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CAN VENDORS INFLUENCE SWITCHING COSTS AND COMPATIBILITY IN AN ENVIRONMENT WITH OPEN STANDARDS[1]

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Abstract

This paper examines the potential social costs of standardization, including possible vendor reactions to standards and their impacts on the adoption of new technology and long-term market structure. Specifically, we study how vendors might react to standards in the market for routers and switches, two of the most important pieces of networking hardware for the information systems infrastructure of modern firms. Using data from over 22,000 establishments surveyed by Harte Hanks Market Intelligence, we provide evidence that vendors are able to maintain high switching costs in the market for routers and switches despite the presence of open standards in the industry. Several vendor actions are discussed in this paper, including manipulating horizontal compatibility between comparable rival products and vertical compatibility between complementary products, maintaining a broader product line, creating product suites, and targeting specific market segments. Our results further suggest that the presence of switching costs can lead to inefficient adoption of new information technology and that vendors may be able to influence the speed of new information technology adoption.

Keywords: Open standards, switching costs, compatibility, switches, routers

Introduction

Investment in communications equipment is one of the areas of fastest growth in information technology spending. Investment in such equipment rose from $60.0 billion in 1995 to $116.6 billion in 2000, an average annual growth rate of 14.2 percent. One of the primary reasons for this rapid growth in spending is the existence of common standards that lower the costs of communication among heterogeneous networking hardware devices.

Information technology vendors can pursue one of two standardization strategies for their products. One alternative is for vendors to employ a proprietary specification (which may evolve into a *de facto* standard), which the vendor controls

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and which producers of competing and complementary products can use only if they license it. This strategy is most successful when vendors are capable of producing the complete set of IT products on their own and when they believe that they can secure enough demand for their proprietary specification. An alternative strategy is for the vendor to adopt open standards that are not controlled by any firm. The advantage to adopting these standards is that they ensure interoperability with complementary products that are offered by other firms.

Although vendors may benefit from embracing common standards, standardization also reduces differentiation, thereby promoting competition among vendors who use the same standard. In order to soften competition, vendors may *extend* standards by improving product functionality that helps differentiate their products and bring more value to customers. Vendors may also create switching costs strategically to retain customers (Shapiro and Varian 1999), for instance, by pursuing product designs or marketing tactics that help “lock-in” customers.

We contribute to the existing literature on standards by examining producer reactions to standards, an issue that has thus far received little attention in the standards literature. By examining buyer behavior in the market for routers and switches, we examine empirically the evidence for whether vendors influence the size of switching costs in markets with open standards. We describe several actions that vendors may take that increase switching costs and show which are consistent with the empirical evidence. Finally, we investigate whether vendor behavior influences the speed with which establishments adopt new technologies.

To this end, we estimate discrete choice models to identify the effects of switching costs on buyer choice of vendor and on new product adoption in the market for routers and switches. We use data on over 22,000 establishments from 1996 through 1998, concentrated primarily in the finance and services sectors. Harte Hanks Market Intelligence, a commercial market research firm that tracks use of Internet technology in business, undertook the survey.

Our results suggest that significant switching costs exist despite the prevalence of open standards in this market. Moreover, we show that switching costs vary significantly across vendors in this market, providing evidence that vendor actions can alter switching costs. We also provide evidence that vendor behavior may influence the speed with which establishments adopt new technologies. These results have important competitive implications, as they suggest that, even in an environment with open standards, incumbent vendors may take actions to embrace new innovations and extend them in ways that preserve incumbent advantage. These findings also suggest that standardization may not level the playing field for all vendors, as is widely believed.

By examining vendor and buyer behaviors in a market with standards, this paper answers the call by Katz and Shapiro (1994) for more empirical testing aimed at drawing out policy implications of standardization. Moreover, our paper contributes to recent empirical work that examines how sellers can create switching costs in apparently frictionless environments such as on-line markets (e.g., Brynjolfsson and Smith 2000; Chen and Hitt 2002).

The organization of the paper is as follows. In the next section, we provide some background information on the market for routers and switches. Vendor strategies and hypotheses are presented, followed by methodology and a description of the data. We show our empirical evidence and discuss various vendor strategies and implications based on these findings, and present our conclusions.

Routers and Switches: Technology, Standards, and Market Structure

Technology

Two major technologies were used in the latter half of the 1990s to transmit data between local area networks (LANs): routers and switches. Both technologies route traffic across LANs in a network and across the Internet following open protocols such as Ethernet or Token Ring.

Prior to the introduction of switches in the mid-1990s, routers represented the primary way in which networks were interconnected. In addition to routing network traffic, routers have additional functionality that enables them to monitor and manage network traffic efficiently. However, this added functionality comes at a cost due to the additional time it takes for routers to route packets. 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 has been 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, they lack the added functionality of routers.

Because of their greater speed and lower cost, enterprise switches are used as a substitute for routers, and they have begun to push routers to the edge of site networks. Nevertheless, due to their additional capabilities, routers have not been completely supplanted by switches. Routers continue to be valued for their management and security features. Moreover, because they are much more intelligent than switches at managing transmission lines, they are commonly used to connect LANs across multiple sites (Panko 2001).

Routers and Switches: Standards

Standards are a set of specifications or rules that govern the communications between different components. They are adhered to by producers to ensure interoperability between hardware and software produced by different vendors. Routers and switches, two of the most important pieces of LAN equipment responsible for both intra-network and inter-network communications, are governed by LAN standards (e.g., Ethernet or Token Ring), WAN standards (e.g., SONET), and Internet standards (e.g., TCP/IP).

Data communications uses a layered standards architecture, with standards at different layers performing separate tasks that together allow communications to occur. Networking standards for the Internet are developed by the Internet Engineering Task Force (IETF), while other standards are developed by the International Organization for Standardization (ISO) and International Telecommunications Union-Telecommunications Standard Sector (ITU-T). These standards are classified as *open* because they are not owned nor can they be changed by any one firm. Data communications hardware vendors such as Cisco Systems and 3Com actively participate in the standards-making process due to fears that they might be locked out of the standards-making process. Moreover, they voluntarily adhere to standards developed by these organizations because of the complexity of networking standards and the need for interoperability with complementary products.

Open standards such as TCP/IP play a valuable role in ensuring the interoperability and successful communication between heterogeneous devices produced by different vendors. However, in a layered standards architecture, these standards define only a fraction of the parameters necessary for communications and interactions among devices. Data communications vendors may extend open standards through enhancements at other layers of the standards architecture or through their interface with protocols governed by open standards.

The Market for Routers and Switches: Switching Costs and Firm Actions

Following previous literature, we define switching costs as any perceived cost from switching vendors, either from lost benefits or from explicit costs of switching (Beggs 1989; Klemperer 1995). The motivation for our study arises from our prior work that suggests switching costs influenced buyer behavior in the market for routers and switches (Forman and Chen 2004). In this paper, our focus is on explaining how vendor attempts to extend open standards may influence the magnitude of switching costs. We begin by stating the null hypothesis that switching costs cannot exist in an environment with open standards, and then we describe ways that vendors may extend standards that may lead to increased switching costs. Table 1 provides a list of strategies and associated hypotheses.

Can Switching Costs Exist in a Market with Open Standards?

As stated earlier, many of the basic protocols used in routers and switches are open standards such as Ethernet, Token Ring, or TCP/IP. Thus, switching costs in this market cannot arise explicitly from incompatibilities in the basic transport or Internet protocols used by routers and switches. They may arise from vendor extensions to these standards, however. Our first hypothesis examines whether buyers face any switching costs in their choice of vendor in the market for routers and switches.

> H0: Positive switching costs do not exist in the market for routers and switches.

Vendor Extensions to Open Standards

Rejection of H0 will have interesting implications, as this suggests that the implementation of open standards does not lead to a *frictionless* environment, as has sometimes been suggested. We are interested in how vendor efforts to extend existing standards lead to higher switching costs. Vendors benefit from open standards that facilitate interoperability with complementary products, thereby increasing potential demand. However, these same standards also reduce differentiation from competing products that use the same standard

Table 1. Strategies and Hypotheses

Strategy Name	Strategy Type	Description	Hypothesis/ Prediction
Horizontal Compatibility	Product	Modify compatibility of a particular product line (e.g., routers) so that vendor's products are more compatible together than with those of other vendors.	H1 and H2
Perceptual Compatibility	Marketing	Modify product to create concerns of incompatibilities among products among buyers.	H1 and H2
Vertical Compatibility	Product	Modify the compatibility of complementary products so that they work better together than with those of other vendors.	H3
Product Suites	Marketing	Place heterogeneous complementary products under a single brand to lower costs of identifying complementary products.	H3
Shopping Costs	Marketing	Offer discounts or additional services to customers purchasing multiple products. Used to increase buyers' shopping costs of using additional vendor so that they prefer to buy multiple products from the same vendor at the same time.	H4a and H4b
Adoption Delay	Marketing	Create concerns of incompatibilities among installed base and new products to delay adoption of new innovations among existing customers.	H5a and H5b
Niche Product	Product/ Marketing	Target a particular market segment to avoid direct competition with other vendors.	H6

and thus increase the intensity of rivalry among vendors. As a result, vendors who compete *within a standard* may have incentives to add proprietary features that add value for customers and differentiate their products. Such improvements in product functionality may indirectly increase switching costs. Moreover, prior literature has noted that oligopolists have incentives to directly manipulate the costs of switching away from their products (see the survey in Farrell and Klemperer 2001). In this paper, we will not be able to separately identify whether vendor actions to extend existing standards are undertaken to improve product functionality, directly manipulate switching costs, or both, because the outcomes of these actions are observationally equivalent: they all lead to increased switching costs. Our goal is to describe vendor actions to extend standards, regardless of their intent, and provide empirical evidence that is consistent with the view that these actions increase switching costs, and explore the potential impact of the presence of switching costs on market structure.

