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Network Effects and Switching Costs in the Market for Routers and Switches

by

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Network Effects and Switching Costs

In the Market for Routers and Switches

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Abstract

This research examines the impact of switching costs on vendor choice in the market for routers and switches. We show that despite the use of open standards which attempt to enhance interoperabilities for equipments from different vendors, vendors in this market are able to maintain high switching costs. Because routers and switches are networked goods, switching costs may arise from prior investments made at the same establishment and/or at other establishments within the same firm. We study how the introduction of switches into the LAN market affected vendor choice in routers. In particular, we provide evidence of significant cross-product switching costs and sizeable shopping costs when buyers purchase routers and switches simultaneously. However, we also show that the introduction of switches may have temporarily reduced switching costs for router buyers investing in switches.

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1. Introduction

Information technology (IT) infrastructure represents a critical element in the construction of state-of-the-art information systems. A recent study by Weill and Broadbent (1998) indicates that firms spend about 58% of their total IT investments on computing hardware and infrastructure, and that infrastructure investment appears to be the most difficult decision faced by senior management. Another study by Strassman (1999) found that 40% of IT spending is on infrastructure activities alone. These studies suggest that IT hardware investments have a major impact on firms and highlight the importance of such investment decisions.

Networking equipments appears to be neural to the infrastructure of most modern IS systems, and routers and switches are among the most important networking gear. Understanding what affects firms' decision on the investments on routers and switches thus has substantial and long term implications on information systems (IS) development in firms.

Research in information systems (IS) has frequently reported that IT hardware investments become embedded. Buyers of information technology make product-specific investments in training, complementary software and data, and installation. Because these investments usually can not be reused on other vendor products, they create "switching costs" when changing vendors. These switching costs can create "lock-in" to existing investments if they are high enough. As a result, "legacy" hardware investments can impact the technical trajectory of a firm's IT infrastructure long past the initial investment date.

We study how switching costs affect vendor choice in the market for LAN equipment over 1996-1998. Over this period a new technology, switches, were introduced into the market. Switching costs have been studied before in online (e.g., Chen and Hitt 2002; Brynjolfsson and Smith 2000) and offline (e.g., Greenstein 1993; Breuhan 1997) settings. However, our unique setting allows us to make several contributions to the existing literature. Because routers and switches are networked goods, we are able to examine whether the effects of incumbency and switching costs extend across establishments within the same firm. We also examine whether they can spill over from one product to another. We examine whether compatibility appears to play a role in vendor decisions when buyers are purchase multiple product lines. This manifests itself in a buyer tendency to purchase routers and switches from the same vendor.

Last, and perhaps most interestingly, we examine how the introduction of a new innovation, switches, affects the switching costs on an existing good, routers. The introduction of new hardware or software may lower the effects of lock-in arising from switching costs or network effects (Breuhan 1997; Brynjolfsson and Kemerer 1996). We examine whether the introduction of switches offered a temporary "window of opportunity" for lower switching costs for routers.

We use discrete choice to model the impact of switching costs on vendor choice. In these models, the probability of choosing a particular vendor is made a function of buyer characteristics and the extent of previous buyer-vendor interaction. One common concern in inferring switching costs from past vendor interaction is the difficulty of identifying true state dependence from spurious state dependence. We offer a unique method of identifying true state dependence from spurious state dependence by estimating how changes in the quantity of installed base affect the magnitude of switching costs. To estimate these models, we analyze data from over 22,000 firms, 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 show that compatibility with the installed base plays a major role in buyer behavior in this market. We demonstrate that although the introduction of switches did temporarily lead to lower router switching costs, there remained significant cross-product switching costs between routers and switches. These results have two important implications for managers. First, they confirm the usefulness of "broad product line" strategies pursued by firms like Cisco (Gawer and Cusumano 1999). Second, they show that although new product introduction did offer a "window" of lower switching costs for router buyers in the short run, in the long run compatibility with the installed base of networking equipment remained important.

The rest of this paper is as follows. In the next section, we provide some background on switching costs as well as the market of routers and switches. The hypotheses and a description of the data are presented in Section 3, followed by methodology in Section 4 and empirical results in Section 5. We discuss the findings and give concluding remarks in Section 6 and 7, respectively.

2. Literature Review and Background

2.1 Switching Costs and Network Effects

In many markets, consumers face non-negligible costs of switching from one vendor to another. Switching costs can be caused by the need for compatibility with other users (i.e., network effects) or/and with existing equipment, transaction costs (or shopping costs), learning costs, search costs, and psychological costs of switching brands. There are also artificial switching costs (vendor-induced). A firm may change the switching cost its buyers face through certain firm-specific practices, such as contracts or discount coupons. Firms may change switching costs through product design by altering compatibility with rival's products (e.g., Matutes and Regibeau, 1988; Economides, 1989; Einhorn, 1992). Klemperer (1995) provides an overview and definitions of the sources of switching costs. When facing switching costs, a buyer will find it costly to switch suppliers and will tend to buy from the same vendor over time. Switching costs shift the locus of competition and have been linked to a number of interesting competitive phenomena in the economics (e.g., Katz and Shapiro 1985; Shapiro and Varian 1999) and IS (e.g., Clemons and Kleindorfer 1992; Riggins et. al. 1994; Wang and Seidmann 1995) literatures.

The empirical literature on switching costs and network effects is much smaller than the theory literature, due primarily to the detailed data on individual- or firm-specific decisions required to test hypotheses. Greenstein (1993) studies mainframe procurement decisions in government agencies and shows that compatibility with installed base is a major factor affecting purchase decisions. Breuhan (1997) examines the role of switching costs on firm software purchase decisions; she finds evidence of switching costs and shows that conversion from DOS to Windows lowered the switching costs of migrating from Wordperfect to Microsoft Word. Gandal (1994) and Brynjolfsson and Kemerer (1996) show that, other things being equal, users are willing to pay a premium for compatibility and goods with larger network in the software market. Kauffman, McAndrews, and Wang (2000) examine how prior investments in proprietary networking technology influence incentives to adopt a multi-bank electronic network.

Recently, several empirical papers have also examined the role of switching costs in electronic markets. For example, Brynjolfsson and Smith (2000) found, using data from a price comparison service (the DealTime "shopbot"), that a consumer's past purchase experience has significant predictive power of her future store choice and that customers are willing to pay premium prices for books from the retailers they had dealt with previously. Chen and Hitt (2002) also find significant switching costs at different online brokerage firms and show how systems usage, service design and other firm level factors might affect customer switching.

