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UNDERSTANDING NETWORK EFFECTS IN SOFTWARE MARKETS: EVIDENCE FROM WEB SERVER PRICING[1]

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Abstract

Prior theoretical research has established that many software products are subject to network effects and exhibit the characteristics of two-sided markets. However, despite the importance of the software industry to the world economy, few studies have attempted to empirically examine these characteristics, or several others which theory suggests impact software price. This study develops and tests a research-grounded model of two-sided software markets that accounts for several key factors influencing software pricing, including network externalities, cross-market complementarities, standards, mindshare, and trialability. Applying the model to the context of the market for Web server software, several key findings are offered. First, a positive market share to price relationship is identified, offering support for the network externalities hypothesis even though the market examined is based on open standards. Second, the results suggest that the market under study behaves as a two-sided market in that firms able to capture market share for one product enjoy benefits in terms of both market share and price for the complement. Third, the positive price benefits of securing consumer mindshare, of supporting dominant standards, and from offering a trial product are demonstrated. Last, a negative price shock is also identified in the period after a well-known, free-pricing rival has entered the market. Nonetheless, network effects continued to remain significant during the period. These findings enhance our understanding of software markets, offer new techniques for examining such markets, and suggest the wisdom of allocating resources to develop advantages in the factors studied.

Keywords: Hedonic pricing, network effects, network externalities, composite goods, two-sided markets, open standards, mindshare, trialability, World Wide Web server market

[1]Ron Weber was the accepting senior editor for this paper.

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Introduction

Packaged software represents the third largest industry in the United States. With revenues totaling roughly $185 billion in 2001, it is one of the fastest growing sectors worldwide (Boulton 1999; Frye 2000; Rudy 2002). The dynamics of this industry are quite different from conventional markets. For example, software products are subject to *network effects*[2]—the idea that a product will become more valuable as its user base expands (Farrell and Saloner 1985; Oren and Smith 1981; Rohlfs 1974). Also, software products can be classified as *digital* or *information goods* with a corresponding theoretical marginal cost of zero (Negroponte 1995; Poirier 1990). The economics of zero (or negligible) marginal cost allow software vendors to leverage strategies such as subsidies, versioning, and trialability to a much greater extent than vendors of conventional goods (Bakos and Brynjolfsson 1999; Bakos et al. 1999; Shapiro and Varian 1998).

Despite the importance of software to the world economy and the notion that software markets are different from conventional markets, few studies have attempted to offer a synthesized analysis and empirical examination of the unique forces at work in this industry. Drawing heavily on the literature related to network economics, strategic complements, and software pricing, we use the Web server market as a context to present an analysis that offers the following contributions. First, we investigate the existence of network effects in markets heavily dependent upon *open standards*[3]. Such products represent one of the fastest growing segments of the software industry (Nua 1997). Little is known, however, about the impact of network effects on such markets. Second, we investigate a network software market that can be characterized as a *two-sided market*. Two-sided markets exist when separate constituencies or user groups coordinate the use of different, yet complementary products (e.g., client software and server software) in order to derive utility (Rochert and Tirole 2001).[4] Two-sided markets represent a sizable portion of the computer industry. For example, in terms of dollar sales, client/server technologies have been classified as the largest category in the software industry (Cowen 2000). Firms producing components for two-sided markets face a key question: Should they concentrate on one component (e.g., server) and let others address the markets for requisite, complementary components (e.g., client), or should they produce both components? Third, we expand prior methods used to model software markets by considering additional factors that theory suggests may influence such markets. Specifically, we investigate the role of *mindshare* (or product awareness), product standards, trial versions, and the impact of a well-known, free-pricing firm entering the market.