Horizontal Compatibility

Vendors can add proprietary enhancements that influence *horizontal* compatibility with rivals' products (Besen and Farrell 1994; Katz and Shapiro 1994). These enhancements may be added strategically to increase product differentiation and switching costs. They may also be added simply to improve functionality and add value to customers, which, in turn, helps to improve customer acquisition and retention. Regardless of the reason, these changes can make compatibility with competing products more difficult to achieve and lead to switching costs (Farrell and Saloner 1992).

In the market for routers and switches, vendors can influence horizontal compatibility in two ways. First, vendors may add enhancements such as proprietary code, management features, and user interfaces to their products. Because of the inherent complexity of networking equipment, even marginal differences in these features can make the costs of switching high. For example, many buyers are forced to employ outside consultants for set-up and installation. Vendor differences imply cost savings for buyers that purchase all of their products from the same vendor. These cost savings transform into lost benefits (a form of switching costs) if buyers switch vendors. As a result, we expect that differences in vendor extensions to standards will be reflected in different levels of switching costs across vendors.

Second, proprietary extensions to standards can also affect buyer perceptions of interoperability among products. Trade press articles emphasize that without proof of interoperability, users may fear that devices from new vendors may not work with their legacy investments (Tolly 2000). Over our sample period, third-party vendors provided batteries of tests of vendor interoperability. The simplest such tests showed that products were interoperable; however, vendor nonparticipation in complicated tests sometimes suggested the presence of significant interoperability problems (Tolly 2000) In particular, Cisco Systems has been reprimanded in the press for adding proprietary enhancements to standards that make interoperability more difficult (Wickre 1996). Such coverage of vendor incompatibilities should further influence buyer perceptions, particularly among Cisco buyers.

Thus, we have the following hypotheses:

H1: Switching costs will vary across router vendors.

H2: Switching costs will vary across switch vendors.

Vertical Compatibility

Vendors may also extend standards, for strategic or nonstrategic reasons, in ways that affect the *vertical* compatibility (or interoperability) between complementary products, thereby discouraging consumers from "mix-and-match" purchases (see Economides 1989; Einhorn 1992; Katz and Shapiro 1994; Matutes and Regibeau 198).

For example, Cisco's Internetworking Operating Systems (IOS) is software that acts as a common "glue" to ensure interoperability among its heterogeneous products: routers, switches, and hubs. Gawer and Cusumano (2002) argue that IOS is an attempt to create a platform that improves network functionality when only Cisco products are used. Cisco itself has claimed that there is enough proprietary code within IOS to allow Cisco products to "work better when they talk to each other, rather than machines made by rivals" (Thurm 2000).

Larger vendors are better able to offer value through vertical compatibility than smaller vendors are. In the market for routers and switches, smaller vendors find it difficult to offer the same breadth that Cisco is typically able to offer in its product line, thus making it difficult to offer the same level of vertical compatibility. Vendors with smaller product lines in communications equipment—such as 3Com, Bay Networks, and IBM—formed the Network Interoperability Alliance (NIA) in 1996 with the expressed goal of improving vertical compatibility among vendors. The NIA said it would promote a common set of open specifications for building integrated networks, and was widely perceived as a counter to advances in vertical compatibility that were made in Cisco's product line and spurred by IOS.

The need for vertical compatibility may engender switching costs that extend across products: prior investments in one product affect vendor choice in another. The presence of such cross-product switching costs may provide incumbent vendors in one market with an advantage when they enter into a new market (Cairns and Galbraith 1990). This also suggests that vendors may use broad product lines as one more instrument for improving their market position. For example, through its acquisitions and its own research and development. Cisco incorporated new innovations into IOS. This strategy made it easier for customers to upgrade to new Cisco products while maintaining their legacy systems (Bunnell 2000) and provided Cisco with an advantage as it moved into new segments of the networking market.

To summarize, vendor efforts to improve compatibility across products within their product lines may lead to buyer switching costs when choosing different router and switch vendors. The magnitude of these switching costs may vary based on vendor investments in vertical compatibility as well as the size of vendor product lines.

H3: Cross-product switching costs are positive and different across vendors.

Shopping Costs

Router and switch vendors commonly include heterogeneous products in a single *product suite* designed to serve many buyer needs. There are many examples: 3Com's NetBuilder, OfficeConnect, and SuperStack II product lines, as well as the BayStackl line by Bay Networks. These product suites lower buyer costs of identifying complementary products. By lowering buyer search and/or shopping costs through cross-selling or a package solution, a multiproduct firm with market power in one market may be able to extend its power into a second market (Choi 2002). Product suites can also be used as part of an entry-deterrence strategy (Nalebuff 1999): vendors with only some components of a bundle may find it hard to enter or compete against an incumbent who maintains a broader product line and sells a package solution.

Even when there are no issues of compatibility or interoperability among products from different vendors, a firm may also deliberately create shopping costs by lowering the costs of purchasing multiple products from the same vendor relative to the costs of purchasing similar products from multiple vendors, *ceteris paribus* (Klemperer 1992). This may be accomplished by, for example, offering discounts or consulting services for multiproduct purchases. These practices are particularly valuable to buyers when the vendor has a broader product line (Klemperer and Padilla 1997).

Overall, vendors may lower the costs of purchasing multiple products from the same vendor relative to the cost of purchasing them from multiple vendors. The magnitude of these switching costs may vary based on vendor investments in shopping costs as well as the size of vendor product lines.

H4a: There is a positive shopping cost from purchasing from more than one vendor at the same time.

H4b: The size of shopping costs will differ across vendors.

Adoption of New Technology

The presence of switching costs not only brings friction into the market but also may impede the diffusion of new innovations (Farrell and Klemperer 2001). When cross-product switching costs are large and persistent, buyers may be slow to adopt new innovations in which their incumbent vendor is still developing capabilities.

In the market for routers and switches, there is evidence that the largest vendor, Cisco Systems, was not immediately well-positioned to react to the rapid diffusion of switching technology. Cisco had no in-house switching technology developed when switches first began to diffuse widely. As customers came to increasingly demand switches as part of any networking solution offered by Cisco, the firm realized that it could be successful only if it obtained switching technology. Thus, Cisco filled holes in its product line though major acquisitions of start-up firms such as Crescendo, Kalpana, Grand Junction, and Granite Systems (Bunnell 2000). Through judicious use of acquisitions, Cisco was able to achieve some success in the switching market.

Not only was Cisco relatively slow in the development of early switching technology, but it also was initially unprepared for the development of layer-three switching capability and gigabit-Ethernet in 1997. Cisco's development of layer-three switching lagged behind that of other vendors, and there was some concern among analysts that Cisco was becoming vulnerable. Reinhard (1997) remarked that Cisco was "late to market with crucial new products that would help Cisco keep up with the pack."

However, the presence and perception of significant within-vendor vertical compatibility and the concerns with respect to cross-product switching costs from a mix-and-match approach may have diminished the extent to which previous Cisco customers adopted new switching technology from other vendors. Over this time period, Cisco felt that its advantage in routers and its IOS operating system would delay adoption of switches among its installed base of users while it developed competing products. This hope was reflected in the comments of Cisco executives: John Chambers claimed that customers were willing to wait for switches that were compatible with IOS rather than adopt a competitor's products (Bunnell 2000). Caruso (1997) describes how this belief was shared by many of Cisco customers.