2.2. Routers and Switches: Technology and Market Structure

In this paper we examine buyer behavior in the market for networking equipment. In particular, we observe purchases of networking hardware that directs packets within a LAN or between LANs, and exclude carrier-class gear that routes packets over the broader Internet.[1] There were three major classes of enterprise networking gear in 1998: hubs, routers, and switches. Hubs and switches work on level 2 of the OSI standards architecture, while routers work on level 3.[2]

Hubs are the simplest class of networking equipment. Hubs are most commonly used to connect computers within a LAN, or to allow multiple users to share a network line. Unlike routers and switches, when a data frame reaches a hub, that frame is broadcast out to all of the ports on the hubs. The purchase and management of hubs is generally straightforward. As Panko (2001) states, "Hubs are hubs. The only things you have to worry about when buying a hubs are the number, speeds, and types (Rj-45, etc.) of ports you want on the hub." Because of this simplicity, interoperability is less of a concern with hubs than it is with other classes of networking equipment. Recently, hubs have begun to be supplanted by switches.

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[1] So, for example, in 1998 our data includes models in the Cisco 7500 series but not in the Cisco 12000 series.

[2] Recently, layer 3 switches have been developed that work on level 3 of the OSI model, but these were not available over our sample.

Dataquest (1999) estimates that end-user spending on hubs declined 37.4 percent between 1995 and 1998, from $4.8 billion to $3.0 billion.

The next class of networking gear that we examine is routers. Prior to the rise in popularity of switches in 1994 and 1995, routers represented the primary way in which networks were interconnected.[3] Routers use information from layer 3 of the OSI standards architecture, and use primarily a store-and forward technique to relay frames: the entire frame is read into memory before it is sent out (Datapro 1999). This means that routers are slower at packet forwarding than either hubs or switches, but gives them additional functionality these other classes of equipment do not have. Routers have functionality which also enables them to monitor and manage network traffic efficiently. Routers are able to update their dynamic forwarding tables by communicating with other routers, enabling them to determine 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. Because of their complexity, routers are the most expensive networking equipment on a per-port basis, and also have the highest switching costs because of learning cost.

Switches were introduced in the mid-1990s to increase bandwidth and reduce delay in networks. Switches operate on layer 2 of the OSI model, combining the fast throughput of hubs with some of the intelligence of routers (Datapro 1999). Unlike hubs, switches have the capability to identify the MAC addresses connected to each of its ports in its forwarding tables; however, unlike routers, switches can not optimize network traffic. Switches are much faster than routers, however. Panko (2001) describes the reason for this difference between router and switch packet forwarding speeds, “With a router forwarding table, the destination IP address has to be compared with every entry in the router forwarding table, and, if there are differences in match length or metrics, these factors must be taken into account. In contrast, the switch has to find only the one match in the table to the destination MAC address, and this lookup can

[3] 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.

be done very quickly." This simplicity allows switches to be both much faster and much less expensive than routers.

Because of their greater speed and lower cost, enterprise switches are used as a substitute for routers, and have begun to push routers to the edge of site networks (Panko 2001; Datapro 1999). However, because of their additional features, routers have not been supplanted by switches completely. Routers continued 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).

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. 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.

3. Hypotheses and Data

To study switching costs, a useful starting point is to look at loyalty rates first to see if the incumbent vendor enjoys an advantage over other vendors. A loyalty rate shows the conditional probability of purchasing from the incumbent vendor, given that an establishment is purchasing routers and switches that year. Figure 1 shows loyalty rates for purchases of routers and switches over 1996-1998. Loyalty rates appear to be high in the market for routers and switches for the well-known vendors. For each of the "Big Three" vendors of 3Com, Bay Networks, and Cisco, loyalty rates for routers and switches are quite high, ranging from 47.8 percent to 83.5 percent in routers and from 67.3 percent to 76.5

percent in switches. Loyalty rates for routers of "Other" vendors are low; many of their buyers eventually migrated to Cisco. Loyalty rates for switches of "Other" vendors are higher.[4]

3.1 Source of switching costs: hypotheses

We examine the effects of switching costs on vendor choice by commercial establishments. While our observations are based on establishment level, we allow firm effect on vendor choice decision at the establishment to account for the need for compatibility and possibly coordination effort made at the firm level. Table 1 provides a summary of our hypotheses and the variable constructs used to test them. We describe each of these hypotheses in detail below.

In section 2.2 we described how LAN equipment vendors could use network configuration, network management, and proprietary software to create switching costs in the presence of open standards. Our first set of hypotheses asks whether switching costs exist in the market for routers and switches and examines the magnitudes of switching costs, if any, in this market.

H1a: Buyers face switching costs in choosing a router vendor different from the incumbent router vendor at the establishment.

H1b: Buyers face switching costs in choosing a switch vendor different from the incumbent switch vendor at the establishment.

As noted above, switching costs arise not only at the establishment level due to the need to be compatible with the installed base at the establishment, but also from other establishments within the same firm. New LAN equipments may need to be compatible with the installed base at other establishments at the same firm; in addition, installation and management of networking equipment may also be provided by personnel from corporate headquarters or from other establishments within the firm. Our next set of hypotheses estimate the impact of firm-wide installed base on establishment-level vendor choice.

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[4] The variance in loyalty rates for routers is greater than that for switches because some establishments with installed base in Bay, 3Com, or Other routers migrated to Cisco over the sample period. This was in part because many Other vendors exited the market.

H2a: Buyers face switching costs when choosing a router vendor different from that installed at other establishments within the same firm.

H2b: Buyers face switching costs when choosing a switch vendor different from that installed at other establishments within the same firm.

As mentioned in Section 2.2, routers and switches are often used together as complementary products and must be compatible for networks to function effectively. Vendors usually design their products to interoperate with one another, and to use common interfaces and software to reduce learning costs. For example, Cisco's IOS (Internetwork Operating System) was thought by some to boost compatibility within Cisco's product line, but to also increase switching costs between the products of Cisco and its competitors (Shapiro and Varian 1999; Bunnell 2000). As a result, switching costs may arise from choosing different router and switch vendors. In the face of imperfectly compatible products from different vendors, incumbency in one type of networking equipment, say routers, will influence the choice of the other, switches.

H3a: Buyers face cross-product switching costs in choosing a different router vendor from its incumbent vendor in switches.

H3b: Buyers face cross-product switching costs in choosing a different switch vendor from its incumbent vendor in routers.

There is yet another source of switching costs related to multi-products purchases: buyers may incur "shopping costs" when purchasing from multiple vendors simultaneously (Klemperer, 1992). It's more convenient for consumers to purchase from the same vendor when they want to buy more than one products at the same time since buying from the same vendor saves on transaction costs and reduces the amount of interactions required. We define "shopping costs" as the perceived costs of using additional suppliers other than the need of compatibility or interoperability considered in H3a and H3b. Previous literature has noted that vendors may strategically increase the breadth of their product line to take advantage of buyer's shopping costs. For example, Klemperer and Padilla (1997) show that when buyers face shopping costs when purchasing from multiple vendors, there exists a strategic incentive for firms to broaden their product lines. We provided some evidence of this behavior earlier in this section; the same big three vendors manufacture both routers and switches. While the result of broader product line design can also be demonstrated using production-side economies of scope (Bulow et al, 1985), production-side economies of scope may be less convincing than "shopping cost" in explaining why customers might prefer to use the same vendor for routers and switches. Our next hypothesis is:

H4: When buyers purchase routers and switches simultaneously, they face shopping costs when choosing different router and switch vendors.