This study presents evidence of strong two-sidedness in the Web software market. A positive relationship between server market share and server price offers evidence of network externalities; while a relationship between browser market share and server price suggests the benefit of securing market share in complementary products. Product awareness is shown to be strongly related to network effects in establishing product-pricing advantages over rivals. Findings also demonstrate the positive price benefits of supporting dominant standards and offering a trial product. Even though a negative price shock is identified in the period after a free-

[2]The literature also refers to network effects as network externalities. We use both terms interchangeably throughout the paper.

[3]An open standard is an industry blueprint recommended by vendor-neutral standards bodies that is meant to ensure interoperability between products from different vendors, i.e., competing products work together. Open standards allow consumers a wide range of choices and speed adoption of new technologies. They are in sharp contrast to vendor-proprietary standards that may be leveraged in an exclusionary manner.

[4]Some literature may also reference this phenomenon as indirect network effects or inter-network effects.

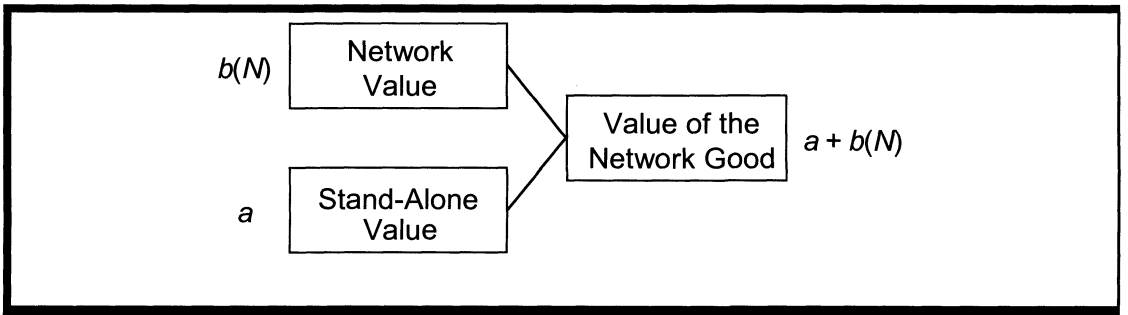

Figure 1. Typical Theoretical Model for Network Goods

pricing rival has entered the market, the positive influence of the above factors continued to remain significant. For researchers, this work synthesizes existing theory and analytical techniques to develop and test a more comprehensive model for gauging the impact of factors influencing two-sided software markets. For practitioners, these findings suggest the wisdom of allocating scarce resources to develop advantages in the influential factors identified above.

The organization of this paper is as follows: we leverage existing theory to develop a series of research hypotheses and a conceptual model related to the perceived value of Web server products. Then we detail methodology and data, and follow these with estimation results. We conclude with a summary of findings and a discussion of the contributions and limitations of this research.

Theory and Hypotheses

Foundation Model and Context

The foundation of our investigation is a well-known theoretical model of network goods (that is, products or services subject to network externalities) presented in Figure 1 (Farrell and Saloner 1986; Kauffman et al. 2000; Saloner and Shepard 1993). In this model, the value that consumers derive from a network product is a function of stand-alone benefit and network externalities. The term *a* denotes the stand-alone benefit that a consumer derives from the product features. The term $b(N)$ represents the feature-independent value derived from a network of size N. Because user value increases with network size, $b(N)$ is an increasing function of the installed base, N.

One challenge for empirical researchers is decomposing factors influencing consumer value with an awareness that some observable factors may be impossible to decompose between a and $b(N)$. Another challenge is that the perceived value of a network product, $a + b(N)$, is unobservable. With these challenges in mind, our approach to enhancing this theoretical model and creating the associated empirical model is similar to that employed by Brynjolfsson and Kemerer (1996). To test hypotheses, we use price (P) as a proxy for consumers' *willingness to pay* (W), or perceived value. This yields a formulation where

$$P \leq W \leq a + b(N)$$

As a result, we can derive a function of price as:

$$P = f(a1, a2 \ldots, b1(N), b2(N), \ldots)$$

Using this approach, we expand the model by considering variables the literature suggests influence the perceived value of a software product. Doing so allows us to construct a richer, more-descriptive model for considering network effects and standards applicable to the unique problems of two-sided software markets.