The discussion above suggests a set of testable hypotheses on the rate with which buyers adopt switching technology. The likelihood of adopting switches will increase in an establishment with prior investments in routers, because increases in router quantity will indicate a predisposition on the part of the establishment to invest in networking equipment. However, the discussion above suggests that the marginal effect of such investments will be lower if they were made with Cisco than if they were made with other vendors. This is because Cisco had the largest installed base in routers, and prior work has shown that incentives to slow down—or at least discourage—the adoption of new innovations may be especially strong for incumbent vendors that have a large installed base but a weaker position in the new product market (Farrell and Saloner 1985). Moreover, as noted above, initially Cisco was at some competitive disadvantage in the market for switches. Thus, efforts made to improve vertical compatibility in Cisco's product line through IOS or other means could also slow their customers' adoption of switches. As noted earlier, these efforts could be either to improve product quality or to discourage switching. Either motivation leads to actions with the same result: slower adoption of switching technology for Cisco customers.[2]

Thus, our next hypotheses are

H5a: The likelihood of adopting switches will increase with in a buyer's prior investment in routers.

H5b: The effects of hypothesis 5a will be lower if buyers invested in routers sold by vendors with a large installed base in the router market.

[2]To be clear, there is one alternative hypothesis that would generate an equivalent prediction. If buyers of routers make vendor-specific complementary investments that are greater for large vendors than for small vendors, this would also imply that such buyers will be slower to adopt switches. However, to the extent that these complementary investments are different across vendors because of variation in product features, this alternative story is also consistent with our broader message: vendor actions give rise to vendor-specific switching costs even in an environment with open standards.

Buyer Differences

In the preceding sections, we have detailed some actions that vendors may take that raise buyer costs from switching vendors. However, switching costs may differ across buyers for reasons unrelated to vendor product strategy: some types of customers may be inherently more loyal than others or face higher switching costs than others. If customers with high and low switching costs self-select to different vendors, this could induce differences in switching costs across vendors.

Vendors may be able to use such differences in buyer characteristics to their advantage. For example, a vendor may attempt to target different groups of buyers using marketing strategies. In addition, when consumers have heterogeneous preferences, economic models suggest that firms prefer to locate away from their competitors. Thus, a vendor may pursue a combination strategy of product differentiation and market segmentation by providing some distinct features sought by certain consumers. As a result, product competition may be softened (Katz and Shapiro 1994).

H6: The conditional distribution of customer characteristics will vary based on the router and switch vendor chosen.

Methodology

Multinomial Logit

In the previous section, we presented a series of hypotheses asserting that vendors may have some control over the level of switching costs faced by their customers. Unfortunately, it is very difficult to observe vendor incentives and strategies. Thus, we are unable to specifically identify what actions were adopted by vendors and, thereby, measure the switching costs created by each action. However, we may be able to gain some insights into vendor actions by examining estimates of vendor switching costs. For example, differences in the magnitude of switching costs across vendors reflect, to some extent, firm decisions with respect to product compatibility and market segmentation. In this paper, we adopt the strategy of examining differences in switching costs across vendors to see whether the empirical evidence is consistent with vendors strategically influencing switching costs through product or marketing strategy.

Switching costs may be positive for reasons other than product or marketing strategy. For example, switching costs may be positive simply because of the inherent complexity of the products or services in question, and hence not directly under the control of vendors. To filter out the exogenous component of switching costs, we adopt Chen and Hitt's (2002) strategy of looking at variations in switching costs across vendors (the exogenous part of the switching cost will be cancelled out when we look at variations across vendors). If switching costs are truly exogenous, we will not observe variations in switching costs across vendors for products that serve the same purpose and follow the same standards. When switching costs differ significantly across vendors, there is some evidence that switching costs may be the result of vendor actions that extend standards in ways that create switching costs.

To identify variations in switching costs across vendors, we employ discrete choice models with a random utility framework (McFadden 1974). In addition to including variables that capture the effects of switching costs, our model includes variables that control for buyer heterogeneity. Formally, consider a set of buyers who associate some utility with each vendor, $U^i_j = v^i_j + \varepsilon^i_j$, that is comprised of two parts: a systematic component, ν, which captures the measured preference of buyers for particular vendors, and a random component, ε, which summarizes the contribution of unobserved variables.

As in Chen and Hitt (2002), we express the utility a buyer associates with a particular vendor as

$$U^i_{j|n} = \alpha_j + \lambda_j Z^i + \varepsilon^i_j \quad (4\text{-}1a)$$

$$U^i_{j|I} = \alpha_j + \lambda_j Z^i - sI^i_{j|I} + \varepsilon^i_j \quad (4\text{-}1b)$$

The superscript i indexes buyers while the subscript j indexes choices (or vendors) from the set of choices, $j \in \{1,\ldots,j\ldots J\}$. Equation (4-1a) describes the utility a buyer has when it has no prior relationship with any vendor and thus faces no switching costs from choosing a vendor. Equation (4-1b) characterizes the utility of a buyer from choosing vendor j when it has a prior relationship with a vendor, $I \in \{1,\ldots, j\ldots J\}$. α_j captures the average overall attractiveness of (or average value a buyer receives from) vendor j. Z^i is a set of observed customer characteristics for buyer i, and vector λ_j captures variation in buyer tastes across vendors. $I^i_{j|I}$ is a vector capturing buyer-vendor interactions for buyer i and vendor j.

s is a vector that measures how a previous relationship between buyer and vendor affects a buyer's utility from vendor choice j relative to other alternatives. Specifically, a buyer will face switching costs when choosing any vendor, say j, different from the incumbent vendor, I, used by the buyer. That is, $I^i_{j|I}$ is "turned on" when $j \neq I$, and the utility from choosing vendor j is lowered relative to the incumbent vendor, I, with which the buyer will not experience any switching costs. In our econometric models, we allow switching costs to depend on the buyer's incumbent vendor.[3] Finally, ε^i_j, the random component, captures the customer's idiosyncratic tastes and/or the effects of other unmeasured variables. The estimation of the switching cost vector, s, is our primary concern.

Let Y^i be a random variable that indicates choice. Each buyer will choose the vendor that maximizes its utility—that is, a buyer will choose vendor j (e.g., $Y^i = j$) if and only if $u^i_i > u^i_k$, $\forall k \neq j$. We assume that the error term is independently and identically distributed across products and consumers according to the extreme value distribution. The choice probability of vendor j for buyer i in a J-choice model is then given by the multinomial logit model:

$$\Pr(Y^i = j) = \frac{e^{v^i_j}}{\sum_{l=1}^{J} e^{v^i_j}} \qquad (4\text{-}2)$$

This type of error structure is governed by the independence of irrelevant alternatives (IIA) property—that is, the ordinal ranking of any two products does not depend on the attributes of other alternatives or even on the presence or absence of an alternative choice, and thus may produce unreasonable substitution patterns. However, we have experimented with more flexible error structures, including the mixed logit model, and the results are qualitatively the same.

Nested Logit

In hypotheses 5a and 5b, we seek to identify the costs of purchasing routers and switches from the same vendor. To identify these hypotheses, we develop a model that allows us to examine router and switch choice simultaneously. Since we believe substitution patterns for these two types of hardware are likely to differ, the IIA assumption for this joint decision is inappropriate. To model this joint decision, we use a *nested logit* model in which we model a buyer's decision of what type of equipment to buy (routers, switches, or routers and switches), followed by the choice of vendor for each type of equipment. Thus, we assume that the structure of a buyer's decision takes the form as presented in Figure 1.

We assume that the utility buyer i associates with a vendor choice is additively separable by equipment type, t, and vendor choice, v,

$$V^i_{t,v} = \alpha_t T^i + \beta_v U^i_{t,v} + \varepsilon^i_{t,v} \qquad (4\text{-}3)$$

where T^i describes variables representing the decision to purchase equipment type t and $U^i_{t,v}$ now represents variables affecting vendor choice, v, under equipment type t. The error term, $\varepsilon^i_{t,v}$, follows the generalized extreme value distribution (McFadden 1981).

The nested logit model allows for richer substitution patterns across branches. However, the choice probabilities within each bottom branch again have the form of a simple multinomial logit model,

$$P^i_{t,v_j} = \frac{\exp[U^i_{t,v_j}]}{\sum_{v_k \in C_t} \exp[U^i_{t,v_k}]} \qquad (4\text{-}4)$$

where C_t denotes the set of choices available to the buyer after a choice of branch t, and the $U^i_{t,v}$ contains the variables describing prior vendor interaction and the switching costs parameters. We model shopping costs by adding an additional vector, O_v, that captures the impact on utility when buyers purchase routers and switches from the same vendor. The parameter vector, c_v, which multiplies O_v, measures the value of reduced shopping costs. Thus, the choice probabilities within the bottom branch take the form

$$P^i_{t,v_j} = \frac{\exp[\alpha_{v_j} + \lambda_{v_j} Z^i - sI^i_{v_j|I} + cO_{v_j}]}{\sum_{v_k \in C_t} \exp[\alpha_{v_k} + \lambda_{v_k} Z^i - sI^i_{v_k|I} + cO_{v_k}]} \qquad (4\text{-}5)$$

The vector c reflects the additional value of choices in which the router and switch vendor are the same, controlling for average brand effects, α_v, observed customer characteristics, Z^i, and switching costs, s, including compatibility between routers and switches. As we did with switching costs, we examine both the average effect of purchasing routers and switches from the same vendor, and also allow the benefits of reduced shopping costs due to the use of single vendor to vary by vendor.

