change vendors, giving incumbent vendors an advantage over nonincumbents. Some empirical papers have examined the effects of vendor incumbency in other settings (e.g., (Greenstein, 1993), (Breuhan, 1997)). Recently, several papers have examined switching costs and brand loyalty within the context of consumer behavior in electronic markets (e.g., (Brynjolfsson and Smith, 2000), (Chen and Hitt, 2000)). Besides examining the effects of incumbency in a new and growing market, this paper will make several contributions to this existing literature. First, it will show within the context of multi-establishment firms, incumbency affects vendor choice both when it occurs at the same establishment and/or at other establishments at the same firm. Second, it will examine how an existing installed base in one product market can spill over and affect purchasing decisions in another. It will also be the first paper to show that installed base effects are present in markets with so-called "open" standards.

A major goal of the study is to explain how compatibility may have influenced market structure in routers and switches. It is well known that the market for these products is quite concentrated. The world-wide market share for the top three firms in the router market ranged from 60.2% to 62.7% over my sample period, while the comparable figure for the switch market ranged from 61.9% to 72.3%.[1] Many explanations have been provided in the popular press for the predominance of the top three firms in these market segments, particular Cisco Systems. These alternative hypotheses have included, but have not been limited to, distribution techniques and

[1] Source: Dataquest Quarterly Market Watch, 1999

acquisition strategies (e.g., (Bunnell, 2000)). While these other hypotheses are likely to be true, it is the hypothesis of this paper demand for compatibility contributes to the high concentration rates in these markets.

I test these hypotheses by estimating a nested logit model of vendor choice. In this model, the probability of choosing a particular vendor is made a function of buyer characteristics and the extent of previous buyer-vendor interaction. The model also accounts for the effects of simultaneous purchases across multiple product lines. I also examine explicitly the factors affecting the choice of whether to purchase computer networking equipment. The results show that compatibility considerations do effect the vendor decision of buyers. These compatibility considerations appear in two ways. First, a buyer's installed base in a particular line of equipment appears to effect future purchases in that equipment line. Buyers show a tendency to show loyalty to a particular vendor over time. Second, compatibility appears to play a role in vendor decision when buyers are purchasing multiple product lines. This manifests itself in a buyer tendency to purchase routers and switches from the same vendor.

I measure the effects of compatibility across product lines within a particular vendor by examining the behavior of buyers choosing more than one class of networking gear. Previous work (e.g., (Katz and Shapiro, 1985)), (Besen and Saloner, 1989), (David and Greenstein, 1990)) has shown that dominant firms may have incentives to manipulate interfaces and to create incompatibilities with complementary devices sold by rival sellers in an attempt to broaden market power. Because of the obvious antitrust implications there have been a number of case studies that have examined this phenomenon (e.g., (Fisher et al., 1983)) . However, because of insufficient data there have been no econometric studies to date that have directly examined this phenomenon. In this paper, I will be able to test directly the importance of compatibility within vendor product lines.

As with most economic papers attempting to measure the importance of past economic behavior on current purchase decisions, this paper is unable to measure directly the importance of installed base on product purchases. Buyers may continue to purchase from the same vendor either because of vendor lock-in or because that vendor's product is particularly well suited to the buyer. This problem is another manifestation of the econometric identification problem of disentangling the effects of “state dependence” versus “unobserved heterogeneity” discussed elsewhere (e.g., (Heckman, 1981)). Moreover, in the model that I use it will be difficult to identify whether the purchase of multiple products from the same vendor is due to compatibility factors or unobserved factors leading to a better “match” between buyer and vendor.

The rest of the paper is as follows. In section 2 I provide some background technical information on computer networking equipment and provide some details on market concentration in this market. In section 3 I describe explicitly how compatibility can affect vendor choice in a market with open standards. Moreover, I describe the econometric identification issues involved in measuring the importance of installed base and product-line compatibility. In section 4 I describe the econometric specification, and section 5 describes the data. Section 6 presents the results of the econometric specification. Section 7 concludes.

2. The Market for Networking Equipment

2.1 Technology

In order to understand how compatibility can effect buyer decisions in the market for computer networking equipment, one must first have some understanding of the underlying technology involved. At the lowest level of the networking hierarchy, networking takes place within what is known as a local area network (LAN). LANs are used to connect small groups of users who are (usually) located physically close to one another and who may often wish to utilize a shared resource such as a printer or some other peripheral.

Two major technologies were used in the latter half of the 1990s to transmit data between LANs, routers and switches. Both technologies are nodes that connect network cabling and route traffic across LANs in a network. Both technologies are also used to route traffic across the Internet.

Routers were introduced in the 1980s by Cisco Systems. Prior to the rise in popularity of switches in 1994 and 1995, routers represented the primary way in which networks were interconnected in the 1990s.[2] Routers are used to direct packets of information across a network. Because of the way in which they work, however, routers have functionality which also enables them to monitor and manage network traffic efficiently. Routers are able to communicate with one another in a way that allows the router to monitor and optimize network traffic, determining the optimal path through which a packet of information should flow. The architecture of routers also allows them to perform network management and security features, allowing network managers to identify problems and congestion within a network with ease as well as providing protection to keep the network safe from outside intruders. However, this added functionality comes at a cost in the form of the additional time it takes for routers to route packets. Throughout the 1990s, increasing network traffic strained the capacities of router-based networks. Significant delays, known in industry terminology as latency, developed as many router-based networks were unable to handle increasing traffic flows. Moreover, the price of routers was very high relative to the prices of other networking hardware.

Switches were introduced in the mid-1990s in part as a solution to the cost and latency problems of routers. Like routers, switches are used to direct packets of information across a network. Their design often results in faster packet forwarding and lower hardware prices than routers, however without the added functionality of routers.

Because routers and switches perform the same basic function – routing data packets – they are sometimes used as substitute products. Switching technology diffused throughout the latter 1990s, as some network managers chose to adopt the new technology while others preferred to maintain entirely router-based networks.

Despite relatively rapid diffusion of switches, few adopters of switching technology abandoned routers entirely, however. Most buyers of switches maintained some routers in their network, and most purchased routers concurrently with their switches. The reason is that many of the network management and security features of routers remained necessary. In particular, networks that relied entirely on switching technology often

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[2] Another type of internetworking technology, known as bridges, had been popular in the 1980s but had begun to die out considerably in importance in the early part of the 1990s.

resulted in broadcast storms, a state in which a message that is broadcast around a network results in increasingly more messages, generating a snowball effect that can cause the entire network to fail. Usually, switch-based networks include routers interspersed periodically to help manage network traffic flow. Routers, because of their added functionality, form the "brains" of the network around which switches and other networking hardware were built. Thus, routers and switches are also commonly employed as complements.

Both routers and switches communicate using open protocol standards like ethernet or token ring. Thus, incompatibilities in this market cannot explicitly arise from proprietary communications standards. However, routers and switches are very complicated devices, carrying advanced processing devices and sometimes costing tens of thousands of dollars. The complexity of these devices leads to two common costs in running multivendor networks: (1) costs to learning new devices; and (2) costs of ensuring compatibility and interoperability between multiple devices.

Configuration of new routers and switches can be very difficult. Despite the prevalence of open networking protocols, vendors often employ proprietary software to run their networking gear. Proprietary software and complicated command-line interfaces can make management of these devices quite difficult. Setup and configuration is also complicated, and for many buyers entails the use of outside networking consultants. These configuration costs imply the presence of cost savings for buyers that purchase from incumbents.

A second cost to multivendor networks concerns the ease with which gear from different manufacturers is able to work together. In the industry trade press, this is known as the interoperability problem. Because of the complexity of the devices, time-consuming and costly configuration is sometimes needed to get hardware from different manufacturers to communicate with one another. These problems are sometimes exacerbated by proprietary enhancements added by vendors.

The importance of product compatibility (or interoperability, as it is known among networking professionals) is a common theme in the industry trade press. Trade press articles emphasize that without proof of interoperability, users may fear that devices from new vendors may not work with their installed base (Tolly, 2000). Cisco Systems is occasionally reprimanded in the press for adding proprietary enhancements to standards (Wickre, 1996). Industry publications have also reported that senior officials at Cisco say the company is trying to create an end-to-end service model such as IBM's Systems Network Architecture (Petrosky, 1996).

There also exists considerable evidence of the importance of compatibility in this market from the actions of vendors themselves. Vendors commonly market their product lines by creating suites of products that work together. Well-known examples include 3Com's NetBuilder, OfficeConnect, and SuperStack II product lines; Bay Networks BayStack line; and Cisco's NetBeyond and CiscoPro brands. Compatibility among routers and switches was also the driving force behind the formation of the Network Interoperability Alliance (NIA) by 3Com, Bay Networks, and IBM. The stated objective of the NIA was to simplify the building of networks, to create support for joint standards and open protocols, and to develop interoperability testing and the create incentives for vendors to use common architectural platforms (Miller, 1996).

Although the NIA was short-lived, it provides evidence of the importance of standards and compatibility in this industry – as well as a concern over the increasing dominance of Cisco Systems.