The introduction of switching technology in the mid-1990s represented an interesting natural experiment to study how a new technology affect consumer switching costs. Previous literature has suggested that a new IT innovation may erase the incumbency advantages arising from switching costs. To take advantage of new IT innovation, buyers usually need to invest considerable sums to learn and implement new information systems, however, these investments are usually independent of prior installed base, and lead to a decrease in switching costs relative to remaining with the incumbent vendor. When purchasing switches, many firms redesigned their networks to capitalize on the new technology. Because the redesigned networks often require new investments in routers and switches, we interpret the simultaneous purchase of routers and switches as capturing possible network redesign.[5] Thus, we expect router incumbency to be less important when buyers undergo a network redesign:[6]

H5: Buyers purchasing switches simultaneously with routers face lower switching costs from existing router installed base.

3.2 Data

We 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

[5] About 80% of the buyers who purchased routers and switches simultaneously were first-time buyers of switches, suggesting that simultaneous purchase of routers and switches is a good indication of possible network redesign.

[6] Given that many migrants to a switch-based platform will have no installed base in switches, we are unable to examine the effects of the introduction of new IT on router switching costs from installed base in switches. Moreover, since some first-time purchases of switches were made without simultaneous purchases of routers, we are unable to identify the effects of platform shift on switch vendor choice.

size, industry, and location and (2) technology purchases of computers, networking equipment, printers, and other office equipment. Harte Hanks obtains these different components of the CI database at different times of year; we assemble 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 was recorded in the CI database in December 1995.

The unit of observation in the CI database is an establishment. The Harte Hanks establishment definition is similar to that used by government organizations such as the Bureau of Labor Statistics in calculating government statistics. Thus, the database will often have data on multiple establishments for a given firm. A unit of observation in the database contains establishment characteristics and the stock of technology goods installed by the establishment as of December of each year.

To keep the analysis of manageable size, we focus on industries that are generally regarded as heavy users of information technology[7] and establishments of over 100 employees from the CI database over the sample period. All establishments are from the U.S. In addition, given the high concentration in the market, we considered only the largest vendors in the market. Specifically, we examined 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. Some observations were dropped from the analysis for several reasons.[8] The final analysis data set contains 6596 observations from 1996, 6923 observations from 1997, and 9249 observations in 1998.

[7] We 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).

[8] We drop establishments that are not in the database in consecutive years, that are missing fields, and that were located in Europe.

4. Methodology

4.1 Base Model: Switching cost measurements

We employ discrete choice models and the random utility framework to identify switching costs (McFadden, 1974). Random utility modeling frameworks have been extensively applied in studying buyer choice among multiple alternatives (McFadden, 1974; Greenstein, 1993; Brynjolfsson and Smith, 2000; Chen and Hitt, 2002). Formally, consider a set of buyers who associate some utility with each vendor, $U^i_j = v^j_j + \varepsilon^i_j$, that are 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.

The following model forms the basis of our regression model. We express the utility a buyer associates with a particular vendor as:

$$U^i_j = \alpha_j + \lambda_j Z^i + sI^i_j + \varepsilon^i_j \qquad (4\text{-}1)$$

The superscript *i* indexes buyers while the subscript *j* indexes choice (or vendor) *j*. α_j captures the average overall attractiveness of (or average utility a buyer gets 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 is a vector capturing prior buyer-vendor interactions for buyer *i* and vendor *j*. *s* is a vector that measures how a previous relationship between buyer *i* and vendor *j* affects a buyer's utility of vendor choice *j* relative to other alternatives. Finally, ε^i_j, the random component, captures the customer's idiosyncratic, specific tastes 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 the choice made. 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 $u^i_j > u^i_k, \forall k \neq j$. We assume that the error term is independently and identically distributed across products and consumers with the "extreme value" distribution (that is, $prob.(\varepsilon_j \le \varepsilon) = e^{-e^{-\varepsilon}}$, where $-\infty < \varepsilon < \infty$). The choice probability of vendor *j* for buyer *i* in a M-choice model is then given by the multinomial logit model:

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

However, this type of error structure is governed by independence of irrelevant alternatives (IIA) – that is, the ordinal ranking of any two products does not depend on the attributes of other alternatives or even presence or absence of an alternative choice, and thus may produce unreasonable substitution patterns. This may pose a problem if there are different substitution patterns among alternatives. As a robustness check, we will run mixed logit models that allow for heterogeneity in buyer preferences. We also will run nested logit models to examine the case where buyers purchase routers and switches simultaneously.

4.2 Robustness Tests--Controlling for Unobserved Heterogeneity

One potential problem with the methodology presented in Section 4.1 for identifying switching costs is that the switching costs parameters may be picking up unobserved variation in buyers tastes. Buyers differ in their tastes, and product offerings from different vendors are heterogeneous. As a result, some vendor's products may represent a better "match" with idiosyncratic consumer tastes. Therefore, customers will continue to buy from the same vendor for reasons unrelated to switching costs. Heckman (1981) refers to this problem as identifying between "true state dependence" and "spurious state dependence."

In this paper, we employ two strategies to identify true state dependence from spurious state dependence: the instrumental variable approach and the commonly-used random effect model, as discussed in 4.2.1 and 4.2.2 respectively.

4.2.1 The Instrumental Variable (IV) Approach

Following the base model shown in Section 4.1, suppose X^i is the vector that captures all exogenous variables (as opposed to Z^i in (4-1)), observed or unobserved, that determine the utility customer i gets from choice j, i.e., U_j^i. β_j captures variation in buyer tastes across vendors along with X^i. All other notations follow those presented in Section 4.1, except that another subscript t is added indicating time t. Thus, the new model is:

$$U_{j,t}^i = \alpha_j + \beta_j X^i + sI_{j,t-1}^i + \varepsilon_{j,t}^i \qquad (4\text{-}3)$$

The problem of spurious state dependency resulting from failure to account for all buyer heterogeneity disappears if we can account for all buyer heterogeneity, $\beta_j X^i$, as shown in (4-3), in which case, a positive s would indicate real switching cost. Unfortunately, in practice, it's almost impossible to account for all buyer heterogeneity given that only a subset of X, Z where $Z \subset X$, can be observed or is actually observed. When only a subset of X is observed, a positive s may simply reflect the effects from uncontrolled buyer heterogeneity (i.e., spurious state dependence). However, as shown in Greene (2002), as long as I is orthogonal (or unrelated) to X, then the missing variables in X does not affect estimates of the coefficients on I, namely, s. As a result, if I is unrelated to X, then a positive s still indicates true switching cost. However, the question now is that we are not sure if X and I are related or not. Fortunately, since I is an accumulated variable that may change from time to time, we can actually take advantage of this property of I to resolve this issue.