[3]Note that, in all of our regressions, we assume that the magnitude of switching costs does not depend on the vendor to which the buyer is switching; that is, we assume that the choice of vendor to which the buyer will switch is captured by the other variables related to the fit between the buyer and the vendor.

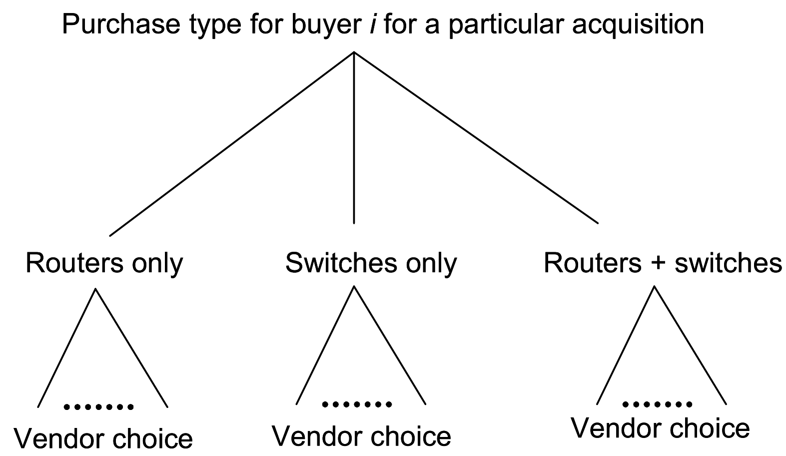

Figure 1. Nested Logit Model

Data and Variables

Data

We obtained data on technology usage from the CI Technology Database (hereafter CI database) over the period 1995 through 1998. The CI database contains data on (1) observation characteristics such as firm size, industry, and location, and (2) technology stocks of computers, networking equipment, printers, and other office equipment. Harte Hanks obtains these different components of the CI database at different times of the year. We assembled our sample by obtaining the most current information as of December of each year. For example, the observation for an establishment in 1995 will contain information on the establishment's characteristics and technology usage as recorded in the CI database in December 1995.

To keep the analysis of manageable size, we focus on industries that are generally regarded as heavy users of information technology[4] and establishments of over 100 employees from the CI database over the sample period. All establishments are located in the United States.

The unit of observation in the CI database is an establishment. Thus, the database will often have data on multiple establishments for a given firm. To infer purchase decisions, we calculate the change in quantity stocks installed from year to year for each vendor. Unfortunately, the database does not contain reliable product-level information on networking products in use at the firm. Thus, we are able neither to examine product-level purchase decisions nor to track the purchase and retirement of a particular piece of networking equipment by the firm.

Our discrete choice models include vendor dummies and variables that control for buyer heterogeneity. Because they do not vary by choice, buyer controls must be interacted with vendor dummies to be identified in the model. Thus, our identification strategy requires us to observe a large number of purchases from each vendor for the establishment controls to be identified. This requires us to drop observations where buyers purchase from smaller vendors, as well as observations that included prior investments from these smaller vendors. As a result, we are able to analyze only buyer decisions to purchase from the four largest vendors. Fortunately for us, these vendors account for over 70 percent of purchases in the CI database over our sample. Specifically, we examine the vendor choice decisions of firms that purchased routers from 3Com, Bay Networks, and Cisco and that purchased switches from 3Com, Bay Networks, Cabletron, and Cisco, which represent the dominant firms in the market for routers and switches.[5] We further drop establishments that are not in the database in consecutive years, that have missing fields, and that

[4]We obtained data from the CI database on SIC codes 60-67, 73, 87, and 27. These SIC codes correspond to the industrial groupings of Finance, Insurance, and Real Estate (60-67); Business Services (73); Engineering, Accounting, Research, Management, and Related Services (87); and Printing and Publishing (27).

[5]As of 1998, these vendors represented 88.1 percent of the market share for routers and 75.5 percent of the market share for switches.

Table 2. Measures of Prior Investments with Vendor

No	Variable $I^i_{j\|J}$	Construction/ Identification	Incumbent Vendor	Mean for Router Buyers	Mean for Switch Buyers
(1)	Prior investment with router vendor at establishment	= 1 when buyer has made prior investments with vendor but switches to another vendor *j*, where j ≠ I	3Com	0.0103	0.0144
			Bay	0.0200	0.0277
			Cisco	0.0787	0.0871
(2)	Prior investment with switch vendor at establishment	= 1 when buyer has made prior investments with vendor but switches to another vendor *j*, where j ≠ I	3Com	. . .	0.0122
			Bay	. . .	0.0148
			Cabletron	. . .	0.0041
			Cisco	. . .	0.0144
(3)	Percent of prior investment in routers from vendor at firm	= (Total routers from incumbent vendor/ Total number of routers at firm) when buyer has made prior investments with vendor but switches to another vendor *j*, where j ≠ I	3Com	0.0102	0.0088
			Bay	0.0294	0.0247
			Cisco	0.1167	0.0837
(4)	Percent of prior investment in switches from vendor at firm	= (Total switches from incumbent vendor/ Total number of switches at firm) when buyer has made prior investments with vendor but switches to another vendor *j*, where j ≠ I	3Com	. . .	0.0151
			Bay	. . .	0.0175
			Cabletron	. . .	0.0084
			Cisco	. . .	0.0221

Notes: The fifth and sixth columns show the average value of these variables for buyers of routers and switches, respectively. The entries in rows (1) and (2) and columns (5) and (6) of the table indicate the percentage of establishments that have made prior investments with the incumbent vendor. The entries in rows (3) and (4) and columns (5) and (6) show the arithmetic average of the variable in column (2) across establishments in our sample.

are located in Europe. The final analysis data set contains 6,596 observations from 1996; it contains 6,923 observations from 1997 and 9,249 observations from 1998. Finally, the majority of site/year observations in our sample purchase neither routers nor switches. We estimate our baseline switching costs models using only observations in which a router or switch is purchased since the focus of this paper is to estimate how switching costs resulting from prior investments in either routers or switches impact the vendor decisions of an establishment.[6]

Variables

We use 1-year lagged measures of prior router and switch investments to capture the effects of switching costs on vendor choice.[7] In our models, we follow Forman and Chen (2004) in allowing prior investments in complementary products to influence the choice of routers and switches. For example, we allow prior investments in routers to influence the choice of switch vendor.

Table 2 provides a list of key constructs for measuring vendor switching costs.[8] We first discuss our measures of prior router and switch investments at the establishment in rows (1) and (2) and then our firm-wide measures in rows (3) and (4). The dummy variables in rows (1) and (2) indicate whether an

[6]We have also estimated nested logit models in which establishments purchase routers and switches in the top "nest." When these models are estimated using sequential maximum likelihood (McFadden 1981), the results of the bottom nest are formally equivalent to the models estimated in this paper.

[7]One potential concern with this methodology arises if an enterprise's networking investment occurs over a period that extends beyond the end of the year. In this case, our measure of switching costs will reflect an extended investment in networking hardware, rather than switching costs. Fortunately, the vast majority of purchases in our data set do not occur over consecutive years. For example, among establishments purchasing routers and switches, only 3.6 percent and 4.2 percent of such purchases were made one year following a prior purchase.

[8]Correlations between variables in rows (1) and (2) representing establishment-level and firm-level installed bases of routers from the same vendor range between 0.43 and 0.49. Correlations between variables in rows (3) and (4) representing establishment-level and firm-level installed bases of switches from the same vendor range from 0.45 to 0.62.

Table 3. Description of Control Variables

Variable Description	Mean	Std. Dev.	Minimum	Maximum
Vendor-specific Bay Networks dummy	0.2000	0.4000	0	1
Vendor-specific Cabletron dummy	0.2000	0.4000	0	1
Vendor-specific Cisco dummy	0.2000	0.4000	0	1
Dummy indicating Finance, Insurance, or Real Estate (SIC 60-67)	0.3685	0.4824	0	1
Dummy indicating service sector (SIC 73 or SIC 87)	0.4538	0.4979	0	1
Log of number of employees	5.4649	0.7441	4.6052	9.7410
Dummy indicating multi-establishment organization	0.5305	0.4991	0	1
Dummy indicating 1997	0.3041	0.4600	0	1
Dummy indicating 1998	0.4062	0.4911	0	1
Dummy indicating branch of larger corporation	0.1198	0.3247	0	1
Dummy indicating large-scale computing applications at establishment	0.5254	0.4994	0	1
Log of total number of data lines at establishment	0.8640	1.5096	0	9.1259

Note: Number of observations is 113,840.

establishment has previously purchased from a vendor and are "turned on" for choices *j* that indicate the buyer chooses a vendor other than the incumbent *I*. For example, the Cisco variable in row (1) will be equal to one for choices *j* in which a buyer has made prior investments in Cisco routers but chooses 3Com or Bay routers. To provide a measure of the size of each vendor's installed base in our sample, columns (5) and (6) of the table indicate the percentage of establishments that have made prior investments with the vendor in rows (1) and (2). For example, row (1) indicates that 7.9 percent of router buyers and 8.7 percent of switch buyers have made prior investments in Cisco routers. The values in column (5) and row (2) are empty because we have insufficient observations to measure in our econometric model how prior investments in switch vendor *I* influence choice of router vendor *j*.