While our study relies on research in the domains of information goods, the economics of standards,

multiproduct complementarities, and software pricing, our primary context is the Web server software market. This context is referred to when developing hypotheses below. The Web server software market has been the focus of a number of recent studies (Cusumano and Yoffie 1998; Gallaugher and Wang 1999a; Gallaugher and Wang 1999b; Gogan and Applegate 1995; Quittner and Slatalla 1998; Yoffie and Cusumano 1999). Yet, despite high interest and earlier qualitative case studies and exploratory work, little rigorous empirical work has investigated this context. Web software represents the first commercially successful software supporting the evolving, ubiquitous, low-cost, global computing infrastructure. Therefore, understanding the dynamics of competition in this market and the factors critical to early market success should yield important insights for a number of current and future industries.

Network Goods and Externalities

Early attempts at modeling the behavior of information technology markets (e.g., workstations) have focused on evaluating the relationship between product features (e.g., processor speed and memory) and price (Lynch et al. 1990; Michaels 1979; Rao and Lynch 1993). However, some products or services become more valuable as more people use them. This phenomenon is referred to as *positive consumption network externalities* (Farrell and Saloner 1985; Katz and Shapiro 1985). Network externalities may be responsible for determining market winners in a variety of IT and electronic commerce areas including software, standards, online services, and virtual communities.

The positive relationship between value and installed base (i.e, the base of users for a particular product or service) develops from three factors: *exchange*, *stability*, and *extrinsic benefits*. All network goods foster some sort of exchange (e.g., content, money, programs). Therefore, each new network user adds potential value through exchange with other network members (Economides 1996). Because the number of network users is assumed to reflect long-term market stability (Katz and Shapiro 1992), consumers generally prefer firms with large installed bases. IT users are particularly concerned about being stranded with a failed and unsupported product given that many users have sunk investments in learning, files, and other resources that may greatly exceed a product's initial purchase price (Fichman and Kemerer 1993). Consumers also prefer dominant products that are more likely to attract extrinsic benefits such as supportive content, books, manuals, add-on products, and skilled labor (Parker and Van Alstyne 2000; Shurmer 1993). In extreme cases, the lack of a rich market for these extrinsic products may lead to incomplete adoption and an inability to achieve critical mass (Moore and Benbasat 1991). Although many studies have discussed network effects within the context of proprietary standards (Church and Gandal 1992; Farrell and Saloner 1985, 1986, 1992), the implied significance of stranding concerns and extrinsic benefits are particularly noteworthy because they suggest that firms can generate network externalities even in environments that support open standards.

Examining the dynamics of network markets is critical because competition in these markets differs significantly from that in conventional markets. It can be especially difficult for newcomers to unseat an established rival in markets where the influence of network externalities is strong (Katz and Shapiro 1994). In light of the value that users place on installed base and market dominance, the importance of feature richness or quality may be diminished—thus, the "best" product or service does not always win (Rochert and Tirole 2001). Postrel (1990) found this to be the case in markets for stereo standards. In a widely cited paper, David (1985) suggested that this is the reason behind the dominance of the QWERTY keyboard format.[5]

In some cases, network externalities may also facilitate platform changes. This is manifested in

[5]Liebowitz and Margolis (1990) disputed David's claims, a conflict that underscores the need for more empirical research.

the so-called *bandwagon effect* when consumers rush to adopt a new technology they expect will become dominant (Farrell and Saloner 1985; Katz and Shapiro 1992). Dominant firms may also be able to leverage their market share in a number of ways. These include using the installed base as a distribution channel for additional services, and distorting open standards to their own advantage (Shapiro and Varian 1998). The existence of proprietary inter-network effects provides market power by helping to eliminate close substitutes. Given the importance of establishing an early market share advantage, network market competition tends to develop early and can be particularly fierce. Such markets also tend toward monopolistic competition, with leading firms able to exploit network externalities through higher pricing (Farrell and Saloner 1985; Katz and Shapiro 1992).