2.2 Market Structure

The router and switch markets in the second half of the 1990s have been characterized by large and increasing market concentration. Table 1 shows how the "Big Three" vendors of 3Com, Bay Networks, and Cisco Systems came increasingly to make virtually all of the router sales to firms in our sample.[3] Sales made by the Big Three rose from over 71.7% to over 88.1% of sales from 1996 to 1998. Sales by smaller vendors, represented by the Other category in Table 1, of course fell concomitantly, from 28.3% to under 11.9%.

[3] Bay Networks was acquired in June, 1998 by Northern Telecom, which then renamed itself Nortel Networks. Throughout the 1995-1998 sample period of this paper Bay Networks operated an independent entity, so I have opted to use the name "Bay Networks" throughout the paper.

Concentration in the market for switches is lower, but displays many of the same characteristics of the router market. Combined market shares for the Big Three vendors of 3Com, Bay, and Cisco ranged from 75.2% to 76.1%. Including Cabletron, another major manufacturer of switches, the market share of the top four firms ranges from 81.1% to 87.2%.

Many explanations could be potentially provided for the high concentration levels in the market for computer networking gear. The popular business press (e.g. (Bunnell, 2000) has emphasized firm-specific capabilities as one explanation for the high market concentration. Though I do not dispute the potential of these alternative explanations, in this paper I hypothesize that incompatibilities across the products of different vendors – exhibited through lock-in and demand for non-hybrid systems – has helped lead to increases in concentration in the router market.

3. Compatibility in Networking Equipment

This section describes how compatibility can influence both individual vendor purchase decisions and overall market structure. It also describes the econometric issues I face in identifying the effects of vendor incumbency and cross-product compatibilities.

Klemperer (1995) describes how a buyer's desire for compatibility between existing systems and new purchases can lead to switching costs in changing vendors. Such switching costs can cause buyers to exhibit "brand loyalty" and so increase the likelihood of repeat purchases from incumbent vendors. Klemperer (1995) lists several types of such switching costs, although in the market for computer networking equipment they are most likely to arise from two sources: (1) need for compatibility with existing equipment; and (2) costs of learning new brands.

The presence of switching costs can confer significant monopoly power upon the vendor among those buyers who have previously purchased the vendor's product. Klemperer (1995) notes that one potential outcome is for incumbent firms to charge higher prices than might otherwise be the case. Roughly speaking, vendors have the incentive to raise price in order to exploit monopoly power among those buyers over which they have incumbency.

Klemperer (1995) also notes the potential effects of switching costs in multiproduct competition. If buyers value variety and prefer to purchase systems consisting of multiple components and if there are switching costs to purchasing products from different vendors, then vendors that sell single products only may be at a disadvantage to those who produce a full product line and who can enable buyers to avoid switching costs in multi-product purchases.

These models lead us to expect several patterns of buyer behavior. The first hypothesis is that we expect buyers with an installed base of routers at the site to be more likely to purchase new routers from the incumbent vendor. Similarly, we expect switch incumbency at the site to affect a buyer's choice of switch vendor. The switching costs of learning to manage new equipment of and ensuring interoperability with the current network will persuade many buyers to continue with the incumbent vendor.

Hypothesis 1: Buyers face costs in changing router vendors. Incumbency will increase the probability a buyer will purchase from a router vendor relative to an identical buyer without incumbency.

Hypothesis 2: Buyers face costs in changing vendors. Incumbency will increase the probability a buyer will purchase from a switch vendor relative to an identical buyer without incumbency.

When buyers that are part of multi-establishment firms purchase networking equipment they must be concerned not only with the installed base of equipment locally at the buyer's establishment but also with the installed base of networking gear used throughout the firm. Networking gear must be compatible not only with local gear but must also interoperate with networking equipment used throughout the firm. Installation and management of networking equipment may also be provided by personnel from corporate headquarters or from other establishments within the firm. Thus, our second hypothesis is that installed base external to the site but within the firm will influence vendor choice.

Hypothesis 3: Buyers face costs in choosing a router vendor different from that used at other establishments throughout the same firm. Incumbency throughout the firm will increase the probability a buyer will purchase from a router vendor relative to an identical buyer without firm-wide incumbency.

Hypothesis 4: Buyers face costs in choosing a switch vendor different from that used at other establishments throughout the same firm. Incumbency throughout the firm will increase the probability a buyer will purchase from a switch vendor relative to an identical buyer without firm-wide incumbency.

The next two hypotheses relate to the effects of compatibility across products within the same vendor. Hypothesis five says that installed base in routers will influence the choice of switch vendor.

Hypothesis 5: Buyers face switching costs in choosing different router and switch vendors. Incumbency in routers will increase the probability a buyer will purchase from a switch vendor relative to an identical buyer without router incumbency.

Along the same lines, the costs of switching suppliers should influence vendor choice among buyers purchasing multiple products simultaneously, *independent of installed base effects.* Hypothesis 6 says that switching costs should increase the likelihood that buyers purchasing multiple products will do so from the same vendor.

Hypothesis 6: Buyers face switching costs in choosing different router and switch vendors. Buyers purchasing routers and switches simultaneously will face costs of purchasing from different vendors.

One way of examining the importance of installed base is to do simple univariate analysis and examine the loyalty of buyers to vendors. Tables 3 and 4 provide some evidence of hypothesis 1. Table 3 presents statistics on loyalty rates for routers over the sample period. A loyalty rate shows the conditional probability of purchasing from an incumbent vendor. Statistics are calculated for each of the Big Three vendors of 3Com, Bay Networks, and Cisco. Because of sample size restrictions, all other vendors are grouped within the class "Other." The columns "Other, Same Vendor" and "Other, Different Vendor" represent buyers that purchased from an incumbent and non-incumbent "Other" vendor, respectively. For each of 3Com, Bay Networks or Cisco, the probability of purchasing from the incumbent vendor is quite high, approaching 50% for 3Com and Bay Networks and exceeding 80% for Cisco systems. Loyalty rates for smaller vendors were much lower, as many buyers who purchased from such vendors switched to Cisco over the sample period.

Table 4 shows statistics on loyalty rates for switches. Loyalty rates are high in the table for each of the Big Three as well as the "Other" category. Loyalty rates for the Big Three vendors hover near 70%. A significant difference between this table and Table 3 is for the "Other" vendors: loyalty rates for other vendors are near 60% for switches, and there is no widespread switching to Cisco as there was in the router tables.[4]

Of course, these loyalty tables do not prove the existence of switching costs and lock-in. High loyalty rates may simply indicate a good 'match' between buyer and vendor. If a particular vendor has repeatedly excelled in providing systems that meet a buyer's needs, then the increase in conditional probability simply represents an unobserved preference on the part of the buyer for the vendor's idiosyncratic features. The problem of determining whether such an increase in the conditional probability is due to a change in preferences or constraints (state dependence) or simply represents unmeasured variation in the subjects (unobserved heterogeneity) has been studied extensively (e.g., (Heckman, 1981), (Heckman, 1991)). Due to stringent data requirements, few papers in the Industrial Organization literature have been able to solve this problem explicitly. Israel (1999) is a notable exception. Throughout this paper I will require the maintained assumption that heterogeneity across firms is sufficiently controlled for by my regressors.

[4] Although this partially reflects high loyalty for Cabletron switches.

Table 5 shows the distribution of vendor choices for buyers that purchase from one router and one switch vendor, and provides some evidence for hypothesis 4.[5] The table shows that among firms who purchase from one router vendor and one switch vendor, roughly 46% buy from the same vendor. The second line of each row in the table shows the probability of purchasing from a given switch vendor conditional on purchasing from the router vendor in that row. Thus, 89.3% of buyers purchasing a 3Com router also buy a 3Com switch, while 72.8% of sites purchasing a Bay router will buy a Bay switch. Interestingly, only 38.4% of sites purchasing a Cisco router will also purchase a Cisco switch, however this figure must be interpreted cautiously because of the large Cisco market share in routers.

Again, I am unable to determine directly from Table 5 whether compatibility issues are driving the purchase behavior of sites in my sample. While one potential hypothesis is that buyers are more likely to purchase from identical router and switch vendors because of compatibility issues, other alternative hypotheses are possible. In particular, it may be the case that there are unobservable factors unrelated to compatibility that are driving a buyer to purchase from the same networking vendors for routers and switches. In particular, there remains the possibility that the bundles of routers and switches offered by some vendors are a better "match" for some buyers than others. For instance, the product line of 3Com is known to cater particularly to smaller firms, thus there may exist the possibility that smaller buyers are more likely to purchase both 3Com routers and switches.

In sum, there exists some anecdotal and simple statistical evidence that product compatibility issues play an important role in the vendor choice decision. However, there may be other factors at work affecting vendor choice, some relating to product compatibility and some not. A more formal framework is needed to account for buyer heterogeneity as much as possible, as well as to explicitly identify the assumptions needed to attribute the behavior identified above as being caused by compatibility.