Because routers and switches are networked goods, we allow prior investments in routers and switches throughout the *firm* to influence vendor choice at an *establishment*. Rows (3) and (4) of Table 2 describe our firm-wide measures of prior investments. For those establishments that are part of multi-establishment firms, these variables are equal to the total number of routers from the incumbent vendor divided by the total number of routers in our database for the firm. Again, they are "turned on" for choices *j* in which the buyer chooses a vendor other than the incumbent *I*. For example, consider a buyer for which 50 percent of prior router investments at the firm are from Cisco. The Cisco variable in row 3 will then be equal to 0.5 for 3Com or Bay choices. Columns (5) and (6) show the arithmetic average of this variable across establishments in our sample.[9]

We include a number of control variables in our multinomial logit to control for buyer heterogeneity. The descriptive statistics of these variables are included in Table 3. To control for average differences in quality and price across vendors, we include vendor dummies in all of our models. We also include industry dummies that indicate whether the establishment is in Finance, Insurance, and Real Estate (Standard Industrial Classification (SIC) codes 60-67) or Business Services (SIC 73 and 87). An industry dummy for firms engaged in printing and publishing activities (SIC 27) is the omitted category.[10] To control for establishment size, we include the log of the number of employees at the establishment. To control for firm status, we include a

[9]To be clear, the value of our installed base variables will depend on a buyer's choice of vendor, while the values of columns (5) and (6) are averaged across establishments in our sample and do not depend on vendor choice. In effect, they are the maximum value of the variable across choices, averaged across establishments.

[10]We have also experimented with using two-digit and three-digit SIC dummies. The results are qualitatively the same.

dummy variable that is one when the establishment is part of a multi-establishment firm. To control for differences in vendor preferences for branch offices versus firm headquarters, we also include a dummy that is equal to one when an establishment is a branch office. Last, to control for differences in IT infrastructure that may influence vendor choice, we also include variables controlling for the total number of data lines and a dummy indicating that there are large-scale computing applications (mainframes, minicomputers, or servers) installed at the establishment.[11]

Empirical Evidence

Table 4 shows the results of multinomial logit regressions capturing buyer choices of router (column 1) and switch (column 2) vendors. The parameter estimates in Table 4 represent our estimates of the average level of switching costs *s* across vendors. Increases in *s* represent increases in the costs of switching vendors. The table shows that buyers face significant switching costs when changing vendors. Moreover, because the switching costs parameter, *s,* enters the buyer's utility function negatively, it decreases the likelihood of changing vendors. For example, column (1) of Table 4 says that if you have made prior investments in 3Com routers at the establishment but choose Cisco routers, your utility will be 1.2771 lower than when you had no prior investment.

In the multinomial logit model, the raw coefficient estimates are usually difficult to interpret because the level of utility for a choice is meaningful only when it is compared to the level of other alternatives. An easier way to understand the effects of switching costs is to look at marginal effects. To derive the marginal effects of switching costs on vendor choice, suppose the probability of vendor *j* being chosen by a buyer *i* with no switching cost is P^i_j. With switching costs, buyer utility will be less when the buyer chooses a vendor different from the incumbent. As a result, continuing to purchase from the incumbent vendor becomes relatively more attractive compared to the case with no switching costs, and thus, the probability of choosing the same vendor will increase when switching costs are present. Specifically, the probability of choosing the same vendor when there are switching costs, *s*, becomes $\frac{e^s P^i_j}{1+(e^s-1)P^i_j}$, which is greater P^i_j than for positive switching costs. As is evident from this formula, marginal effects generally differ across alternatives in the logit model because they are functions of the attributes of the alternative of interest relative to other alternatives. For instance, in Column (1) of Table 4, the switching cost of router incumbency is 1.2771, implying that the marginal impact of incumbency is $\frac{e^{1.2771} P^i_j}{1+(e^{1.2771}-1)P^i_j} = \frac{3.6P^i_j}{1+2.6P^i_j}$. Using this formula, we can see that the probability of an establishment purchasing 3Com routers increases from 11 percent without prior buyer-vendor interaction to 31 percent with prior interaction. Switch incumbency at an establishment similarly affects the choice of switch vendor.

Table 4 further shows that switching costs can arise from incumbency at the establishment or from other establishments at the same firm. The easiest way to read our variables representing firm-wide prior investment is to consider the effects that increasing the percentage of prior investment make with a given vendor from 0 to 100 percent when a buyer switches vendors. For example, using the same formula as the previous paragraph, an increase in the share of Cisco routers throughout the firm from 0 to 100 percent will increase the likelihood of buying a router from Cisco from 72 to 92 percent. All of the switching costs estimates are statistically significant. In all, this table motivates the current study, showing that there exist significant switching costs in the market for routers and switches. We now turn to the major purpose of this paper: demonstrating how vendor extensions to standards alter the magnitude of switching costs across vendors.

Variation in Switching Costs Across Vendors

Horizontal Compatibility

Table 5 shows that there is significant variation in the size of switching costs across vendors, providing some evidence that switching costs in this market may be influenced by vendors. Columns (1) and (2) demonstrate the impact of switching costs on the vendor choice of routers, while columns (3) and (4) show the impact on the vendor choice of switches.

Column (1) of Table 5 shows, by vendor, the estimates of our brand-specific switching costs parameters, *s,* in our model of router vendor choice. Because these coefficients enter the buyer's utility function negatively for vendors other than the incumbent vendor, an increase in *s* increases the likelihood of remaining with the incumbent vendor. Switching costs are stronger for 3Com (3.5424) than for either Bay (2.1827) or Cisco (1.5623). A Wald test shows that these differences are

[11]We have experimented with a broad array of controls other than those listed in Table 3, including number of network protocols, number of external data lines, headquarters controls, and types of Internet technologies in use. The results remain qualitatively the same.

Table 4. Multinomial Logit of Router/Switch Choice (after controlling for buyer characteristics and year trend)		
	Router (1)	**Switch (2)**
Prior investment with router vendor at establishment	1.2771**	0.6124**
	(0.22)	(0.17)
Pct of prior investment in routers from vendor at firm	1.5319**	0.4715**
	(0.20)	(0.22)
Prior investment with switch vendor at establishment	1.8453**	1.6420**
	(0.42)	(0.26)
Pct of prior investment with switches from vendor at firm	0.1526	0.6062**
	(0.34)	(0.24)
N	2997	2708
Log Likelihood	-576.62	-768.79
Pseudo R-Sq	0.4746	0.1808

Notes: Multinomial logit estimates with asymptotic standard errors in parentheses, estimated on a sample of buyers of routers and switches. Model also includes control variables listed in Table 3. *Indicates significance at 10% level. **Indicates significance at 5% level.

significant at the 5 percent level. By applying the formulae for marginal effects described above, these results imply that, other things equal, a switch from 3Com to Cisco is more than 15 percent less likely than a switch from Bay to Cisco.[12] Column (2) shows that when variables capturing firm-wide router investments are included, the effects of prior investments at the establishment on future router vendor choice are still statistically significantly greater for 3Com than for either Bay or Cisco. Similar patterns are found at the firm level: switching costs are again larger for 3Com (2.7927) than for Bay (1.8583) or Cisco (0.9876); the difference between 3Com and Cisco is significant at the 5 percent level. Again, these variables should be read as identifying the impact of an increase from 0 to 100 percent in the share of prior investments from the vendor. The results imply that if an establishment has all of its routers from 3Com, it is about 10 percent less likely to switch to Cisco than if all of its routers are from Bay.

Columns (3) and (4) of Table 5 show that the impact of prior switch investments on switch vendor choice varies by a buyer's incumbent vendor. In all specifications, we include the effects of routers and switches on switch vendor choice. As was the case with routers, the presence of an incumbent switch vendor at the establishment has a significant impact on switch vendor choice. However, there is somewhat less variation in switching costs than there is for prior router investments on router vendor choice. In Column (3), 3Com (2.3276), Bay (2.1312), and Cabletron (2.4453) all display similar magnitudes of switching costs arising from prior investments in switches at the establishment, while switching costs for Cisco are lower (1.0898). The coefficients for 3Com and Bay are each significantly different from the coefficient for Cisco at the 10 percent level. Column (4) shows that the pattern of switching costs arising from prior investments at the establishment are similar when firm-wide measures of prior vendor interaction are also included. Examining variation in switching costs from firm-wide prior investments, 3Com (1.4447) is again significantly different from Cisco (0.0913) at the 10 percent level, while no other differences are significant. Overall, our results provide strong support for hypotheses 1 and 2.