Because consumers' valuation is unobservable, the classical approach to testing the network externalities hypothesis has been to use price as a proxy for consumer value (Brynjolfsson and Kemerer 1996; Gandal 1994). This is appropriate because a rise in value should reflect a consumer's increased willingness to pay for a particular product. Given that the relative attractiveness of a network product is influenced by its sales history, firms that dominate their markets should be able to extract higher rents than their competitors (Katz and Shapiro 1986b). Hypothesis 1 frames the network externalities hypothesis in the context studied. Following earlier work, market share is used as a proxy for a product's relative installed base.

> HYPOTHESIS H1: *Server products with a greater market share will enjoy higher prices than their less successful rivals.*

Two-Sided Markets

Prior empirical studies considering network externalities in software markets focused on networks consisting of a single product—namely, computer spreadsheets (Brynjolfsson and Kemerer 1996; Gandal 1994). However, recent theory suggests that many, if not most, markets subject to network externalities are characterized by the presence of two distinct sides. The ultimate benefit to consumers stems not from owning both components, but from interacting with owners of the complementary product through a common platform (Parker and Van Alstyne 2000; Rochert and Tirole 2001). Such markets are referred to as *two-sided markets*. Table 1 identifies a subset of information technologies that can be classified as two-sided markets. This classification is appropriate for Web software, because the browser (client) and server are used concurrently and by separate parties. Theory suggests that firms that offer products for both sides of a two-sided market may be at an advantage.

Pioneering work on two-sided markets combines insights from the literature on competitive multiproduct pricing (Baumol et al. 1982; Wilson 1997) and strategic complements and substitutes (Bulow et al. 1985) with theory on network economics (Farrell and Saloner 1985; Katz and Shapiro 1985; Rohlfs 1974). It also builds on the idea of vertical organization, or internalizing the offering of complementary network components (Economides 1996; Farrell et al. 1998; Schilling 2002). However, several characteristics distinguish two-sided markets from standard multiproduct markets and from markets for single-product network goods. First, consumers of one segment in a two-sided market need never acquire the complement. Unlike the classic multiproduct case of razors and blades, consumers of products such as browsers may, at their discretion, forgo the cost of the server now and forever (Parker and Van Alstyne 2000). Second, the interaction between the two sides leads to strong complementarities. However, unlike in the multiproduct or single-product network literature, end users of one class of goods do not internalize the corresponding externalities in this context. Rather, the growth of the user base on one side of the market creates share and price benefits for the complement's side. Finally, profits in such markets need not derive from intertemporal lock-in (where a market is initially subsidized only to be exploited later) as is the case for razor buyers who generate profits through later

Table 1. Examples of Two-Sided Markets

System	Product (Firm)
Streaming Media	RealMedia (Real Networks), Windows Media (Microsoft)
Radio Broadcast	Imagine Radio, RadioWave (Motorola), Sirius, SonicNet, Spinner, XM
Document Distribution	Acrobat (Adobe)
Personal Data Management	Palm, Passport and TrustBridge (Microsoft)
Software Distribution	Castinet (Marimba), OilChange (Network Associates), Windows (Microsoft)
Television Convergence	Ultimate TV (Microsoft); AOLTV (AOL/Time-Warner)
Wireless Broadband	MMDS (Sprint; MCI/WorldCom), LMDS (CellularVision), GEO Satellite (Hughes/DirectTV), LEO Satellite (Teledesic)

purchases of blades. In two-sided markets, a firm providing both components may indefinitely subsidize the market for one component as long as the benefits flowing to the second component's market outweigh the initial cost outlay.