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[5] Results from firms purchasing from multiple router and switch vendors are qualitatively similar, however are difficult to display in tabular form.

4. Structure of the Model

In this section I detail the model used to describe the demand for routers and switches. I use this model to explicitly examine the decisions of (1) whether or not to purchase a router or switch and (2) conditional on the purchase decision, the choice of vendor.

The model is derived from a discrete choice model of buyer behavior (e.g., (McFadden, 1974) or (McFadden, 1981)). The model examines the purchase decisions of buyers over the course of one year. Buyers in this model are assumed to be individual sites within a firm, where a site represents a geographic location within the firm and can be viewed as being similar to establishments in government statistical data. Thus, a maintained assumption throughout the paper will be that the decision-making process for purchasing networking equipment is decentralized across firms in my sample.[6]

All sites i associate some utility with a choice j, U_j^i. Utility takes the form of a random utility model (e.g., (McFadden, 1974)), $U_j^i = u_j^i + \varepsilon_j^i$. Thus, a site's utility for a choice is decomposed into two components: a deterministic component u_j^i that is a function of site as well as choice characteristics and also includes information on previous vendor-site interaction. The error term ε_j^i is a residual that captures the effects of unmeasured variables.

A choice in the model consists of (1) a 0/1 decision of whether to purchase a router; (2) a 0/1 decision of whether to purchase a switch; (3) if a router is purchased, a choice of router vendor; and (4) if a switch is purchased, a choice of switch vendor. Buyers choose a router or switch vendor rather than a particular model of networking equipment because of limitations with the data set. For most router observations and all switch observations, the data identify vendor only and do not identify a particular model type.

Purchasers of networking gear frequently purchase more than one unit of routers and/or switches from a vendor. Because I am more concerned with the issue of vendor choice than with the quantity of networking equipment actually demanded, I do not

[6] This hypothesis is consistent with that made by previous users of this data source, including Bresnahan and Greenstein (1996), Bresnahan and Greenstein (1997), and Breuhan (1997).

consider the quantity decision here. Accordingly, I make the necessary assumption that the quantity decision is separable from the purchase and vendor decisions. Because most sites in my data set purchase small quantities of routers and switches, this assumption is less problematic than it may first seem. For example, among purchasers of routers, 37.8% of sites purchase one router, and 78.7% purchase five of fewer. Among purchasers of switches, 36.9% purchase one switch while 75.7% purchase five or fewer.

As in Goldberg (1995), I decompose a decision j into k disjoint subsets according to the decision to purchase a router (r), the decision to purchase a switch (s), the choice of router vendor (v), and the choice of switch vendor (w), so that each choice j can be indexed by a quadruple subscript (r,s,v,w). Then the utility function can be expressed as

$$U^i_{r,s,v,w} = u^i_{r,s,v,w} + \boldsymbol{e}^i_{r,s,v,w}$$

As in Goldberg (1995) I assume that utility is additively separable into components that vary with the decision to purchase a router, the decision to purchase a switch, the choice of router vendor, and the choice of switch vendor. Under these assumptions the utility function can be written as

$$U^i_j = \boldsymbol{a}' R^i_r + \boldsymbol{b}' S^i_{r,s} + \boldsymbol{g}' V^i_{r,s,v} + \boldsymbol{d}' W^i_{r,s,v,w} + \boldsymbol{e}^i_{r,s,v,w}$$

where $\boldsymbol{a}$, $\boldsymbol{b}$, $\boldsymbol{g}$, and $\boldsymbol{d}$ represent parameters to be estimated and the vectors R^i_r, $S^i_{r,s}$, $V^i_{r,s,v}$, and $W^i_{r,s,v,w}$ represent variables affecting the decision to purchase a router and switch and the decisions of router and switch vendor, respectively. Following the literature on the nested logit model (e.g., (McFadden, 1978), (McFadden, 1981)), I assume that the error term $\boldsymbol{e}^i_{r,s,v,w}$ follows a generalized extreme value distribution. I further assume that the decision process can be nested according to Figure 1.

A potential problem with use of the nested logit model is that the order in which decisions are nested determines the error process and can affect estimation of the coefficients in the model. The nestings in the model do not describe the order of the decision process, and instead specify the structure of the error terms in the model: choices within a branch are more similar to one another than are choices outside of a branch. The structure of Figure 1 was used because routers often form the core of a network around which other hardware is built: thus a nesting structure which assumed choices conditional on a particular router decision to be more similar than those that included a different router decision was preferred. Figure 2 presents an alternative nesting structure. We later use implications of the generalized extreme value distribution derived by McFadden (1978) to test whether our nesting structure is consistent with utility maximization.

It will be convenient to decompose further the vector of characteristics $V^i_{r,s,v}$ and $W^i_{r,s,v,w}$. Following Greenstein (1993), I decompose this vector of characteristics into variables that describe the extent of buyer-vendor interaction and variables measuring buyer characteristics that may indicate vendor preference (independent of previous buyer-vendor interaction). In particular, we can define $\gamma' V^i_{r,s,v} = \gamma_1' X^i_{r,s,v} + \gamma_{2v}' Z^i_{r,s}$ where $X^i_{r,s,v}$ measures the extent of previous buyer-vendor interaction and $Z^i_{r,s}$ measures buyer characteristics independent of vendor interaction that may signal predilection towards a particular vendor. Further, I rewrite $\delta' W^i_{r,s,v,w} = \delta_1' P^i_{r,s,v,w} + \delta_{2w}' Q^i_{r,s,v} + \delta_3' T^i_{r,s,v,w}$, where $P^i_{r,s,v,w}$ measures the extent of previous buyer-vendor interaction, $Q^i_{r,s,v}$ measures buyer characteristics that may indicate preferences for a particular vendor (independent of previous interaction), and $T^i_{r,s,v,w}$ indicates the potential benefits or costs of making a choice that includes an identical router and switch vendor.

The vectors $X^i_{r,s,v}$ and $P^i_{r,s,v,w}$ reflect the impact of previous buyer-vendor interaction on the utility of purchasing from a particular router and switch vendor, respectively. We may expect the effects and sources of buyer-vendor interaction to differ across stand-alone sites and those that are part of a larger firm. For instance, sites that are directly connected to the broader network of a large firm may base their vendor decision in part on the installed base of equipment throughout the firm, implying both that (1) firm-wide installed base will affect decisions and potentially (2) site-wide installed base effects may be stronger or weaker for sites which are part of a larger firm than they are for stand-alone sites. To account for this, I again rewrite

$$\gamma' V^i_{r,s,v} = \eta_{if} \gamma_1^{f\prime} X^i_{r,s,v} + (1-\eta_{if}) \gamma_1^{nf\prime} X^i_{r,s,v} + \gamma_{2v}' Z^i_{r,s}$$

where h_{if} is defined to be 1 if the site is part of a larger firm and 0 otherwise and so allow the effects of buyer-vendor interaction to vary depending on whether a site is part of a larger firm. Similarly,

$$d'W^i_{r,s,v,w} = h_{if} d_1^{f\prime} P^i_{r,s,v,w} + (1-h_{if}) d_1^{nf\prime} P^i_{r,s,v,w} + d_{2w}{}' Q^i_{r,s,v} + h_{if} d_3^{f\prime} T^i_{r,s,v,w} + (1-h_{if}) d_3^{nf\prime} T^i_{r,s,v,w}$$

The joint probability of a particular choice j in this model will be

$$P^i_j = P^i_r P^i_{s|r} P^i_{v|s,r} P^i_{w|v,s,r}$$

where P^i_j is the joint probability of choosing a particular (r,s,v,w) combination, P^i_r represents the marginal probability of purchasing a router, $P^i_{s|r}$ is the probability of purchasing a switch conditional on router choice, $P^i_{v|s,r}$ is the conditional probability of purchasing from a particular router vendor, and $P^i_{w|v,s,r}$ is the conditional probability of purchasing from a switch vendor.

The generalized extreme value distribution implies that given choices (r,s,v), the conditional probability of making a choice of switch vendor w^* takes the following form:

$$P^i_{w^*|v,s,r} = \frac{\exp(d'W^i_{r,s,v,w^*})}{\sum_{w \in C_{v,s,r}} \exp(d'W^i_{r,s,v,w})} \quad (1)$$

where $C_{v,s,r}$ denotes the set of choices available to the buyer at the node defined by (v,s,r).

At the next level up, the probability of choosing router vendor v^* will be

$$P^i_{v^*|s,r} = \frac{g'V^i_{r,s,v^*} + l I^i_{r,s,v^*}}{\sum_{v \in C_{r,s}} g'V^i_{r,s,v} + l I^i_{r,s,v}} \quad (2)$$

where $I^i_{r,s,v} = \log\left[\sum_{w \in C_{r,s,v}} \exp(d'W^i_{r,s,v,w})\right]$ is the inclusive value, the expected aggregate value of choice v. The coefficient on the inclusive value, l, measures the dissimilarity of alternatives available to the buyer given different choices v. McFadden (1978) has shown that the choice structure given by Figure 1 is consistent with expected utility maximization if and only if the inclusive value parameter in (2) lies within the unit interval.