Vertical Compatibility

Columns (3) and (4) of Table 5 also provide evidence of significant differences in cross-product switching costs across vendors, suggesting that vendor actions influenced vertical compatibility. In column (3), cross-product switching costs

[12]Because marginal effects in the logit model (in terms of changes in probability) are a function of the attributes of the alternative of interest relative to other alternatives, they generally differ across alternatives. The 15 percent figure was calculated as the difference between two conditional probabilities. The likelihood of choosing Cisco given a 3Com installed base is 18.9 percent, while the likelihood of choosing Cisco given Bay is 34.9 percent.

Because we have insufficient observations to identify the parameters of interest, we do not include the effects of a vendor-specific installed base of switches in this model. In an alternative specification, we included the effects of average switching costs arising from switches plus a single vendor-specific effect for routers and switches. The results are qualitatively the same.

Table 5. Vendor-Specific Effects (Dependent Variable: Router/Switch Vendor Choice)				
	Router (1)	**Router (2)**	**Switch (3)**	**Switch (4)**
Prior investment in 3Com routers at establishment	3.5424**	2.6078**	2.2301**	1.6212**
	(0.4484)	(0.4878)	(0.4649)	(0.5254)
Prior investment in Bay routers at establishment	2.1827**	1.2316**	0.9026**	0.6411*
	(0.3093)	(0.3656)	(0.2862)	(0.3551)
Prior investment in Cisco routers at establishment	1.5623**	1.1289**	0.6565**	0.5294**
	(0.2842)	(0.3002)	(0.1978)	(0.2218)
Pct of firm-wide router investment from 3Com		2.7927**		2.5354**
		(0.6508)		(1.2712)
Pct of firm-wide router investment from Bay		1.8583**		0.5253
		(0.3850)		(0.4542)
Pct of firm-wide router investment from Cisco		0.9876**		0.2797
		(0.2897)		(0.3178)
Prior investment in 3Com switches at establishment			2.3276**	1.8762**
			(0.5570)	(0.5820)
Prior investment in Bay switches at establishment			2.1312**	2.0561**
			(0.4122)	(0.4967)
Prior investment in Cabletron switches at establishment			2.4453**	1.8528**
			(0.6494)	(0.7496)
Prior investment in Cisco switches at establishment			1.0898**	0.9898**
			(0.4070)	(0.4536)
Pct of firm-wide switch investment from 3Com				1.4447**
				(0.6369)
Pct of firm-wide switch investment from Bay				0.1894
				(0.5216)
Pct of firm-wide switch investment from Cabletron				0.9735
				(0.7231)
Pct of firm-wide switch investment from Cisco				0.0913
				(0.4211)
N	2997	2997	2708	2708
Log Likelihood	-615.17999	-578.3271	-763.45101	-752.47082
Pseudo R-Sq	0.4395	0.4731	0.1865	0.1982

Notes: Multinomial logit estimates with asymptotic standard errors in parentheses, estimated on a sample of buyers of routers and switches. Model also includes control variables listed in Table 3.
*Indicates significance at 10% level.
**Indicates significance at 5% level.

arising from the prior investments in 3Com routers at the establishment (2.2301) are significantly different from those arising from Bay (0.9026) and Cisco (0.6565) at the 5 percent level. These results imply that, other things equal, an establishment with a 3Com router is about 13 percent less likely to purchase switches from Cisco than is an establishment with a Bay router. Column (4) shows that these results are robust to the inclusion of variables proxying for firm-wide investments. Column (4) also shows that there are significant differences in switching costs arising from prior investments in routers throughout the firm: 3Com switching costs are significantly different from Cisco at the 10 percent level.[13] Thus, our results provide evidence that vendor actions can influence the switching costs arising from prior investments in complementary products, supporting hypothesis 3.

Shopping Costs

The shopping costs estimates from our nested logit model are shown in Table 6.[14] To identify shopping costs, we add an additional variable that is equal to one when buyers choose the same router and switch vendor: increases in the parameter estimate on this variable imply greater utility from buying routers and switches from the same vendor or, equivalently, greater shopping costs from involving multiple vendors, after accounting for cross-product switching costs between routers and switches. We find that buyers purchasing routers and switches together face significant shopping costs when they purchase from multiple vendors. In column (2), the coefficient on our shopping cost variable, 1.4368, is significant and suggests that buyers purchasing routers and switches together are more than 60 percent more likely to buy from a vendor offering both products than from an otherwise identical vendor offering only one.

We also allow the benefits of purchasing routers and switches from the same vendor to vary across vendors. In this case, we create separate dummies for when buyers purchased both routers and switches from 3Com, Bay Networks, or Cisco. The benefits of purchasing routers and switches from the same vendor are significant for all three major vendors. In addition, we find the benefits of buying routers and switches together from 3Com (2.3899) and Bay (1.9863) to be significantly higher (at the 5 percent level) than buying them together from Cisco (0.4020). That is, among those buyers purchasing routers and switches together, the additional value buyers get from choosing identical router and switch vendors is greater for 3Com or Bay than for Cisco.

Switching Costs and the Adoption of New Technology

In this section, we examine how variations in a vendor's installed base of routers affect the likelihood that a buyer will adopt switching technology. To do this, we examine the effects of prior router investments in 1995 on the decision to adopt switches in 1998.[15] In our experiment, we allow these buyer decisions to depend on prior investments in IT, particularly in networking technology such as routers. We then allow the marginal impact of prior networking investments to vary based on the identity of the buyer's router vendor. If hypothesis 5 is correct, the likelihood of adopting switches will be increasing with the number of routers currently installed at the establishment: however, this positive effect will be lower if those investments were made with vendors with a large installed base in the router market. Since Cisco has by far the largest installed base in routers, we test this hypothesis by interacting a dummy that indicates the buyer has purchased Cisco routers with the number of routers that have been installed at the establishment. Our control variables are similar to those used in the vendor choice models. We assume the value to establishment *i* of adopting switches to be the following:

$$\begin{aligned} Y_i \; = \; & \beta_0 + \beta_1 EMPLOYMENT_i + \beta_2 DATALINES_i + \\ & \beta_3 PCS\text{-}PER\text{-}EMP_i + \beta_4 MIPS\text{-}PER\text{-}EMP_i + \\ & \beta_5 TOTALROUTERS_i + \beta_6 PRIOR\text{-}CISCO_i + \\ & \beta_7 PRIOR\text{-}CISCO_i \times TOTALROUTERS_i + \\ & \beta_8 PCT\text{-}LAN_i + \varepsilon_i \end{aligned}$$

If we assume the error term ε_i is i.i.d. normal, then the probability that establishment *i* participates can be estimated with a probit regression. Because the majority of buyers in our sample purchase neither routers nor switches, we expect the uninteracted Cisco dummy to pick up the effects of unobservable propensity to invest in routers and switches, and to be positive. In contrast, we expect the coefficient on the interaction between the Cisco dummy and the number of routers installed to be negative, indicating that the marginal effect of prior investments in routers will be weaker if they

[13]We also considered alternative specifications in which we included a constant vendor-specific term that impacted all installed base terms (routers and switches, establishment-level and firm-wide) equally. Not surprisingly, the results mirror those of Table 5.

[14]Due to space constraints, we include only our shopping cost estimates. Estimates for establishment controls and switching costs are available from the authors upon request.

[15]In this section, we depart from the strategy used in the rest of the paper by using 1995 data for our explanatory variables rather than prior-year data. The reason is that prior-year router variables may capture IT investments that were made simultaneously with the decision to adopt switches by 1998.

Table 6. Shopping Costs Estimates

	(1) Total	(2) By Vendor
Shopping Costs	1.4368**	. . .
	(0.1553)	. . .
3Com	. . .	2.3899**
	. . .	(0.2683)
Bay Networks	. . .	1.9863**
	. . .	(0.2298)
Cisco	. . .	0.4020**
		(0.1979)

Notes: Nested logit estimates with asymptotic standard errors in parentheses, estimated on a sample of buyers of routers and switches. These estimates indicate the additional value of reduced shopping costs among those buyers purchasing routers and switches simultaneously. Model includes control variables listed in Table 3 and controls for switching costs.
*Indicates significance at 10% level.
**Indicates significance at 5% level.