The literature on two-sided markets thus extends the concept of intra-market network externality to an inter-market context. Parker and Van Alstyne (2000) modeled a situation in which the demand for one product is influenced linearly by the quantity of the other product sold. They demonstrated that price structure can be characterized as a function of network externalities that occur across markets. This work illustrates the incentive for a producer of one good to enter the market for its requisite complement; firms that do so can be particularly tough competitors. Rochet and Tirole (2001) modeled how an increase in installed base for one side of the market can tilt the price structure to the benefit of its complement provider. They offered several illustrative examples, including operating systems, computer games, telecommunications services, and streaming media networks. Due to open standards, providing both components in a competitive two-sided market may offer limited opportunity to enhance a firm's exchange benefits. However, consumers may still be uncertain of the extent of compatibility. Hence, they may favor servers with a larger browser installed base to reduce potential risk.

A large installed base for one component in a two-sided product mix may also *signal* the viability of the firm, establish the firm's reputation, and generate a positive make-related premium (Tam and Hui 2001). Such factors may be critical in network markets because adopters are interested not only in present market position but also in a product's prospects for future success (Katz and Shapiro 1986b). In the absence of perfect information, browser share may be used as a proxy for future installed base and server viability. Thus, the signaling influences on user familiarity and perception may be significant. The above theoretical discussion suggests that the market for Web server software exhibits the characteristics of a two-sided market and that the externality runs across markets from consumers of browsers to consumers of servers.

> HYPOTHESIS H2: *Firms with a greater browser market share will enjoy higher server prices than rivals with a smaller browser share.*

Mindshare

Consumers in today's market form expectations regarding the future size of competing networks (Katz and Shapiro 1985). This is one of the fundamental reasons why network markets are

different from conventional markets. While a consumer of a product such as bread or blue jeans may gain little value if others adopt the same product, consumers of network goods should gain value if the product is widely adopted. The term *mindshare* is often used to describe consumer awareness, the perceived importance of a product with respect to its rivals, and its likelihood for future success (Shapiro and Varian 1998). The concept is related to the notion of *visibility* used in the IT adoption literature—that is, the extent to which potential adopters recognize a product in the adoption context (Moore and Benbasat 1991).

Given the implied importance of mindshare, understanding how consumers form rational expectations about future adoption is critical. Earlier empirical studies attempted to capture a given product's brand premium (sometimes referred to as *make effect*) via a single indicator variable. However, this approach provides a coarse measure and fails to take into account any variance in degree of make among competitors. In addition, results examining the impact of make effects remain mixed. In studies of the spreadsheet market, for example, Gandal (1994) identified a price premium associated with the Lotus brand. Using a different data set, however, Brynjolfsson and Kemerer (1996) did not find a Lotus-related make effect. Developing a clearer understanding of the factors that may influence the perception of future market dominance is critical for firms competing in markets subject to network externalities.

Even though identifying and quantifying the perception of an entire base of potential adopters is impossible, consumers clearly seek proxies or surrogates to simplify decision making and help predict the future (Arthur 1994). Media influence, such as the frequency of product mentions in the popular press, likely serves as such a surrogate. Economic models have also suggested the influence of media on customer perception. For instance, Farrell and Saloner (1986) argued that preannouncements might prevent a bandwagon from gaining momentum. Consequently, press mentions of a product are used as a proxy for mindshare. It is hypothesized that products that appear more often in the popular press will, *ceteris paribus*, exhibit higher prices.

> HYPOTHESIS H3: *Server products that are mentioned more often in the press will enjoy higher prices than rivals with fewer mentions.*

Compatibility and Standards

Literature suggests that if users place value on compatibility, such compatibility should be a source of network externalities (Katz and Shapiro 1992). This is because membership in an established standard provides access to a larger network composed of firms all complying with that standard. Even though consumers reap network benefits from compatibility in the form of a larger base of exchange, in some cases manufacturers may not desire standardization. A firm offering a proprietary product with a large network base can view the lack of competitor compatibility as a strategic asset because new products that enter the market will initially have a smaller installed base, and these products will be unable to interact with the market leader. Similarly, firms that offer new products in a market are motivated to establish critical mass. These firms may initially seek compatibility to promote adoption (Regibeau and Rockett 1996).