Suppose at some time t=1, I_0 is related to one or a set of unobserved variables in W where W=X-Z, and there is no real switching cost (i.e., s=0). So the true model is

$$U_{j,1}^i = \alpha_j + \lambda_j Z^i + \gamma_j W^i + sI_{j,0}^i + \varepsilon_{j,1}^i$$

But since W is unobserved, the model we actually estimate is:

$$U_{j,1}^i = \alpha_j + \lambda_j Z^i + \tilde{s} I_{j,0}^i + \varepsilon_{j,1}^i$$

In this case, $\tilde{s}$ will pick up effects from W (i.e., $\tilde{s}$ will be a function of γ) and will not indicate the true switching cost since I is correlated with W, in this case, we have got a measure with spurious state dependence. Interesting, we may be able to solve this problem by using the change in I as the instrumental variable since I is changing over time. Consider time t, we can write the model as:

$U^i_{j,t} = \alpha_j + \lambda_j Z^i + \tilde{s} I^i_{j,0} + s(I^i_{j,t-1} - I^i_{j,0}) + \varepsilon^i_{j,1}$ that $(I^i_{j,t-1} - I^i_{j,0})$ will not correlate with the missing variable *W* although $I^i_{j,0}$ may be. With this approach, if $\alpha_j + \lambda_j Z^i + \gamma_j W^i$ has explained all systematic utility contained in U^i_j, that is, there is no real switching cost, then the estimate of *s* will be zero although $\tilde{s}$ may not be zero. On the other hand, if *s* is shown to be significantly different from zero, then we know that there exists real switching cost.

4.2.2 Random Effects Model

The most common strategy adopted in the literature to identify true state dependence from spurious state dependence is to add increasing heterogeneity to the model through random coefficients and known buyer characteristics or to add independently and identically distributed random brand-specific effects to buyer utility. This strategy has been followed by, for example, Jain, Vilcassim, and Chintagunta (1994), Keane (1997), and Shum (2002). Goldfarb (2003) suggests that one can add a random error term to loyalty coefficients as well. Identification is achieved by utilizing the panel structure of the data and assuming the brand and loyalty effects are independent.

Formally, we again have the utility of buyer *i* for choice *j* as $u^i_j = v^{it}_j(\beta^i) + \varepsilon^{it}_j$, where β^i is unobserved for all *i* and varies with the true population density $f(\beta \mid \theta^*)$, where θ^* is the true parameters of the distribution and ε^{it}_j is an iid extreme value error term as before.[9] Conditional on β^i, the probability that consumer *i* chooses alternative *j* in time *t* is a standard multinomial logit:

$$L^{it}_j(\beta^i) = \frac{\exp(v^{it}_j(\beta^i))}{\sum_k \exp(v^{it}_k(\beta^i))}$$

The unconditional probability is the integral over all possible values of β^i, which depends on the parameters of the distribution f().Several distributions are commonly used for f, including normal, log normal, uniform, and triangular. Jain, Vilcassim, and Chintagunta (1994) argue for approximating and

[9] This section relies heavily on Revelt and Train (1998) for the mixed logit model discussion.

underlying continuous distribution of unobserved heterogeneity using a discrete distribution. Here, we assume a normal distribution for f(). Thus, the choice probability for an establishment i at time t under this density becomes:

$$Q_{ijt}(\theta^*) = \int L_j^{it}(\beta^i)\phi(\beta^i \mid \theta^*)d\beta^i \ .$$

For maximum likelihood estimation we need the probability of each sampled person's sequence of observed choices. Let j(i,t) denote the alternative that person i chose in time t. Conditional on β^i, the probability of person i's choices is the product of standard logits:

$$S^i(\beta^i) = \prod_t P^i_{j(i,t)t}(\beta^i)$$

and the unconditional probability for the sequence of choices is:

$$P^i(\theta^*) = \int S^i(\beta^i)\phi(\beta^i \mid \theta^*)d\beta^i$$

Ultimately, the goal is to estimate θ^*, the population parameters of the distribution. Maximum likelihood estimation is not possible since the integral above cannot be calculated analytically. Instead, we approximate the above integral using simulation and maximize the simulated maximum likelihood function. Train (2002) provides a fuller discussion of simulated maximum likelihood estimation under the mixed logit model. We estimation the above equation in GAUSS, using code developed by Ken Train (1999).

4.3 The Nested Logit Model: Testing Shopping Costs and the Effect of New IT Innovation

In hypotheses 4 and 5, we seek to identify whether buyers who purchase routers and switches simultaneously may behave somewhat differently than those buying them separately. Since we believe substitution patterns for these two types of buyers are likely to differ, we assume a nested model that includes a buyer's decision on what type of equipment to buy (routers, switches, or routers and switches), given they make a purchase, followed by the choice of vendor for each type of equipment (Figure 2).

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

$$U^i_{t,v} = \alpha_t T^i + \beta_v V^i_{t,v} + \varepsilon^i_{t,v} \tag{4-4}$$

where vectors T^i and $V^i_{t,v}$ represent variables affecting the decision of purchase type, *t*, and vendor choice, *v*, under purchase type *t*, while α and β are the effects of these variables on buyer choice. 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 simple logit model. Thus, we can assume that the utility model for vendor choice (*j*) assumes the form of a multinomial logit probability:

$$P^i_{t,v_j} = \frac{\exp[\beta_v V^i_{t,v_j}]}{\sum_{v_i \in C_t} \exp[\beta_v V^i_{t,v_k}]} \tag{4-5}$$

where C_t denotes the set of choices available to the buyer after a choice of branch *t*, and the vector $V^i_{t,k}$ contains the installed base variables I^i_k and the switching costs parameters s_k.

We have different parameter estimates for different branch, and examine how switching cost estimates ($s_{t,k}$) differ across purchase types. In particular, we examine whether $s_{t,k}$ is lower when purchasing routers and switches simultaneously (Hypothesis 5).

To identify shopping costs (Hypothesis 4), we include a dummy variable in the branch in which buyers purchase routers and switches simultaneously; the dummy is set to one when a buyer purchases routers and switches from different vendors.

4.4 Control Variables and Constructs

To account for different buyer preferences for vendors or possibly some buyer-vendor match, we include several buyer characteristics in our regression, including industry type, number of employees, total number of network nodes at establishment, whether there's large-scale computing applications at establishment, whether the establishment is a branch of larger corporation and whether the firm is a multi-establishment organization. In addition to buyer characteristics, year dummies are added as control variables to capture possible year trend. Table 2 provides a summary of the control variables and their descriptive statistics.