The probability of a choice at a node in the first or second level of Figure 1 is similar in form to (2). In the second level decision, the probability of a particular choice of whether to buy a switch will be equal to

$$P_{s|r}^{i} = \frac{\boldsymbol{b}' S_{r,s^*}^{i} + \boldsymbol{x} I_{r,s^*}^{i}}{\sum_{r \in C_r} \boldsymbol{b}' S_{r,s}^{i} + \boldsymbol{x} I_{r,s}^{i}} \tag{3}$$

where the inclusive value $I_{r,s}^{i} = \log\left[\sum_{v \in C_{r,s}} \boldsymbol{g}' V_{r,s,v}^{i} + \boldsymbol{l} I_{r,s,v}^{i}\right]$.

Last, the probability of a particular choice at the first stage of the decision tree in Figure 1 is equal to

$$P_{r}^{i} = \frac{\boldsymbol{a}' R_{r^*}^{i} + \boldsymbol{q} I_{r^*}^{i}}{\sum_{s \in C} \boldsymbol{a}' R_{r}^{i} + \boldsymbol{q} I_{r}^{i}} \tag{4}$$

and the inclusive value $I_{r}^{i} = \log\left[\sum_{s \in C_r} \boldsymbol{b}' S_{r,s}^{i} + \boldsymbol{x} I_{r,s}^{i}\right]$.

I estimate the model using sequential maximum likelihood. In this method, I first estimate model (1). I use the estimates of this model in this stage to calculate the inclusive values needed to estimate (2) using maximum likelihood. The parameters in this stage are used to calculate inclusive value parameters for (3), and so on. It is well known that this method ensures consistent, but inefficient, estimates of the parameters. McFadden (1981) shows how to adjust the standard errors when using this procedure.

5. Data

To carry out the vendor choice analysis, I use data from the Harte Hanks CI Technology Database. The CI Technology Database is a comprehensive survey of the technology usage of firms. It includes data on purchases of computers, networking equipment, and other office equipment, as well as data on phone usage and general descriptive firm data. In section 5.1 I describe the sample that I use for the analyses. In section 5.2 I describe the regressors.

5.1 Sample

I obtained data on technology usage from the CI Technology Database (hereafter CI database) over the period 1995-1998. The CI database contains data on (1) observation characteristics such as firm size, industry, and location; (2) technology purchases of computers, networking equipment, printers, and other office equipment; and (3) contact information on IT professionals at the site. Harte Hanks obtains these different components of the CI database at different times of year; my sample is assembled by obtaining the most current information as of December of each year. For example, the observation for a site in 1995 will contain information on the site's characteristics and technology usage as was recorded in the CI database in December 1995.

A unit of observation in the CI database is a site. Roughly speaking, a site refers to a particular branch or location of a firm. It is similar to the concept of establishment used by government organizations such as the Bureau of Labor Statistics in calculating government statistics. Thus, the database will often have data on multiple sites for a given firm.

To keep the analysis of manageable size, I obtained data from the CI database on SIC codes 60-67, 73, 87, and 27. These SIC codes correspond to the industrial groupings on Finance, Insurance, and Real Estate (60-67); Business Services (73); Engineering, Accounting, Research, Management, and Related Services (87); and Printing and Publishing (27). These industries were selected because they are generally regarded as heavy users of information technology and are thought to be heavy users of Internet services. The sample contains data on all sites of over 100 employees from the CI database over the sample period. Thus, the analysis will not consider the effects of small site behavior on the router and switch industries. All sites are from the U.S.

A unit of observation in the database contains site characteristics and the stock of technology goods installed by the site as of December of each year. To infer purchase decisions, I calculate the change in quantity installed from year to year for each vendor. Unfortunately, the database does not contain reliable model-level information on networking products in use at the firm. Thus, I am neither able to examine model-level purchase decisions nor am I able to track the purchase and retirement of a particular piece of networking equipment by the firm.

Because of the way the database was constructed, many observations had to be dropped. The sample began with 18,870 observations in 1996, 22,439 in 1997, and 18,726 in 1998. Many observations had to be dropped because a site was not in the database in the previous year, and so inferences on purchase quantities could not be made. I drop observations for which there is no general site-specific information on such things as company name and industry. Observations were dropped for which Harte Hanks did not update their networking database from the previous year, because such sites may have made purchases that I could not observe. Observations were also dropped for which the quantity of networking equipment installed was missing from the database. I also removed European sites which were provided to me in the database.

For many smaller vendors in the database, the number of purchase observations was too small to estimate the parameters g_{2v} and d_{2w}. Thus, observations representing purchases from smaller vendors had to be dropped. Moreover, because of the way this experiment was designed, sites who had an installed base in one of these smaller vendors were dropped as well. In the end, I examined the vendor choice decision of firms that purchased routers from 3Com, Bay Networks, and Cisco and that purchased switches from 3Com, Bay Networks, Cabletron, and Cisco. The final data set which I use for analysis contains 8077 observations from 1996, 8301 observations from 1997, and 11,710 observations in 1998.

5.1 Variables

In this section I describe the variables that I use in my analysis. Table 6 lists the means, standard deviations, minimums, and maximums for the sample. As was discussed in section 4, there are four classes of variables used in the nested logit regression. Each set of variables maps to a level in the nested logit model. I consider each group in turn.

A. $W^{i}_{r,s,v,w}$*: Variables affecting the switch vendor decision*

The variables *IRTR* and *ILSW* are dummy variables indicating that the site has an installed base of routers and switches from a particular vendor. These variables will measure the importance of incumbency at the site level. If previous buyer-vendor interaction has an important effect on the vendor choice decision, then we expect that the coefficients on these variables to be positive. As was noted above, these variables can not directly test the effects of tenure dependence on demand because of the potential presence of unobserved buyer heterogeneity.

The variables *PCLSW* and *PCRTR* are defined as the percentage of a particular vendor's switches and routers installed throughout *a firm.* Thus, these variables test whether firm-wide (as opposed to site-wide) installed base effects are important. If firm-wide installed base effects are important, we should expect the coefficients on these variables to be positive, however I will be unable to attribute a positive significant coefficient directly to tenure dependence because of potential unobserved heterogeneity.

The variable *RSCOMP* measures potential effects of compatibility within a vendor's product line. *RSCOMP* is an indicator variable which is one when a choice includes the same router and switch vendor. If product compatibility across routers and switches is important to buyers when making a vendor choice, then we should expect the coefficient on this variable to be positive if there are costs to having different router and switch vendors. I will be unable to attribute a positive coefficient on *RSCOMP* directly to compatibility effects, because there may be unobserved factors affecting whether a buyer chooses an identical router and switch vendor.

I additionally include a vector of factors to account for the effects of buyer heterogeneity on vendor choice. We expect that for a variety of reasons some vendors may be a better "match" with certain sites. For example, the product line of 3Com is known to be tailored to the "edge" of the network, and is most commonly used for small firms and branch offices. Thus, smaller sites or sites from smaller firms may be more likely to purchase 3Com equipment.

To account for the effects of site size and network complexity on vendor choice, I include variables on number of network nodes (*TOTNODES*) and number of network protocols (*TOTPROT*). Because of the reduced-form nature of my discrete choice model, it is difficult to say a priori what we should expect the sign of these coefficients to be.

We may expect second-time buyers to have different vendor preferences that first-time buyers. This may be due, for instance, to the fact that second-time buyers may be more technically sophisticated that first-time buyers and so more interested in obtaining technically superior equipment than in product compatibility. To capture the difference in behavior between first-time and second-time buyers, I include the dummy variable *STIME* to indicate second-time buyers.

The variable *DHQ* indicates whether a site is a firm-wide or regional firm headquarters. This variable is included to capture the fact that headquarters sites may be likely to purchase and use different types of networking gear than are branches. A headquarters site will often be the center of a corporate network, and so will carry a large load of network traffic. Such sites will likely require high-end routers and switches, and so may have different vendor preferences than other sites. Because Cisco is known in particular to target the network core, we may expect such sites to be more likely to purchase from Cisco.

I also include vendor-specific dummies *DBAY*, *DCAB*, and *DCIS* (a vendor-specific dummy for 3Com is omitted). These variables are included to capture the effects of unobserved product quality and price for each vendor.

B. $V^i_{r,s,v}$: Variables affecting the router vendor decision

A number of variables included in $V^i_{r,s,v}$ were also elements in $W^i_{r,s,v,w}$. In other words, a number of variables are included at multiple stages of the nested logit model. Including variables at multiple levels of the model implies those variables affect the router vendor decision in two ways. First, such variables affect router vendor choice through the inclusive value term, representing the aggregate expected utility obtained from the router decision. Second, such variables affect the router vendor choice decision directly as elements impacting the utility obtained from a particular router vendor choice.