Table 7. Prior Vendor Choice and the Adoption of Switches (Dependent variable: switch adoption decision: yes or no)

	(1) Probit	**(2) OLS Conditional on Adoption**
Constant	-3.7246**	-0.0318
	(0.1474)	(0.2277)
Total Employment	0.4578**	0.2398**
	(0.0251)	(0.0368)
Total Data Lines	0.1009**	0.0298
	(0.0227)	(0.0316)
PCs per Employee	0.0625**	0.2201**
	(0.0230)	(0.0403)
MIPs per Employee	0.0099	0.0491**
	(0.0087)	(0.0163)
Total Installed Routers	0.1429**	-0.0002
	(0.0377)	(0.0469)
Prior Cisco Dummy	0.1869*	-0.1525
	(0.0999)	(0.1228)
Prior Cisco Dummy × Total Installed Routers	-0.1812**	0.0978
	(0.0692)	(0.0812)
Percent LAN Applications	0.5949**	-0.1361
	(0.0686)	(0.0970)

Notes: Model (1) is a probit model with asymptotic standard errors in parentheses. Model (2) is OLS conditional on the decision to adopt switches.
*Indicates significance at 10% level.
**Indicates significance at 5% level.

have been made with a vendor with a large installed base. To account for potential nonlinearities and to smooth large values, we take logarithms of TOTALROUTERS, EMPLOYMENT, and DATALINES.[16]

Column (1) of Table 7 shows the results of the probit regression. As predicted, prior investments in routers increase the likelihood of adopting switches. However, the interaction of Cisco and the number of routers installed has a negative effect on adoption. In all, the net effect of prior investments in Cisco routers is negative if an establishment has five or more routers.[17] The other variables in the equation have the expected effect on adoption: switch adoption is increasing in employment, total data lines, PCs per employee, MIPs per employee, and the fraction of enterprise software applications that are accessed over the LAN.

Column (2) of Table 7 shows the results of a linear regression of the logged number of switches in 1998 on the same variables, conditional on the decision to adopt switches. We run this regression to measure whether investment in Cisco has any effect on deployment, conditional on the adoption decision, and to serve as a robustness check to Hypothesis 5. Though prior investment in Cisco routers affects the decision to adopt switches, it has little effect on deployment of switches. This is precisely the pattern one would expect if prior investment in Cisco routers raises the costs of adopting switches. Overall, our results support Hypothesis 5a and 5b. Prior investments in router increase the likelihood of adopting switches, however these effects will be lower if these prior investments were made with Cisco. In some cases, investment in Cisco routers is actually associated with lower probability of adopting switches.

Variations in Buyer Characteristics by Vendor Choice

The differences in vendor switching costs recorded in Table 5 may not only reflect strategic product decisions by vendors, but they may also reflect unobserved differences in buyer characteristics across vendors. While we have controlled for buyer heterogeneity in all our previous regression analyses, there might be other unobserved factors that lead to differences in buyer characteristics across vendors that cannot be explained by including observed buyer attributes *independently*. Vendors may target certain market segments with certain combinations of attributes or buyers may self select them into different vendors' products. These unobserved differences in buyer characteristics may influence estimates of the magnitude of vendor switching costs. For example, 3Com's product line caters primarily to the "edge" of corporate networks, and trade press articles emphasize 3Com's strategy to sell to small- and medium-sized buyers (Mehling 1997). If small- and medium-sized buyers have systematically higher switching costs than other buyers, the results of Table 5 may partly reflect differences in buyer characteristics, rather than strategic product decisions by vendors.

Table 8 presents some evidence that is consistent with this hypothesis. It exhibits several measures of establishment size, and then displays how the means of these variables vary by vendor choice. It shows that buyers of 3Com routers are generally smaller than those of Bay or Cisco. This is true regardless of whether we measure size using employment, total mainframe and server capacity (MIPS), total data lines, total data line capacity (bandwidth), or total routers. However, using any of these measures, there is no statistically significant difference in establishment size between 3Com buyers and buyers of Bay or Cisco. This is due in part to the large standard errors for 3Com. These large standard errors suggest that buyers of 3Com routers are on average smaller than other vendors; however, a great deal of dispersion remains. 3Com buyers are also less likely to be part of a multi-establishment firm; this result is statistically different from buyers of Cisco (5 percent level) and Bay (10 percent level).

The bottom panel of Table 8 shows differences in establishment size measures by switch vendor choice. As was the case with routers, 3Com buyers tend to be smaller than those of other vendors. However, unlike routers, these differences are often significant. For example, 3Com buyers are significantly smaller than Cisco buyers when measured using total employment, MIPS, and routers.

Figure 2 provides further evidence that 3Com targeted lower-end buyers. It presents data on quantity market shares of small office/home office (SOHO) routers by vendor over our sample period.[18] Quantity shares for this growing market segment increased for all four vendors. However, for all quarters but one, 3Com had the largest market share in SOHO equipment. By the end of 1998, the market share held by 3Com in this segment approached 50 percent.

[16]To be precise, because some values of total data lines and total routers are equal to zero, we take the logarithm of one plus the values of these variables.

[17]To calculate this variable, we must sum the effects of total installed routers, prior Cisco dummy, prior Cisco dummy × total installed routers. For five routers, this is equal to (0.1429 × 5) + 0.1869 – (0.1812 × 5) = -0.0046.

[18]Data for this chart is from the Dataquest Quarterly Market reports. Dataquest defines four segments in the router market: small office/home office, low end, midrange, and high end. The SOHO market consists of smaller, desktop routers that are the smallest, most inexpensive devices sold in the router market.

Table 8. Differences in Buyer Characteristics by Vendor Choice

		3Com	Bay	Cisco	Cabletron
A. Router Choice	Employment	789.750	961.289	971.270	…
		(112.230)	(88.188)	(39.099)	…
	Total MIPS	120.283	179.208	227.445	…
		(93.035)	(73.105)	(32.412)	…
	Multi-Est Status	0.576	0.685	0.686	…
		(0.049)	(0.038)	(0.017)	…
	Total Data Lines	44.141	68.154	74.073	…
		(32.161)	(25.271)	(11.204)	…
	Total Bandwidth	30.871	174.391	260.094	…
		(271.027)	(212.968)	(94.422)	…
	Total Routers	0.978	1.020	1.280	…
		(0.548)	(0.430)	(0.191)	…
B. Switch Choice	Employment	694.000	961.910	1179.614	1055.507
		(71.122)	(69.205)	(61.767)	(109.568)
	Total MIPS	158.449	402.702	673.021	296.600
		(149.469)	(145.439)	(129.809)	(230.266)
	Multi-Est Status	0.596	0.681	0.636	0.693
		(0.036)	(0.035)	(0.031)	(0.055)
	Total Data Lines	67.466	72.484	55.631	105.560
		(29.478)	(28.684)	(25.601)	(45.413)
	Total Bandwidth	41.891	347.398	142.747	203.049
		(93.284)	(90.769)	(81.014)	(143.709)
	Total Routers	1.045	1.612	4.165	3.120
		(0.798)	(0.776)	(0.693)	(1.229)

Notes: Variables means calculated by router and switch vendor chosen. Standard errors and hypothesis tests calculated using pooled OLS regression of variable on router and switch vendor choice dummies.

Although differences in buyer characteristics across vendors may be one reason for variation in switching costs across vendors, we consider this explanation to be complementary to our hypothesis of vendor-induced switching costs. Based on economic and marketing theories, both vendor-induced switching costs and differences in buyer characteristics reflect endogenous product choices made by vendors to maximize profits. Vendors make decisions on product functionality, usability, and software to strategically target different market segments and, conditional on those market segment choices, to increase or decrease switching costs.

Discussion

Our empirical results suggest that despite the widespread use of open standards, there exist significant switching costs in the market for routers and switches. We show not only that switching costs arise from repeated purchases of the same product, but also that switching costs arise when choosing products complementary to an establishment's prior investments. Significant differences in the magnitude of switching costs across vendors suggest that vendors may have some influence over switching costs. Our results suggest that ven-