5. Data Analysis

5.1 Switching Cost Measures: Base Model

Switching cost estimates based on equation set (4-1) are given in Table 3. The table shows the results of estimating multinomial logit models of the choice of router (column 1) and switch (column 2) vendor. The model includes controls for possible buyer-vendor match with available buyer attributes (Z^i), vendor-specific dummy variables and time dummy variables.

Columns 1 and 2 show that there exists significant costs of switching from the establishment's incumbent vendor (Hypothesis 1); this holds both for routers and switches. The presence of switching costs makes switching to other vendors less attractive than remaining with the incumbent vendor. We calculate marginal effects to identify the impact of incumbency on vendor choice. Because marginal effects in the logit model are a function of the attributes of the alternative of interest relative to other alternatives, they generally differ across alternatives.[10]

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_j^i. Then the probability of choosing this same vendor when there exists switching costs s_k, becomes $\frac{e^{s_k} P_j^i}{1+(e^{s_k}-1)P_j^i}$, which is greater than P_j^i for positive switching costs. For instance, in Table 3, Column 1, the switching cost of router incumbency on router vendor choice is 1.2771. Thus, the marginal impact of incumbency is $\frac{e^{1.2771} P_j^i}{1+(e^{1.2771}-1)P_j^i} = \frac{3.6P_j^i}{1+2.6P_j^i}$, which is depicted in Figure 3 as a function of P_j^i. In Figure 3 we use

[10] Train (2003) provides a derivation of marginal effects in the multinomial logit.

this formula to calculate the probabilities of the three router vendors being chosen by an average buyer[11] with no router incumbency (in green line) and with router incumbency (in red line), the differences between the two lines captures the marginal effect of router incumbency on the vendor choices for these three vendors. For example, the probability that an average buyer will purchase 3Com without incumbency is 11%, however with incumbency the probability jumps to 31% -- an increase of over 100%. On the other hand, the probability of an average buyer purchasing from Cisco increases from 72% to 90% with Cisco incumbency, a 25% increase. Column 2 suggests that switch incumbency at an establishment also has a similar effect on switch choice (switching cost of 1.6420).

The results in Table 3 further show that the effects of switching costs extend across establishments within the same firm, supporting hypothesis 2. Column 1 shows that the firm-wide installed base of routers has a significant impact on router vendor choice (1.5319). The effect of router incumbency throughout the firm is as important as that at the establishment: for example, an increase in the share of Cisco incumbency from 0 to 100 percent increases the likelihood of buying a router from Cisco at the establishment level from 72% to 92%. The firm-wide installed base of switches has a weaker marginal effect (0.6062) on switch vendor choice at establishment than the installed base of switches at the establishment (1.6420). This is not surprising, however, as routers are usually the gateway between an establishment and the outside world and are used more frequently than switches for inter-establishment communication.

Columns 1 and 2 also show the importance of cross-product switching costs on router and switch vendor choice, supporting Hypothesis 3. For example, switch incumbency at the establishment not only increases the probability of buying from the same switch vendor but also influences the buyer's router vendor choice. Specifically, the installed base of switches at the establishment creates significant switching cost (1.8453) for buyers making a router vendor choice, which corresponds to an increase of over 30% in the likelihood of purchasing Cisco routers (from 72% to 94%). The installed base of switches

[11] As an example, an average buyer is described as taking mean values for all continuous variables and zero for other dummies except the year dummy of 1997.

at other establishments is less important in influencing the router vendor choice at establishment, however this again is expected as switches are mainly used for intra-establishment communication. On the other hand, the installed base of routers at the establishment and throughout the firm also creates significant cross-product switching costs on switch vendor choice, although at smaller magnitudes than switches (0.6124 and 0.4715 respectively).

5.2 Switching Cost Measurements: Random Coefficient Mixed Logit Models

Columns 3 and 4 of Table 3 present the results of the mixed logit model. We assume that the parameter estimates for router and switch installed base are normally distributed, while other parameters are held fixed. In contrast to the models in section 5.1, we include establishments who did not purchase routers or switches in our sample and include variables that control for the propensity to purchase networking hardware. This is because many establishments do not purchase routers and switches every year, and our strategy is to employ the full panel of data to identify switching costs from spurious state dependence. Although the models are not directly comparable, they do suggest that switching costs continue to have an effect on vendor choice, even when buyer heterogeneity is accounted for. The only exception is in the impact of firm-wide installed base of switches on switch vendor choice, which becomes statistically insignificant.

5.3 Switching Cost Measurements: Instrumental Variables Model

Columns (1) and (3) of Table 4 show the results of our IV model on router and switch vendor choice. Because 1996 is the first year in which establishments bought switches, we estimate the model over 1997 to 1998. We identify switching costs by examining the change in router and switch installed base between 1996 and 1997.

For routers, increases in the installed base of routers (0.4080, statistically significant) and switches (0.5118, statistically significant) from a vendor increased the likelihood of purchasing from that vendor again. For switches, increases in the installed base of switches increase the likelihood of buying from the same switch vendor (0.5990). However, both the level and change in routers has no impact on switch vendor choice. This may reflect the difficulty of identifying how router switching costs influence switch vendor choice in a smaller sample.

5.4 Shopping Costs and the Effects of New IT Innovation on Switching Costs

Table 5 presents the results of our joint router-switch purchase model. We find that buyers purchasing routers and switches together face significant shopping costs (1.3824) after accounting for cross-product switching costs, supporting hypothesis 4. In other words, buyers purchasing routers and switches together are about 60% more likely to buy from a vendor offering both products than an otherwise identical vendor offering only one. This result combined with the significant cross-product switching cost illustrate the importance of broad product lines in this market.

As noted earlier, new product introduction can have interesting effect on the switching costs faced by buyers. A new IT platform may erase incumbent advantages, resulting in lower switching costs. Hypothesis 5 argues that switching costs arising from a buyer's installed base of routers will be lower if buyers take advantages of the new IT innovations in switches, which usually requires the use of routers and switches as complementary products in the network. We examine the difference in switching cost parameter estimates across model nests to identify the effects of new IT innovations on switching costs arising during router vendor choice.

The results on switching cost estimates for each type of purchase are given in Table 5. Column 4 of Table 5 shows the difference in switching costs when routers and switches are purchased separately versus when they are purchased simultaneously. As before, the coefficients measure various sources of switching costs, however, we are most interested in understanding changes in router switching costs due to router installed base when a firm redesign their networks to takes advantage of switches. We find that switching costs arising from installed base in routers fall when there is a possible network redesign, captured by purchasing routers and switches together. This result supports Hypothesis 5. Switching costs due to installed base of routers at establishment falls from 1.7843 to 1.0707, a statistically significant drop (at the 5 percent level) of 0.7136. This significant drop in switching costs greatly reduces the incumbent advantage, as shown in Figure 4. For example, the likelihood that an establishment with 3Com routers will purchase 3Com routers again drops from 42% to 26% when the buyer purchases switches concurrently with routers. We also examined the behavior of switching costs arising from firm-wide installed base. These fell by 0.3376, a positive but statistically insignificant difference.