The variable *IRTR* is again a dummy variable indicating that the site has an installed base of routers from a particular vendor. If previous buyer-vendor interaction has an important effect on the vendor choice decision, then we expect that the coefficient on *IRTR* to be positive. *PCRTR* is again the percentage of a particular vendor's switches and routers installed through *a firm*. If firm-wide installed base effects are important, we should expect the coefficients on this variable to be positive.

The variables *TOTNODES*, *TOTPROT*, *STIME*, and *HQ* are again included as controls. Their interpretation will be similar as in $W^i_{r,s,v,w}$. I also include the indicator variables *DBAY* and *DCIS* (a vendor-specific dummy for 3Com is omitted). These variables are included to capture the effects of unobserved product quality and price.

C. $S^{i}_{r,s}$: Variables affecting the decision to purchase a switch

We should expect variables on firm and network size and network complexity to affect a firm's choice of whether to adopt switching equipment. Because the vast majority of sites that acquired switches purchased their first model after 1995, the variables in $S^{i}_{r,s}$ can be interpreted as factors affecting the switch adoption decision. Thus, we should expect variables commonly used in adoption studies (e.g. (Bresnahan and Greenstein, 1996), (Augereau and Greenstein, 2000)), such as location and industry effects, to potentially affect the decision to purchase a switch.

We should expect the likelihood of a firm adopting switching equipment to increase with the size of the network. When they were originally introduced, switches were originally hailed as a way of alleviating the network congestion problems inherent in large and complex networks.[7] Thus, I include variables on total number of network nodes at the site *(TOTNODES)* and total number of data connectivity links to points outside the site *(TOTDATA)* to capture the effects of network size on the switch adoption decision.

We also expect that the size of a firm's installed base in routers and switches to also affect the likelihood of purchasing switching technology. There are two reasons for this. First, a larger installed base of routers and switches will indicate a larger network, which will increase the likelihood of purchasing switches. Second, switches were commonly used as replacements for routers and hubs, thus any simple model of investment would suggest that a larger installed base of hubs and routers should increase the likelihood of

[7] Switches represented an improvement over previous generation internetworking devices, namely hubs and routers, for a number of reasons. Network congestion rises rapidly with size for networks that rely heavily on hubs, as hubs broadcast data packets to all nodes connected to the hub (rather than directing the packet only on to one node, as necessary). Although routers can direct data packets to only one node and are capable of finding the most efficient path possible for a packet of data, their technology involves significant overhead that can introduce delays in messages sent over large networks.

switch purchases in any given year.[8] Accordingly, I include the variables *INSTRTR* and *INSTHUB*, which represent the site's installed base of routers and hubs, respectively.

As network size grows, the site will require additional internetworking devices to connect the expanding network. Sites may choose to fill this internetworking need with switching technology. Accordingly, I include variables capturing the change in network size in the model. Δ *TOTNODES* captures the change in the number of nodes at the site.

We expect firms that rely more heavily on advanced, bandwidth-intensive networking technologies as being more likely to purchase switching technology. The variables *DHOME, DINTRANET,* and *DRESEARCH* indicate the existence and/or use of a homepage, intranet, and Internet research within the firm, respectively. The variables *DFETHER* and *DFDDI* indicate the usage of fast ethernet and FDDI technology at the site. These variables capture the presence of more advanced networking technology at the firm, which will increase the likelihood of switch adoption for two reasons. First, the usage of advanced networking technologies will imply high bandwidth usage which will increase the probability of the site adopting new switching technology to route the expected heavy network traffic. Second, if the site is an advanced user of technology, work from other adoption studies (for many example see Rogers (1995)) suggests that the site will be an early adopter of switches because of a potential propensity for early adoption of innovative technologies.

Because the data are pooled over the period 1996-1998, I include the time dummies *D97* and *D98* to capture the effects of changes in the pattern of networking equipment purchases over time. The variables *DBANK* and *DSERV* capture industry effects of firms in banking and service industries (industry effects from the publishing industry are omitted).

Headquarters sites may be more likely to be the center of a firm's network and so have particularly heavy traffic loads. To account for this effect, I include the variable *DHQ*, which indicates whether the site is a firm-wide or regional headquarters.

[8] A true model of investment would account for the age of capital installed at the site (e.g., (Ito, 2000)). Unfortunately, the data do not allow me to identify the age of networking equipment installed.

D. $P^{i}_{r,s,v,w}$: Variables affecting the decision to purchase a router

We expect that many of the same variables that affected the switch purchase decision to affect the router purchase decision as well.

The variable *INSTRTR* again indicates the size of the installed base of routers at the site, and Δ *TOTNODES* again indicates the change in the number of network nodes. Routers are used especially to connect dissimilar networks together, thus the greater the site's network segmentation and external linkages between the site and other networks, the more likely is the site to purchase routers. I include the variables *TOTSITE* (number of sites in the firm[9]), *TOTLAN* (total number of network nodes at the site), *TOTPROT* (total number of network protocols at the site), and *TOTDATA* (total number of external data links from the site) to account for these affects.

Once again, I expect firms that rely more heavily on advanced, bandwidth-intensive networking technologies as being more likely to purchase switching technology. The variables *DHOME*, *DINTRANET*, and *DRESEARCH* indicate the existence of a homepage, intranet, and Internet research at the *firm*-level, respectively. The variables *DFETHER* and *DFDDI* indicate the usage of fast ethernet and FDDI technology at the site.

To account for year effects, I again include the variables *D97* and *D98*, and to account for industry effects I include the variables *DBANK* and *DSERV*. I again include the variable *DHQ* to account for headquarters effects.

6. Results

The model of networking gear choice is estimated in four stages, each of which corresponds to a level of the tree in Figure 1. The model was also estimated according to the alternative nesting structure shown in Figure 2, however the inclusive value parameter for the second node (decision to purchase a router) was 1.3539 with a standard error of 0.294. This inclusive value is outside the zero to one range consistent with utility

[9] Actually, this variable indicates the number sites that the firm has in my database in that particular year, and so undercounts the number of sites in total.

maximization (McFadden, 1978), however I am just barely unable to reject at the 10% level the hypothesis that the true inclusive value parameter is less than or equal to one. Based on this evidence and because there is strong prior evidence that the error structure consistent with Figure 1 is the correct one for this model, I present the results from the baseline model of Figure 1.[10] The parameter estimates and standard errors of the baseline model are captured in Tables 7 – 10 below. To increase the sample size, I pool observations over the entire sample 1996-1998. The estimation results of each stage are listed below.

A. Results from Switch Vendor Choice Model

The results from the model of switch vendor choice are presented in Table 7. I focus attention primarily on the variables measuring the importance of previous buyer-vendor interaction and product compatibility.

The presence of an incumbent switch vendor appears to have an important effect on a buyer's decision of switch vendor, providing support for hypothesis 2. If either a standalone site or firm branch has an incumbent switch vendor (*ILSW),* then that site is likely to purchase from the same vendor again. The coefficients on the site-level incumbency variables are high and significant for both standalone sites and firm branches. Firm-wide incumbency may also play a role in the switch vendor decision, as shown by the variable *PCLSW,* however the effects are weaker and just barely insignificant at the 10% level. Thus, the coefficient estimates provide some support for hypothesis 4.

Hypothesis 5 suggests that the presence of an incumbent router vendor may also have an effect on the switch vendor decision. Previous interaction with a vendor's routers may be important in choosing a switch vendor if compatibility across routers and switches is an issue. The effect of router vendor incumbency at a site (*IRTR*) is significant, however is less powerful than the effect of switch incumbency. Firm-wide router incumbency (*PCRTR*) appears not to be important in determining a firm's switch vendor, however. Because firm branches are most likely to connect to other sites and to

[10] The estimation results from the alternative model of Figure 2 were also fully consistent with hypotheses 1-6.

the outside world through routers (rather than switches), the insignificance of firm-level effects on switch vendor choice are unsurprising. However, if this hypothesis about firm-wide effects is true, one question that does arise is why firm-wide switch incumbency (*PCLSW*) appears to have some effect on vendor choice, while firm-wide router incumbency (*PCRTR*) does not.

Further confirming the importance of vendor product-line compatibility and providing evidence in support of hypothesis 6 is the coefficient on the variable *RSCOMP*. *RSCOMP* is a dummy variable which is one if a site is simultaneously purchasing router hardware from the same vendor. Thus, this variable measures compatibility effects when the site is choosing to purchase routers and switches simultaneously. The variable is a "one-way" measure of the importance of compatibility, i.e. router vendor choice may feed into the simultaneous decision of switch vendor but not the other way around. However, because of the structured way in which networks are commonly built with routers often forming the core of the network, this limitation is not a major concern. A more important potential flaw in this measure of compatibility is that it may be picking up unobserved heterogeneity that may make a particular vendor a good "match" in both routers and switches.

The rest of the variables capture the effects of buyer heterogeneity. In the nested logit model, buyer characteristics do not vary across vendor choices, thus to identify the effects of buyer heterogeneity we must estimate a separate set of coefficients for each vendor by interacting buyer characteristics with a vendor-specific dummy. The omitted vendor in the specification is 3Com, thus all coefficient estimates should be judged as representing the effects of that variable on the vendor choice decision relative to 3Com. Although they are not the focus of the estimation, several results are surprising.