Gandal (1994) conducted some of the first studies that empirically examined software standards as a source of network externalities. Applying hedonic pricing techniques to a study on 91 observations of 10 spreadsheet vendors, Gandal found that spreadsheets offering access to a broader network of users (through the Lotus standard, connectivity to external databases, or LAN compatibility) exhibited a price premium and hence were more highly valued by consumers. This analysis was later extended to include database software. Looking at three periods from 1989 athrough 1991, Gandal (1995) concluded that the Lotus spreadsheet standard was also significant in generating network externality-based price premiums in the database market. These results suggest that network externalities can be signi-

ficant across non-requisite complementary goods. Building on Gandal's work, Brynjolfsson and Kemerer (1996) considered the value of the Lotus menu tree interface, finding that compatible products commanded a price premium of roughly 46 percent over otherwise comparable rivals. The significance of these factors was interpreted as evidence of network externalities. However, the inclusion of compatibility features may also enhance the overall quality of a product. Therefore, such measures influence both components of the base model in Figure 1.

With respect to the Web server market, standards for secure file transmission can be considered similar to file compatibility standards. Firms that support a given standard can exchange information, whereas those that do not support it are barred from secure exchange opportunities. Thus, we expect servers that include dominant standards to exhibit larger price premiums.

> HYPOTHESIS H4: *Server products including the dominant security standard will enjoy higher prices than rivals that do not.*

Trialability

Rogers (1995) cited trialability as an important factor when adopters are evaluating products and services. Moreover, trialability has been shown to play a significant role in the adoption of information technologies (Agarwal and Prasad 1997). The Internet extends trialability by allowing potential adopters to download limited use or time-expiring versions of products. Such products can be distributed at near-zero marginal cost (Nejmeh 1994). Peer users may also provide proxied trialability (Bandura 1977). Even if a product is not actually tried, however, the knowledge that it could be sends a quality signal to the consumer similar to a guarantee. Therefore, it is expected that consumers given the opportunity to test a product before buying will pay a higher price. Perceived risk may be particularly high in early-stage, evolving markets where factors such as lifetime aggregate investment outlay and vendor stability are unclear. As such, we expect trialability to be positively related to price.

> HYPOTHESIS H5: *Products that offer a trial version will enjoy higher prices than rivals that do not.*

Empirical Model and Data

The empirical model used in this study is based on the hedonic pricing approach, which measures how individual product attributes or features contribute to product valuation by the average consumer. Price is used as a proxy for consumer value. This approach assumes that attribute bundles can be appropriately quantified. It has been used successfully in several studies of IT pricing (Lynch et al. 1990; Rao and Lynch 1993) prior to its inclusion in network externalities studies in IT markets (Brynjolfsson and Kemerer 1996; Gandal 1994, 1995).

To test the hypotheses, the following model was used:

$$P_{it} = f(N^{p}_{it}, N^{c}_{it}, M_{it}, S_{it}, Tr_{it}, F_{it}, T_{t})$$

where the price of a given product i at time t, P_{it}, is expressed as a function of standards S_{it}, product features F_{it}, and time T_t. However, the model extends earlier work in three important ways. First, it accounts for the situation presented by two-sided markets. The network externalities variable is decomposed into the share of the primary product N^{p}_{it} and the share of the composite component N^{c}_{it}, because two products (the browser and server) may generate share-based benefits that influence the observed product (the server). Second, the model considers consumer awareness (mindshare, expressed as M_{it}). Third, trialability is considered as the variable Tr_{it}. Figure 2 presents an expanded version of the conceptual model, along with variable operationalizations and hypothesized direction of influence, while the next section describes the units used in the current operationalization.