6. Discussion

- **Switching costs in the market for routers and switches:** Overall, all of our hypotheses are supported (as summarized in Table 6), suggesting that there exist significant switching costs of various sources in the market of routers and switches despite the prevalence of open standards which attempts to increase interoperability of network equipments from different vendors.

- **What effect did the introduction of switches have on switching costs in the market for LAN equipment?** We set out two competing hypotheses of how the introduction of switching technology might affect switching costs in the LAN equipment market. One hypothesis argued that switching technology might "free" incumbent users from switching costs by initiating a platform shift to switch-based networks. A second hypothesis argued that because of the importance of cross-product compatibility in network equipment, new switch purchases must remain compatible with the existing installed base of routers.

Our results support both viewpoints. In the short run, the introduction of switches did lower switching costs arising from the installed base of routers. We showed that establishments purchasing switches for the first time often made complementary router investments to optimize network performance in light of the new switching technology. We provided some evidence that because these new switch investments forced establishments to redesign and rebuild their network infrastructure, they effectively "freed" them from the switching costs arising from their installed base. Thus, a short window existed after the initial introduction of switches that reduced buyer switching costs for routers.

In the long run, however, the importance of compatibility in this market effectively ensured the switching costs would continue to play a role in buyer decisions. Cross-product switching costs tied buyers to investments made in other products and other establishments within the organization. Shopping costs drove buyers to purchase from incumbent vendors with broad product lines in routers and switches.

Thus, in the long run the fundamental issues of compatibility in these products tended to reassert themselves. Indeed, our results suggest that new innovations may raise market concentration if a proliferation of new products forces vendors to become a "one-stop shop" for many different varieties of networking equipment; the fixed costs of development will become a barrier to all but the largest vendors. These results are applicable to many IS hardware and software products, including software (Brynjolfsson and Kemerer 1996; Breuhan 1997), computing hardware (Bresnahan and Greenstein 1999), and networking protocols (von Burg 2001; Gawer and Cusumano 2002). However, ours is one of the first papers to examine this phenomenon empirically, and the first to examine it within the context of a networked good.

• **Implications for Managers:** This paper contributes to an existing literature that shows short-run decisions can have long-run implications for buyers of IT equipment. However, we have several new lessons. For buyers, our results raise a caution flag to optimists who believe that open protocols will be the solution to multi-vendor interoperability problems in computer networks. Based on buyer's observed decisions, we show that compatibility issues still play a major role in computer networks. Moreover, our results show that the traditional "legacy problem" in IS will be exaggerated as information systems move increasingly toward multi-tier client/server platforms.

Our research has tested prior assertions that new technologies may temporarily reduce buyer switching costs. However, our results show that this window may be fleeting, and that continued new product introductions in the networking market may work to increase market concentration.

For sellers, our research explicitly addresses the importance of broad product lines to vendor success in networked markets. We show that product line compatibility has important implications for vendor choice, and offer evidence that suggests vendors may strategically alter the compatibility of their products with other vendors to achieve competitive advantage.

7. Conclusions

This research examined the impact of a new product introduction and how this new product introduction influenced vendor choice in an environment with switching costs and network effects.

Though previous papers have studied switching costs in other environments, our paper makes several unique contributions to the literature.

First, the paper demonstrates how an existing installed base in one product or establishment can spill over and affect the purchase decisions of other products from other establishments within the same firm. Previous work had examined switching costs in relatively simple settings, where switching costs are isolated within the same product and the same buyer. These first two findings show that in networked information systems, the legacy problem is much more severe than commonly thought. Lock-in can occur due to prior investments of completely different products, or from the investments of other establishments within the same firm.

Second, this paper demonstrates how the introduction of a new technology affects vendor choice in an environment with switching costs. We found some evidence that new technologies may reduce the costs of switching in the short run. However, our results also suggest that vendors can maintain an advantage through product design by creating incompatibilities across products and employing a broad product line strategy. This suggests that in the long run maintenance of compatibility with the installed base will remain important, while high fixed costs of development may increase market concentration.

These results suggest several potential avenues for future research. One aspect of the buyer-vendor relationship left unexplored in this paper is the role of third-party network managers and IT outsourcing on vendor choice. IT outsourcing may strengthen the effects of incumbency if third-party vendors are associated with particular vendors; alternatively, third-party network managers or designers may be able to help their clients overcome switching costs. Another potential course would be to examine how the existence of switching costs affects the product line decisions of each of these competitors. The framework and data used here are well-suited to address these questions.

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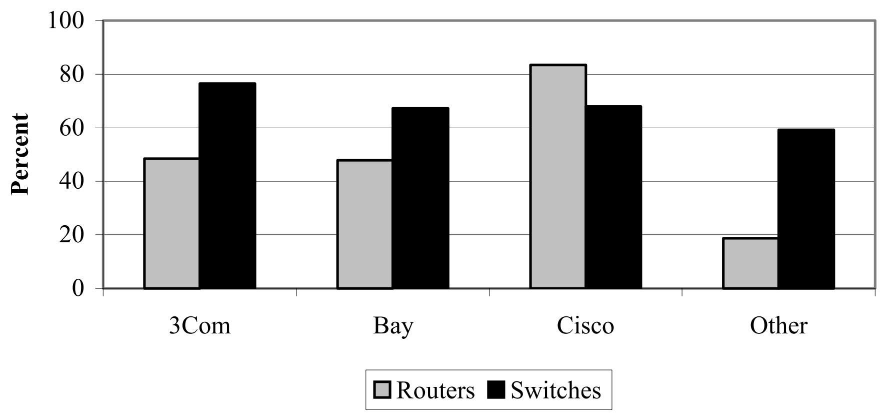
Figure 1
Loyalty Rates for Routers and Switches



Notes: Sample is 1996-1998. Shows conditional probability of purchasing from incumbent vendor in a year, among those establishments purchasing routers and switches. Other includes all vendors besides 3Com, Bay Networks, and Cisco (including Cabletron).