The vendor specific constants for Cabletron and Cisco are large in size, negative, and significant, indicating that there are unmeasured effects that make Cabletron and Cisco an inferior choice to 3Com and Bay Networks. Because the vendor-specific constants in the model capture the effects of unobserved product quality and price, they may indicate that Cabletron and Cisco have much higher quality-adjusted prices relative to their major competitors, and represent poorer values to buyers.

The coefficient estimates for *TOTNODES* indicate that firms with larger networks may be more likely to purchase from Cisco than from other vendors. Moreover, as network size increases, both Bay Networks and Cabletron have an advantage over 3Com. This is to be expected, as Cisco's product line is known to be tailored especially to large enterprise systems, thus larger firms are more likely to purchase from Cisco. Conversely. among all vendors, 3Com has been known historically to tailor its product line to smaller firms and sites.

The coefficients on *TOTPROT* and *DHQ* are insignificant, while the coefficient on *STIME* indicates that second-time networking purchasers are more likely to buy from Cisco and Cabletron than from 3Com and Bay.

B. Results from Router Vendor Choice Model

The results from the model of router vendor choice are presented in Table 8. Again, I focus attention primarily on the variables measuring the importance of previous buyer-vendor interaction. Because of the nested logit specification, I am unable to include a variable like *RSCOMP* at this stage that measures the effects of product-line compatibility when a buyer is purchasing a router and switch simultaneously. Moreover, at this stage I do not include variables measuring the effects of switch installed base on router purchases. The reason for this exclusion is that I expect that product compatibility issues arising from an installed base of switches to be relatively unimportant because routers are far more complicated devices than switches. This hypothesis was affirmed empirically in regressions that included the effects of switch installed base. In results not presented here, switch installed base variables were shown to have no significant impact on router vendor choice.

Router incumbency appears to have had an important impact on the router vendor decision. Among standalone sites, the importance of router vendor incumbency was strong and significant. Vendor incumbency at the site was significant although somewhat less important at the site level for sites that were part of a larger corporation, however combined with firm-wide effects (*PCRTRC*), the impact of vendor incumbency was very similar (2.439 vs. 2.714 for sites within firms that have an installed base comprised completely of one vendor). Thus, there is strong support for hypothesis 1. Firm-wide incumbency effects appear to be important in the router vendor choice model, providing support for hypothesis 3. Because branch office routers must be able to frequently communicate with other sites within the firm, this result is expected.

The omitted vendor for the variables capturing the effects of buyer heterogeneity is again 3Com. As noted earlier, sample size considerations dictated that I drop observations in which buyers purchased from Cabletron.[11] Thus, the variables representing buyer heterogeneity were interacted with vendor-specific constants for Bay Networks and Cisco.

As we expect, the vendor-specific constant for Cisco is large in size, positive, and significant. Because this variable captures the market share effects not controlled for by our other variables, its large size raises potential concerns that I am not adequately controlling for all factors affecting the vendor choice decision. This coefficient estimate is either capturing perceived quality or price advantages for Cisco products or unobserved buyer heterogeneity.

The coefficient estimates for *TOTNODES* again suggest that larger firms are most likely to purchase from Cisco and least likely to purchase from 3Com. I am unsure how to interpret the negative coefficients on *STIME* for Cisco and Bay. The coefficient estimates for *TOTPROT* and *DHQ* are insignificant.

The coefficient estimate for the inclusive value parameter is 0.715, indicating that the model is consistent with utility maximization (McFadden, 1981)).

C. Results from Switch Purchase Choice Model

Table 9 displays the coefficient estimates on variables affecting the decision of whether to purchase a switch. Two separate constant terms were estimated at this level of the model, depending on whether or not the site had also decided to purchase a router. Both coefficients are significantly negative, reflecting the fact that the majority of sites do not purchase switches. However, I am also able to firmly reject the hypothesis that the likelihood of purchasing a switch is equivalent regardless of whether a router is purchased: sites are much more likely to purchase a switch in conjunction with a router than without. The present model makes it difficult to say exactly what factors are causing

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[11] There were less than 15 such observations in the sample.

routers and switches to be purchased together. However, this fact again potentially underscores the importance of compatibility in vendor choice.

The remainder of the variables at this stage say little about the effects of compatibility on vendor choice, however are interesting in their own right because they represent the first attempt (to my knowledge) of identifying the factors that are important to the switch adoption decision.

The variables representing the size of installed base of routers and hubs (*INSTRTR* and *INSTHUB)*, are both positive and significant. This likely reflects the fact that firms that have purchased networking gear in the past are more likely than other firms to do so in the future. It may also represent the fact that switches were first used as replacements for hubs and then later as replacements for switches.

The variables *TOTNODES* and Δ*TOTNODES* are both positive, reflecting that sites with large and/or growing networks are more likely to require networking gear. However, both are insignificant.

Of the three variables representing the intensity of the firm's Internet usage, only *DRESEARCH* is significant. The industry dummies *DBANK* and *DSERVICE* are negative and significant, indicating (somewhat surprisingly) that sites involved in the publishing industry are more likely to purchase switches than other sites in my sample. Firms using advanced networking technology, characterized by *DFDDI* and *DFETHER*, are, as we would expect, more likely to adopt switching technology. The fact that a site is a firm or regional headquarters seems to have relatively little effect on the likelihood of switch adoption.

The dummy variables D97 and D98 are both positive and significant, consistent with the increasing adoption of switching equipment over time.

The inclusive value parameter is 1.051. Although this point estimate is outside the range that is consistent with utility maximization, it is insignificantly different from 1.0, suggesting that the model is still consistent with one of a utility maximizing site.

D. Results from Router Purchase Choice Model

Table 10 shows the coefficient estimates on the variables affecting the decision of whether to purchase a router. The constant estimate is large in absolute value, negative, and significant, again reflecting the fact that the majority of observations in my sample purchase neither routers nor switches. The presence of a significant installed base of routers (*INSTRTR*) increases the likelihood that the firm will purchase routers again. Sites are more likely to purchase routers if they have many protocols (*TOTPROT*); many LANs (*TOTLAN*); and/or many data links to the outside world (*TOTDATA*). This reflects the fact that routers excel at connecting dissimilar networks together.

Sites that are within firms that use the Internet for research (*DRESEARCH*) or have a homepage (*DHOME*) are more likely to purchase routers. Sites that are within firms that have an intranet are less likely to adopt routers, although this likely is a spurious correlation. Sites that use frontier protocols such as fast ethernet (*DFETHER*) or FDDI (*DFDDI*) are more likely to purchase routers: these variables likely are capturing technical sophistication at such sites.

Sites that are involved in banking are more likely to adopt routers than are firms in publishing, while sites that are involved in service industries are less likely. Once again, the fact that a site is a firm or regional headquarters seems to have relatively little effect on the likelihood of switch adoption.

The dummy variable D97 is negative and D98 is negative and significant, suggesting decreasing purchases of routing technology. This result is surprising considering the continued overall growth of the router market, as listed in several industry reports (e.g., (Dataquest, 1999)). One explanation is that fewer firms are now purchasing routing technology, however the quantity purchased by such firms is higher.

The inclusive value parameter is 0.431, and so is well within the range consistent with utility maximization.

E. The Effects of Compatibility

The effects of incumbency vary with a site's characteristics. To measure the effects of incumbency while controlling for site heterogeneity, I use the parameter estimates of the above model to simulate the probability of choosing a particular router and switch vendor with and without vendor incumbency at the site level. Thus, the simulations show the impact of changing one factor – site-level vendor incumbency – on the vendor choice decision. These simulations are performed for all sites purchasing routers and/or switches, i.e. sites not purchasing networking gear are not included in the simulations. Tables 11 and 12 present the sample means of these simulations. Both tables examine the effects of incumbency when the site is and is not jointly purchasing routers and switches.

Table 11 examines the effects of site-level incumbency on the router vendor decision. It shows that, depending on the circumstances, vendor incumbency increases the probability of purchase from 14% to over 25%. Cisco incumbency at a site virtually ensures that a buyer will purchase Cisco again. Simulations showing firm-level effects (not included) showed similar results.

Table 12 shows the effects of site-level incumbency on switch purchases. Simulations showing firm-level effects showed similar results. The effects of vendor incumbency on the decision are dramatic. The smallest mean increase in probability associated with incumbency is 27.4%. In most cases, the increase in probability is above 34%.

Table 12 also shows something else of note. The distribution of switch market shares differ widely depending on whether a site is concurrently purchasing a router.[12] Firms concurrently purchasing a router are much more likely to purchase from Cisco and less likely to purchase from other vendors. Cabletron in particular fares poorly among sites simultaneously purchasing routing gear.[13] This result is consistent with major vendors acquisition spree of switching technology after the introduction of switching technology in the 1990's. After the introduction of switches, many networking firms and networking analysts felt that (1) switching technology would at least partially displace routers and that (2) firms which provided a full product line would win the networking war. As a result, major vendors such as Cisco and Bay acquired smaller switching firms in hope of catching up with the new technology. The results of Table 12 suggest that such firms may have been correct in their assessment of the importance of having a broad product line.