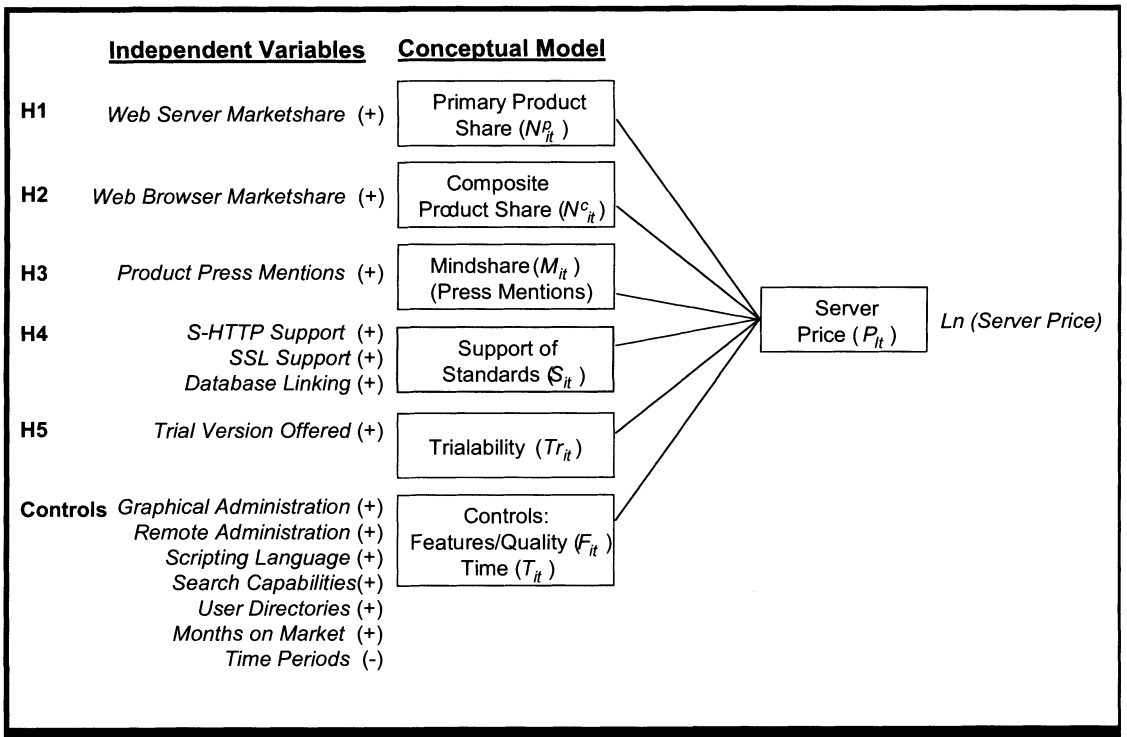

Figure 2. Variables, Hypothesized Influences, and Conceptual Constructs

Data

To test the model, data on relative market share, standards, product features, press mentions, and price in U.S. dollars was collected. Data used in this study consists of a cross-sectional time series over 19 months from August 1995 through February 1997. In keeping with earlier studies and the restriction of the hedonic pricing method, only priced products were included in the data set.[6] The 321 observations in the data set reflect 34 stand-alone, non-shareware, commercial Web server products available for the Windows software platforms.[7] Table 2 offers descriptive statistics on the data used in this study. All hedonic studies suffer from limited richness conveyed by selected feature variables. However, the depth of resources consulted for this study and the consistency of selected criteria with factors suggested in prior research allow for a representative set of time-adjusted feature and price data.

Monthly data on server market share was obtained from NetCraft Consulting. Since August 1995, NetCraft has run a monthly survey to determine the current installed base of various Web server products. The server share variable reflects the percentage market share during a given time for a particular product. The NetCraft survey represents the most widely quoted analysis of server software market share. The NetCraft survey was cited over 50 times in the trade and busi-

[6]An additional analysis was performed to gauge the impact of free servers. These results are also presented in Results and Interpretation.