Figure 2
Nested Logit Model

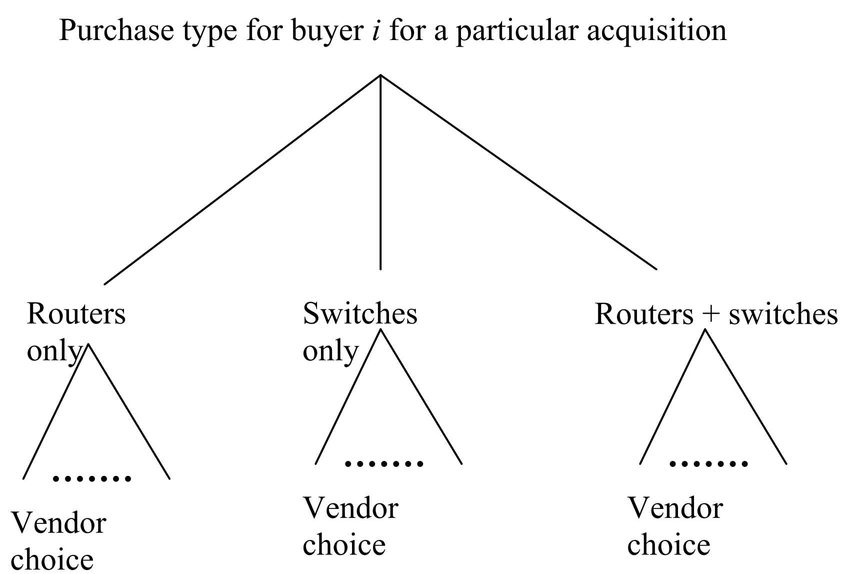


Figure 3
Marginal Effects of Router Installed Base on Router Choice

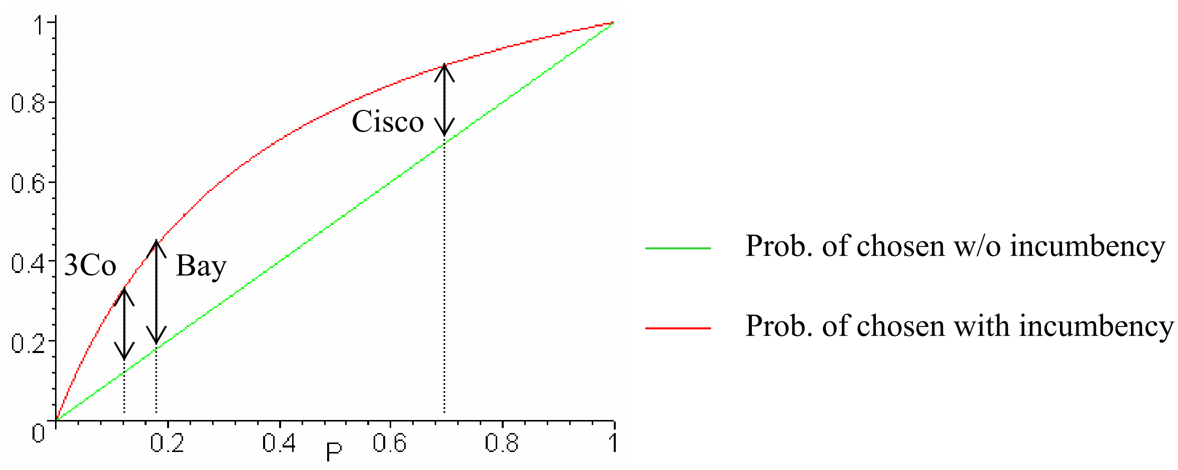


Figure 4: Effects of platform shift on incumbent advantage

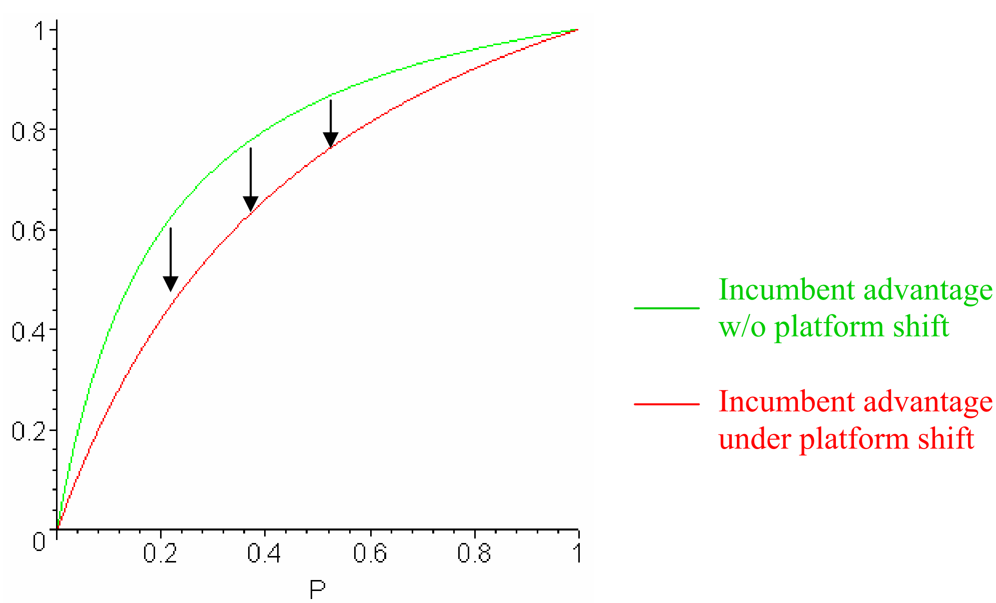


Table 1: Variable Constructs

No	Variable	Hypothesis	Measure	Construction/Identification
(1)	Installed base of router vendor at establishment	Hypothesis 1a	Measures the *switching costs* of router incumbency on router vendor choice at establishment	=1 for vendor choices different from incumbent router vendor at establishment
		Hypothesis 3b	Measures *cross-product switching costs* of router incumbency on switch vendor choice at establishment	
(2)	Installed base of switch vendor at establishment	Hypothesis 1b	Measures the *switching costs* of switch incumbency on switch vendor choice at establishment	=1 for vendor choices different from incumbent switch vendor at establishment
		Hypothesis 3a	Measures the *cross-product switching costs* of switch incumbency on router vendor choice at establishment	
(3)	Pct of installed base of routers from vendor at firm	Hypothesis 2a	Measures the *network effects* of *other* buyers' router vendor decisions on the establishment's router vendor choice	= (Total routers from vendor *x* at firm/ Total installed base of routers from vendor at firm) for choices different from vendor *x*
		Hypothesis 3b	Measures the *cross-product switching costs* arising from router vendor incumbency throughout the firm on the establishment's switch vendor choice.	
(4)	Pct of installed base of switches from vendor at firm	Hypothesis 2b	Measures the *network effects* of *other* buyers' switch vendor decisions on the establishment's switch vendor choice.	= (Total switches from vendor *x* at firm/ Total installed base of switches from vendor at firm) for choices different from vendor *x*
		Hypothesis 3a	Measures the *cross-product switching costs* arising from switch vendor incumbency throughout the firm on the establishment's router vendor choice.	
(5)	Effect shopping costs	Hypothesis 4	Measures shopping costs.	=1 when choose identical router and switch vendor*
(6)	(1) and (3)	Hypothesis 5	Measures how switching costs may vary with purchase type.	Variables are allowed to vary across nests for routers only, switches only, and routers + switches*

Notes:
*Used in multi-product choice model

Table 2: Description of Variables

Variable Description	Mean	Std. Dev.	Min.	Maximum
Vendor-specific Bay Networks dummy	0.2	0.4000	0	1
Vendor-specific Cabletron dummy	0.2	0.4000	0	1
Vendor-specific Cisco dummy	0.2	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 network nodes at establishment	0.8640	1.5096	0	9.1259

Note: Number of observations is 113840.