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[12] Strictly speaking, of course, these probabilities do not represent true market shares, as they only represent probabilities of purchasing from a particular vendor, and do not include the effects of quantity or value at all. Still, they represent an important point.

[13] The low likelihood of Cabletron switch purchase among firms purchasing routers is compounded by the fact that I dropped observations in which firms purchased Cabletron routers. However, because the number of such observations were so low (see footnote 8), the bias created should be small.

The results of section 6 provide strong support for the view that compatibility affected buyer's choice of vendor in the market for computer networking equipment. Evidence was found in support of hypotheses 1-6. Compatibility appears to have had an impact both within product lines and across product lines of firms. This may provide one explanation for vendors aggressive pursuit of broad product lines in this market. In all, compatibility issues have influenced buyer behavior in an important way in the market for computer networking equipment, and may have indirectly contributed to high concentration levels in this market.

7. Conclusion

This article examines the effects of compatibility on buyer choice of computer networking vendor. It is one of the first papers to examine the effects of compatibility and installed base within products utilizing open standards.

The analysis finds that even controlling for buyer heterogeneity, the presence of an installed base of equipment affects the choice of vendor when purchasing routers and switches. I also find that not only local, but firm-wide installed base effects impact the vendor decision for establishments within a firm. Thus, the analysis finds that compatibility within a particular vendor's router or switch lines plays an important role in the vendor decision.

However, the effects of compatibility do not end within product lines. The results also find that there are substantial compatibility effects across product lines sold by a vendor. In particular, the results show that even controlling for other factors influencing the buyer-vendor relationship, buyers appear to show a preference for purchasing routing and switching gear from the same vendor. This finding may confirm the demand-side incentive for aggressive acquisition strategy of some networking vendors in obtaining complementary networking technologies to add to their product lines, a strategy that contributes to the high concentration levels in this market.

Further work should examine the effects of compatibility on the observed pattern of entry in this market. Most new firm and new product entry has occurred in the very low and very high ends of the product spectrum in these markets. Further analysis could test whether compatibility issues are less important in these market segments, and if so whether this pattern of entry can be ascribed to effects of compatibility. Additionally, one could examine how the decision of start-up firms developing new networking technologies to compete with incumbent firms or to be acquired by such firms may be affected by buyers concerns over the importance of compatibility in such markets.

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Table 1

Router Market Share by Sales Quantity, 1996-1998

Year/Vendor	*3Com*	*Bay Networks*	*Cisco*	*Other*
1996	4.5	13.9	53.3	28.3
1997	8.3	13.0	64.4	14.4
1998	4.2	15.3	68.6	11.9

Source: Harte Hanks Market Intelligence and author's calculations

Table 2

Switch Market Share by Sales Quantity, 1996-1998

Year/Vendor	*3Com*	*Bay Networks*	*Cisco*	*Other*
1996	20.6	14.7	40.8	23.9
1997	25.8	11.1	38.3	24.8
1998	16.4	23.5	35.7	24.5

Source: Harte Hanks Market Intelligence and author's calculations

Table 3
Loyalty Rates for Routers, 1996-1998

Incumbent/ Acquired Vendor	*3Com*	*Bay*	*Cisco*	*Other, Same Vendor*	*Other, Different Vendor*
3Com	32 48.5%	4 6.1%	25 37.9%	-- --	5 7.6%
Bay	11 8.2%	64 47.8%	50 37.3%	-- --	9 6.7%
Cisco	19 4.8%	19 4.8%	328 83.5%	-- --	27 6.9%
Other	13 6.4%	22 10.8%	111 54.7%	38 18.7%	19 9.4%

Source: Harte Hanks Market Intelligence and author's calculations
The first line in each row is number acquired. The second line in each row represents percent acquired of vendor conditional on incumbent vendor. Observations are pooled over the sample period 1996-1998.

Table 4
Loyalty Rates for Switches, 1996-1998

Incumbent/ Acquired Vendor	*3Com*	*Bay*	*Cisco*	*Other, Same Vendor*	*Other, Different Vendor*
3Com	39 76.5%	4 7.8%	5 9.8%	-- --	3 5.9%
Bay	3 5.8%	35 67.3%	11 21.2%	-- --	3 5.8%
Cisco	3 6.0%	5 10.0%	34 68%	-- --	8 16%
Other	3 6.1%	5 10.2%	9 18.4%	29 59.2%	3 6.1%

Source: Harte Hanks Market Intelligence and author's calculations
The first line in each row is number acquired. The second line in each row represents percent acquired of vendor conditional on incumbent vendor. Observations are pooled over the sample period 1996-1998.

Table 5
Frequency of Vendor Choice Among Firms Making Joint Router and Switch Choices, 1996-1998

Incumbent/ Acquired Vendor	*3Com*	*Bay*	*Cisco*	*Other, Same Vendor*	*Other, Different Vendor*
3Com	50	2	0	--	4
	89.3%	3.6%	0%	--	7.1%
Bay	6	59	7	--	9
	7.4%	72.8%	8.6%	--	11.1%
Cisco	70	71	156	--	109
	17.2%	17.5%	38.4%	--	26.8%
Other	18	10	3	10	12
	34.0%	18.9%	5.7%	18.9%	22.6%

Source: Harte Hanks Market Intelligence and author's calculations
First row of line provides frequency. Second row of line shows probability of purchasing from switch vendor conditional on concurrently purchasing from router vendor.

Table 6

Means, Standard Deviations, Minimums, and Maximums for Sample

Table 6a: Data for Switch Vendor Choice

	Mean	*Standard Deviation*	*Minimum*	*Maximum*
IRTR	0.020	0.141	0	1
ILSW	0.003	0.054	0	1
PCRTR	0.075	0.241	0	1
PCLSW	0.025	0.142	0	1
RSCOMP	0.150	0.357	0	1
TOTNODES	148.0	360.8	0	15691
TOTPROT	0.780	0.679	0	6
STIME	0.079	0.270	0	1
DHQ	0.125	0.331	0	1

Table 6b: Data for Router Vendor Choice

	Mean	*Standard Deviation*	*Minimum*	*Maximum*
IRTR	0.020	0.141	0	1
PCRTR	0.075	0.241	0	1
TOTNODES	148.0	360.8	0	15691
TOTPROT	0.780	0.679	0	6
STIME	0.079	0.270	0	1
DHQ	0.125	0.331	0	1

Table 6c: Data for Switch Purchase Choice

	Mean	*Standard Deviation*	*Minimum*	*Maximum*
INSTRTR	0.353	2.979	0	205
INSTHUB	1.401	13.90	0	960
TOTNODES	148.0	360.8	0	15691
Δ TOTNODES	14.23	286.1	-13125	8201
DCRES	0.343	0.475	0	1
DCINTRA	0.274	0.446	0	1
DCHOME	0.310	0.462	0	1
DBANK	0.369	0.483	0	1
DSERV	0.457	0.498	0	1
DHQ	0.125	0.331	0	1
DFETHER	0.019	0.137	0	1
DFDDI	0.025	0.155	0	1
D97	0.296	0.456	0	1
D98	0.417	0.493	0	1

Table 6c: Data for Router Purchase Choice

	Mean	*Standard Deviation*	*Minimum*	*Maximum*
INSTRTR	0.353	2.979	0	205
TOTSITE	9.222	15.82	1	86
TOTLAN	2.365	9.188	0	422
TOTPROT	0.780	0.679	0	6
TOTDATA	18.60	175.6	0	10450
DCRES	0.343	0.475	0	1
DCINTRA	0.274	0.446	0	1
DCHOME	0.310	0.462	0	1
Δ TOTNODES	14.23	286.1	-13125	8201
DBANK	0.369	0.483	0	1
DSERV	0.457	0.498	0	1
DHQ	0.125	0.331	0	1
DFETHER	0.019	0.137	0	1
DFDDI	0.025	0.155	0	1
D97	0.296	0.456	0	1
D98	0.417	0.493	0	1

Table 7

Results from Demand Estimation

Choice: Switch Vendor

Observations: 28,088

Log-Likelihood Function for Choice Model: -713.0412

Variable	Coefficient	Standard Error
Characteristics of the choice		
Standalone sites		
ILSW*	1.68250	0.42243
IRTR*	1.0092956	0.26928
RSCOMP*	1.31089	0.21576
Firm branches		
ILSW*	1.90655	0.35064
PCLSW	0.44033	0.26818
IRTR*	0.657715	0.27872
PCRTR	0.00083484	0.27256
RSCOMP*	1.52413	0.17122
Variables measuring buyer heterogeneity		
DBAY	-0.18632	0.29648
DCAB*	-1.76804	0.37443
DCIS*	-1.31385	0.31520
DBAY×TOTNODES*	0.044398	0.020555
DCAB×TOTNODES**	0.041013	0.023453
DCIS×TOTNODES*	0.073345	0.019410
DBAY×TOTPROT	-0.15195	0.17392
DCAB×TOTPROT	0.30274	0.19543
DCIS×TOTPROT	0.0063392	0.16472
DBAY×STIME	0.061701	0.24713
DCAB×STIME*	0.61950	0.30549
DCIS×STIME**	0.48847	0.27936
DBAY×DHQ	0.17133	0.29502