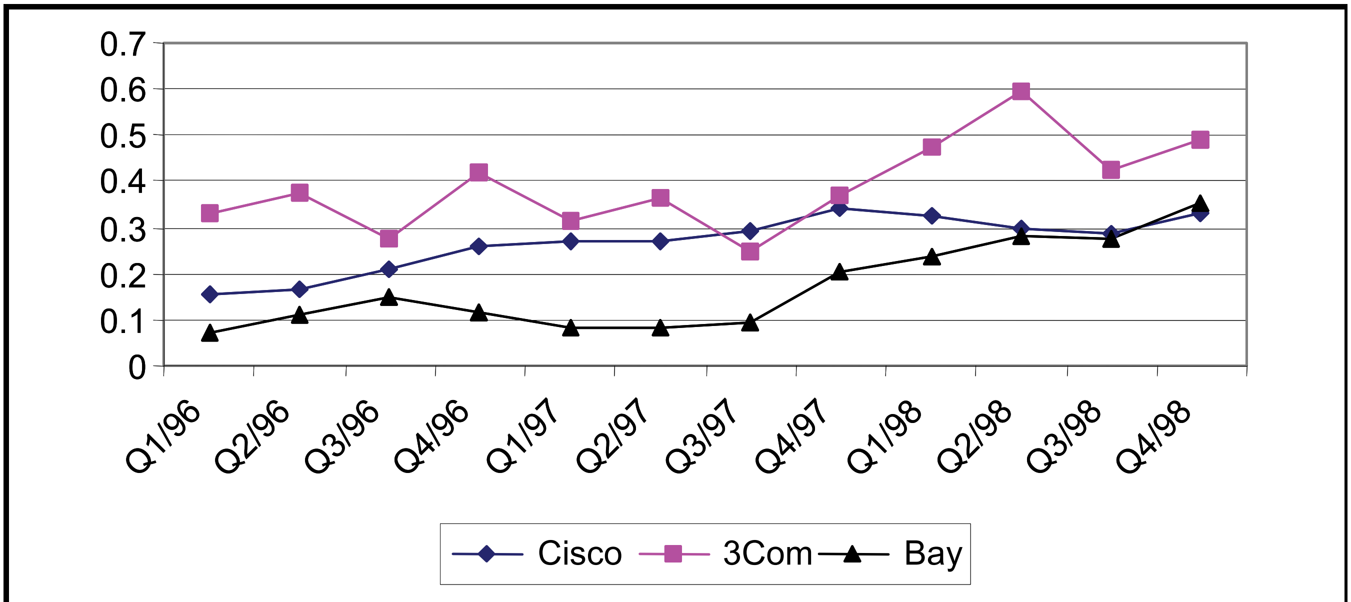

Figure 2. Quantity Share of SOHO Routers

dor extensions to open standards create incompatibilities and switching costs. While we are unable to determine whether these switching costs are created strategically or are a result of vendor actions to improve product functionality, these switching costs both have the same impact on buyer behavior and market competition. In all, our results suggest that this market is not as frictionless as is commonly believed.

In addition to positive cross-product switching costs, we find significant shopping costs for buyers that purchase from multiple vendors at the same time. These shopping costs may arise as a result of discounted consulting and configuration services or as a result of bundle discounts offered to buyers who purchase multiple products from one vendor. These additional benefits discourage buyers from mix-and-match and may allow a vendor to cross-sell other products to buyers.

Our data also suggest that customer profiles differ across vendors, suggesting that vendors may have tried to segment the market to reduce market competition. Overall, our results suggest that vendor actions reduce the intensity of competition in the market for routers and switches.

Prior literature has suggested that vendors that have disproportionately benefitted from older technologies will tend to resist new innovations (Farrell and Saloner 1985). However, until now this proposition has remained relatively untested due to lack of data. Since our sample coincides with the time period over which switches initially diffused, we are able to examine whether vendors are able to influence the speed with which their customers adopt switches. After accounting for buyer propensity to adopt new IT, our results show that establishments with Cisco routers adopt switches more slowly than otherwise identical buyers that have purchased routers from other vendors. These results suggest that switching costs not only can soften competition in the market, but that they may also offer dominant vendors a way to influence the speed of new IT adoption.

Why Were 3Com Switching Costs Larger than Bay Networks or Cisco?

One surprising result of this paper is that 3Com switching costs exceeded those of Bay Networks, Cabletron, and Cisco. This result is surprising because coverage of network interoperability and switching costs in the trade press has focused primarily on the costs of switching from *Cisco* to other vendors (e.g., Bunnell 2000; Miller 1996; Wickre 1996).

How did 3Com switching costs come to exceed those of its competitors, particularly Cisco? One possibility is that 3Com raised its switching costs in response to deteriorating market fortunes. Our data indicate that 3Com's share of router and switch sales fell over our sample period, from 4.5 percent to 4.2 percent in routers and from 20.6 percent to 16.4 percent in switches. 3Com's deteriorating market position may have provided it with incentives to raise switching costs and guard its installed base. On the other hand, the high switching costs faced by 3Com's customers may reflect the characteristics of 3Com buyers. As noted above, 3Com has focused on the small business market and the "edge" of the network market (Mehling 1997), and customers in the small business segment may have inherently higher switching costs. Our results, reported in the previous section, offer some evidence in support of this argument.

Policy Implications

Overall, our results raise a cautionary flag to optimists who believe that use of open standards will reduce product switching costs to zero and create a level playing field for vendors. In particular, our results suggest that there are still various instruments vendors may adopt to raise switching costs, and their incentives to influence switching costs may be higher when standardization is taking place. Our results also indicate that the impact of these actions can extend across different markets and across different time periods. This is not to say that standardization is bad for society. In fact, previous literature has shown that standardization can enhance social welfare as it promotes product adoption and reduces unnecessary friction for product switching. Our paper shows, however, that switching costs are not likely to be completely eliminated under standardization.

In this paper we show that, because of cross-product switching costs and shopping costs, vendors with a prior advantage in one market can use this to gain competitive advantage in related complementary markets. Thus, cross-product switching costs and shopping costs highlight the value of broad product-line strategies pursued by firms like Cisco (Bunnell 2000).

Moreover, we provide evidence that the presence of switching costs may allow incumbent vendors to maintain market advantages over time, even in the presence of new disruptive technologies (Christensen 1997). With these switching costs, an incumbent vendor can slow down the diffusion of new IT innovations to allow itself sufficient time to embrace the new innovation and incorporate it in its product line, which helps preserve and extend its advantageous position to new product markets. This strategy has been successfully deployed by vendors such as Microsoft and Cisco. While a delay in new IT introduction can also occur because the firm does not have the requisite capabilities and it takes time to develop the necessary skills, our results also suggest that the presence of switching costs can help alleviate the firm's disadvantage associated with such delay, which in turn can help preserve a firm's market position. That is, regardless of strategic delay of adoption or lack of sophistication, the presence of cross-product switching costs can favor dominant firms.

Thus, our results suggest that incumbent vendors can extend open standards in ways that work to preserve their market power. This raises some interesting questions. In particular, should standardization organizations attempt to identify and punish extensions to standards that are intended to reduce competition?

A major challenge to the *ex post* regulation of vendor adherence to standards is the difficulty of evaluating vendor intent. Current antitrust law will not act against a firm that does not attempt to act anticompetitively (Lemley 1996). In this paper, we have highlighted the challenges of identifying whether extensions to standards or other vendor conduct will enhance buyer value or to raise switching costs. Under these conditions, how can one determine whether enhancements to standards are used to raise switching costs?

The challenges of identifying vendor intent have been demonstrated in recent antitrust proceedings. One example is the Sun Microsystems-Microsoft dispute over Sun's Java programming language, in which Sun alleged Microsoft made illegal changes to its Java programming environment (Fordahl 2004), while Microsoft claimed that it made these changes to improve Java's functionality in a Windows environment. While Microsoft claimed that such extensions to standards improve the value of Microsoft products to its customers, others interpret such moves as anticompetitive strategies that unfairly extend Microsoft's market power to other markets. The difficulty of identifying vendor intent would make potential *ex post* regulation of extensions to open standards exceedingly difficult.

Conclusions

Our paper is in the spirit of the call by Katz and Shapiro (1994) for empirical testing in order to draw out policy implications of standardization. By examining buyer behavior in the market for routers and switches, our paper is one of the first to empirically examine the implications of vendor reactions to open standards. Overall, our paper establishes three main results.

1. Vendors in our sample were able to maintain significant switching costs despite the presence of open standards.

2. We show that vendors in the market for routers and switches appeared to be able to influence switching costs,

which may simply result from adding value to buyers or else may result from strategic actions by vendors. Our findings provide some evidence consistent with the literature that vendors may create switching costs by influencing *horizontal* compatibility between comparable rival products as well as *vertical* compatibility within the product line. We also provide evidence of significant *shopping costs* faced by buyers when they purchase from multiple suppliers. These shopping costs may be created by vendors to discourage buyers from purchasing from multiple vendors. Moreover, we provide evidence suggesting that vendors targeted different market segments to avoid direct competition.

3. Our results further show that the vendor with the largest market installed base of an older technology appeared to be able to influence the speed of new technology adoption.

Altogether, these findings suggest that the presence of switching costs can lead to inefficient competition and inefficient adoption of new information technologies and that a vendor with initial advantages in a market may be able to parlay its advantage into a larger, lasting one (Katz and Shapiro 1994), even when the vendor does not engage in any anticompetitive conduct. Such persistence may even occur in products with open standards. Our paper represents a first attempt to document and measure vendor actions that may increase switching costs in the presence of standards. Understanding the implications of these actions is important in drawing useful policy decisions.

These results have important implications for standardization bodies and antitrust authorities. Standardization bodies should consider how vendors may respond to standards, and how these vendor reactions to standards may influence the value of standards and evaluate whether such actions should precipitate changes to the standards-making process. Moreover, given increasing use of standards in Internet and other communication technologies, these results suggest that antitrust authorities may need to carefully consider the impact of vendor reactions to standardization on competition and consumer welfare to ensure that an appropriate amount of competition and innovation takes place in the market.

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