Table 3: Multinomial Logit of Router/Switch Choice (after controlling for buyer characteristics and year trend)

	Multinomial Logit		Mixed Logit	
	Router (1)	Switch (2)	Router (3)	Switch (4)
Installed base of router vendor at establishment	1.2771** (0.22)	0.6124** (0.17)	1.4860** (0.50)	0.6572** (0.19)
Standard Deviation of installed base of Router vendor at establishment	… …	… …	0.9720 (0.72)	0.7607** (0.25)
Pct of installed base of routers from vendor at firm	1.5319** (0.20)	0.4715** (0.22)	0.8388** (0.20)	0.6732** (0.20)
Standard Deviation of pct of installed Base of routers from vendor at firm	… …	… …	0.1593 (0.56)	0.7593** (0.27)
Installed base of switch vendor at establishment	1.8453** (0.42)	1.6420** (0.26)	1.0370** (0.43)	2.3979** (0.73)
Standard Deviation of Installed base of Switch vendor at establishment	… …	… …	1.7152** (0.5044)	1.3921* (0.83)
Pct of installed base of switches from vendor at firm	0.1526 (0.34)	0.6062** (0.24)	0.0433 (0.17)	0.1415 (0.22)
Standard Deviation of Pct of installed Base of switches from vendor at firm	… …	… …	0.0066 (0.3487)	0.5367** (0.26)
N	2997	2708	90,960	113,840
Log Likelihood	-576.62	-768.79	-15,510.59	-15856.66
Pseudo R-Sq	0.4746	0.1808		

Notes:
Columns 1 and 2 are multinomial logit estimates with asymptotic standard errors in parentheses, estimated on a sample of buyers of routers and switches. Columns 3 and 4 are random parameters mixed logit models. Coefficients on brand dummies, purchase constant, and switching cost variables are normally distributed. Random coefficients are independently distributed across corporations. Some variables dropped from model (4) due to multicollinearity. Estimates are maximum simulated likelihood with asymptotic standard errors in parentheses. *Indicates significance at 10% level. **Indicates significance at 5% level.

Table 4: Effects of Increases of Installed Base on Switching Costs (after controlling for buyer characteristics and year trend)

	(1) Routers-Estab Only	(2) Routers-Including Firm	(3) Switches-Estab Only	(4) Switches-Including Firm
Installed Base of routers at Est in 1996	1.0896**	0.5494**	0.0119	-0.0085
	(0.19)	(0.1897)	(0.0185)	(0.0188)
Chg in Est Installed Base of Routers From 1996 to 1997	0.4080**	0.2885**	-0.0091	-0.0199
	(0.1471)	(0.1869)	(0.0239)	(0.0259)
Installed Base of switches at Est in 1996	0.5121	0.6142	1.0419**	0.8770**
	(0.4054)	(0.4061)	(0.2335)	(0.2593)
Chg in Est Installed Base of switches From 1996 to 1997	0.5118**	0.1447	0.5990**	0.4038**
	(0.1904)	(0.2080)	(0.1533)	(0.1603)
Pct of installed base of routers from Vendor at firm in 1996		1.8001**		1.0752**
		(0.3126)		(0.2485)
Chg in pct of installed base of routers From vendor between 1996 and 1997		0.6977		0.4467
		(0.4806)		(0.3801)
Pct of installed base of switches from Vendor at firm in 1996		-0.2441		0.3744
		(0.4679)		(0.3523)
Chg in pct of installed base of switches From vendor between 1996 and 1997		1.7705**		0.6992*
		(0.5624)		(0.4031)
Observations	1581	1581	1536	1536
Log-likelihood	-300.672	-275.304	-437.835	-424.752

Multinomial logit estimates with asymptotic standard errors in parentheses. Estimated over 1997-1998, among establishments who purchase networking equipment. *Indicates significance at 10% level. **Indicates significance at 5% level.

Table 5
First Level: Equipment Type
Second Level: Vendor

	Routers Only (1)	Switches Only (2)	Routers & Switches (3)	Difference Btw (1) & (3) (4)
Effect installed base of router vendor at establishment on router ch	**1.7843**** **(0.2901)**		**1.0707**** **(0.2873)**	**0.7136***
Effect pct of installed base of routers from vendor at firm on router ch	**1.3932**** **(0.2355)**		**1.0556**** **(0.2889)**	**0.3376**
Effect installed base of switch Vendor at establishment on router ch	1.5403** (0.4685)		0.8118* (0.4858)	
Effect pct of installed base of switches from vendor at firm on router ch	0.1522 (0.3611)		0.2427 (0.3828)	
Effect installed base of router vendor at establishment on switch ch		-0.1265 (0.2315)	0.5024** (0.2223)	
Effect pct of installed base of routers from vendor at firm on switch ch		1.2259** (0.2746)	0.1684 (0.2387)	
Effect installed base of switch Vendor at establishment on switch ch		1.8622** (0.3516)	1.5436** (0.3875)	
Effect pct of installed base of switches from vendor at firm on switch ch		0.5831* (0.3479)	0.2618 (0.3063)	
Effect shopping costs			1.3824** (0.1430)	
Inclusive Value	0.7076 (0.1380)			
N	23883			
Log Likelihood	-2461.5021			

Notes:
*Indicates significance at 10% level.
**Indicates significance at 5% level.
Model is run using only observations on establishments purchasing routers or switches.

Table 6: Summary of Hypotheses Tests

Hypotheses		Test Results
H1a	Buyers face switching costs in choosing a router vendor different from the incumbent router vendor at the establishment.	Supported
H1b	Buyers face switching costs in choosing a switch vendor different from the incumbent switch vendor at the establishment.	Supported
H2a	Network externalities influence router vendor choice. Buyers face switching costs when choosing a router vendor different from that installed at other establishments within the same firm.	Supported
H2b	Network externalities influence switch vendor choice. Buyers face switching costs when choosing a switch vendor different from that installed at other establishments within the same firm.	Supported
H3a	Buyers face cross-product switching costs in choosing a different router vendor from its incumbent vendor in switches.	Supported
H3b	Buyers face cross-product switching costs in choosing a different switch vendor from its incumbent vendor in routers.	Supported
H4	Buyers face significant shopping cost in choosing different router and switch vendors when they purchase them at the same time.	Supported
H5	Buyers purchasing switches simultaneously with routers face lower switching costs from existing router installed base.	Supported