$DCAB \times DHQ$	*0.33727*	*0.35202*
$DCIS \times DHQ$	*-0.25657*	*0.30447*

*Indicates significance at 5% level

**Indicates significance at 10% level

Table 8

Results from Demand Estimation

Choice: Router Vendor

Observations: 28,088

Log-Likelihood Function for Choice Model: -577.8143

Variable	*Coefficient*	*Standard Error*
Characteristics of the choice		
Standalone sites		
*IRTR**	*2.71467*	*0.46166*
Firm branches		
*IRTR**	*0.73801*	*0.26602*
*PCRTR**	*1.69987*	*0.20233*
Variables measuring buyer heterogeneity		
DBAY	*0.26843*	*0.33452*
*DCIS**	*2.07042*	*0.28109*
*DBAY×TOTNODES***	*0.040752*	*0.024249*
*DCIS×TOTNODES***	*0.041934*	*0.022306*
DBAY×TOTPROT	*-0.067779*	*0.19709*
DCIS×TOTPROT	*-0.24165*	*0.16291*
*DBAY×STIME**	*-0.79519*	*0.36240*
*DCIS×STIME**	*-0.74237*	*0.29871*
DBAY×DHQ	*0.53223*	*0.37385*
DCIS×DHQ	*0.14693*	*0.33214*
*INCL VALUE**	*0.71549*	*0.32701*

*Indicates significance at 5% level.

** Indicates significance at 10% level.

Table 9

Results from Demand Estimation

Choice: Whether to Buy Switch

Observations: 28,088

Log-Likelihood Function for Choice Model: -1866.5523

Variable	*Coefficient*	*Standard Error*
*CONSTANT, No Router**	*-5.55057*	*0.16628*
*CONSTANT, Purch Router**	*-2.32855*	*0.20932*
*INSTRTR**	*0.023387*	*0.0065958*
*INSTHUB***	*0.0022988*	*0.0013739*
TOTNODES	*0.012755*	*0.011209*
ΔTOTNODES	*0.0061640*	*0.010825*
TOTDATA	*-0.0011855*	*0.016048*
*DRESEARCH**	*0.42940*	*0.13894*
DINTRANET	*-0.0023935*	*0.13786*
DHOME	*0.066730*	*0.14034*
*DBANK**	*-0.60886*	*0.13228*
*DSERV**	*-0.53173*	*0.12888*
DHQ	*0.14016*	*0.13071*
*DFETHER**	*1.55659*	*0.16024*
*DFDDI***	*0.87641*	*0.14870*
*D97***	*0.25308*	*0.13439*
*D98***	*0.23216*	*0.13657*
*INCL VALUE**	*1.05096*	*0.15059*

*Indicates significance at 5% level.

** Indicates significance at 10% level.

Table 10

Results from Demand Estimation

Choice: Whether to Buy Router

Observations: 28,088

Log-Likelihood Function for Choice Model: -47,766.000

Variable	*Coefficient*	*Standard Error*
*CONSTANT**	*-5.82123*	*0.20718*
*INSTRTR**	*-0.032436*	*0.012031*
TOTSITE	*-0.0012074*	*0.0023216*
*TOTLAN**	*0.80305*	*0.26175*
*TOTPROT**	*1.0042422*	*0.060723*
*TOTDATA**	*0.029784*	*0.011208*
DRESEARCH	*0.14466*	*0.10680*
*DINTRANET**	*-0.40114*	*0.10811*
*DHOME**	*0.41280*	*0.10707*
*TOTNODES**	*0.20972*	*0.015744*
DBANK	*0.15939*	*0.099799*
*DSERV**	*-0.45307*	*0.10441*
DHQ	*0.11356*	*0.10053*
*DFETHER**	*0.71947*	*0.14938*
*DFDDI***	*0.24863*	*0.14158*
D97	*-0.099513*	*0.092964*
*D98**	*-0.55422*	*0.098776*
*INCL VALUE**	*0.43052*	*0.049037*

*Indicates significance at 5% level.

** Indicates significance at 10% level.

Table 11

Effects of Incumbency at Site Level

*on Router Purchases**

Table 11a: Sites not concurrently purchasing switch

Vendor	*Probability with Incumbency*	*Probability without Incumbency*
3Com	*0.313*	*0.094*
Bay Networks	*0.391*	*0.142*
Cisco	*0.906*	*0.764*

*Notes: Probabilities calculated for sites purchasing routers in the given period. Probabilities represent sample means of probability of purchasing from vendor given that the site does and does not have an installed base with the vendor in question.

Table 11b: Sites concurrently purchasing switch

Vendor	*Probability with Incumbency*	*Probability without Incumbency*
3Com	*0.336*	*0.110*
Bay Networks	*0.412*	*0.159*
Cisco	*0.888*	*0.731*

*Notes: Probabilities calculated for sites purchasing routers in the given period. Probabilities represent sample means of probability of purchasing from vendor given that the site does and does not have an installed base with the vendor in question.

Table 12

Effects of Incumbency at Site Level

*on Switch Purchases**

Table 12a: Sites not concurrently purchasing router

Vendor	*Probability with Incumbency*	*Probability without Incumbency*
3Com	*0.699*	*0.304*
Bay Networks	*0.709*	*0.298*
Cabletron	*0.530*	*0.162*
Cisco	*0.614*	*0.236*

*Notes: Probabilities calculated for sites purchasing switches in the given period. Probabilities represent sample means of probability of purchasing from vendor given that the site does and does not have an installed base with the vendor in question.

Table 12b: Sites concurrently purchasing router

Vendor	*Probability with Incumbency*	*Probability without Incumbency*
3Com	*0.579*	*0.230*
Bay Networks	*0.610*	*0.254*
Cabletron	*0.360*	*0.086*
Cisco	*0.761*	*0.431*

*Notes: Probabilities calculated for sites purchasing switches in the given period. Probabilities represent sample means of probability of purchasing from vendor given that the site does and does not have an installed base with the vendor in question.

Figure 1 – Networking Gear Choice Model

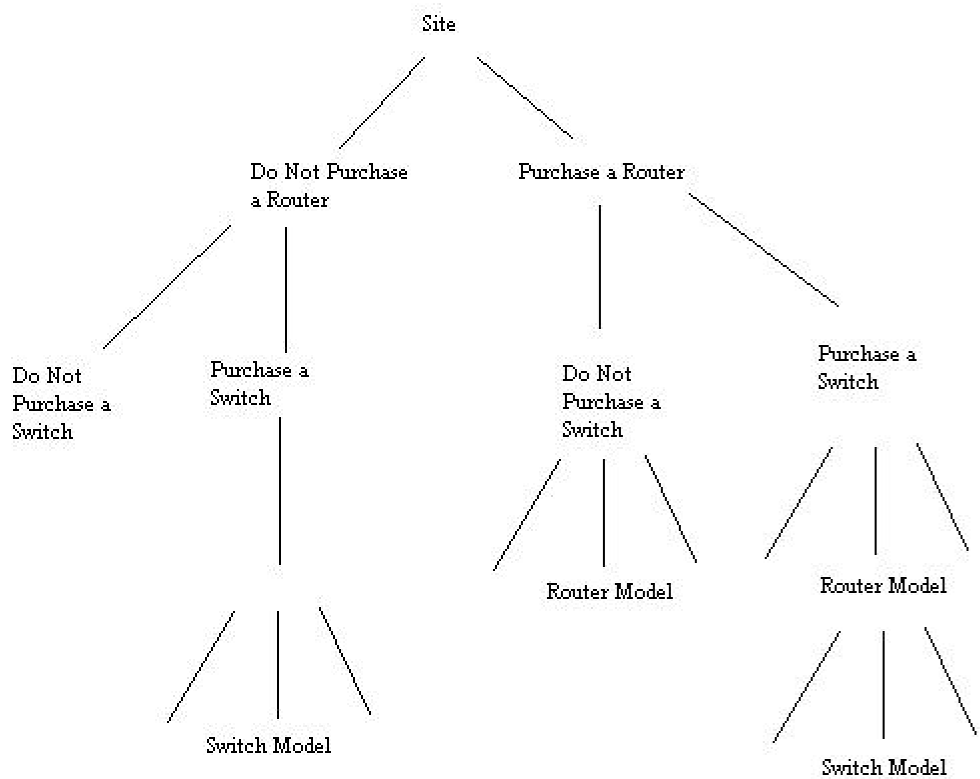

Figure 2 – Alternative Networking Gear Choice Model