[7]At the time of the study, shareware products made up only a very small fraction of the market for Windows platform Web server software. The elimination of shareware products is consistent with earlier hedonic pricing studies in software markets.

Table 2. Descriptive Statistics for Model

	Variable Name	Min.	Max.	Mean	Std. Dev.
	Price (USD)	40	2995	567.902	508.080
Dep. Var.	*LnPrice*	3.69	8.29	5.973	0.980
H1	*Server Share*	0.0002	11.48	1.275	2.597
H2	*Browser Share*	0	83.3	9.527	25.299
H3	*Product Mentions*	0	0.458	0.059	0.088
H4	*SSL Security*	0	1	0.399	0.490
	S-HTTP Security	0	1	0.178	0.383
	Database Linking	0	1	0.548	0.498
H5	*Trial Version*	0	1	0.555	0.498
Controls	*GUI Interface*	0	1	0.897	0.304
	Remote Administration	0	1	0.673	0.470
	Scripting Support	0	1	0.642	0.480
	Searchability	0	1	0.321	0.468
	User Directories	0	1	0.589	0.493
	Months on Market	0	27	10.199	6.058
	Time in Months	0	18	10.682	4.960
	Free Product Entry	0	1	0.717	0.451

ness press during the course of his study. As such, it is probably the most representative proxy of user's perception of a product's network size. Data on Web browser market share was obtained from Web site usage logs at Yahoo! and the University of Illinois and from the consulting firm Intersé. This figure represents a firm's share of the Web browser market.

Standards and features variables were chosen (1) when they were employed by previous studies, or (2) when they appeared across multiple product reviews from separate sources. A common set of feature definitions was suggested in material provided by MecklerMedia (the publisher of industry magazines that provide server product reviews and owner of the site Webcompare.com). An identified feature was then chosen for inclusion in the test model when it was cited in multiple trade press articles (Airborne 1996; Wingfield 1996) and in a popular text on Web server deployment (Stein 1995). The choice of feature variables is also consistent with prior research on technology adoption and acceptance (Davis et al. 1989; Rogers 1995). For example, the presence of a graphical interface for server maintenance and the ability to administer the server from a remote location both appear across the product evaluation literature. They are considered ease-of-use features, enhancing consumers' valuation and so their likelihood of acceptance. Similarly, the choice of standards variables for database and security were aligned for consistency with prior studies of network externalities in software industries (Brynjolfsson and Kemerer 1996; Gandal 1994). If a particular product was offered with a feature during the observation, then the respective variable was coded as a one, otherwise it was

coded as a zero. Three standards-related feature variables were considered: support for the SSL and SHTTP security standards and support for linking the Web server to third-party database products. Stand-alone features considered included offering a graphical user interface, the ability to administer the server remotely (i.e., not from the host console), support for a scripting language, support for search and indexing of server pages, and the ability to support separately administered directories for multiple users or groups. Trialability was recorded as a one if a trial version of the product was offered. Time was recorded as the period of a given observation (zero for the first period). Months on market was recorded as the number of months a given product had been available commercially during the observed period.

Time-adjusted price, feature, standards, and trialability data were collected via a content analysis of company press releases, version update logs, and industry product reviews. The variety of sources allowed for cross-checking and corroboration and for a highly consistent and reliable data set. In the rare case where a discrepancy was noted, the software developer was contacted for clarification. The use of such industry- and company-supplied sources to acquire time-reflected data is similar to that used by Brynjolfsson and Kemerer (1996), Gandal (1994, 1995), and Lynch et al. (1993), among others.

Recognizing the importance that consumer awareness may play in generating network effects (Katz and Shapiro 1985), we use a proxy variable for mindshare that is intended to reflect product awareness. Data on press mentions was gathered using the full-desktop license of Lexis-Nexis. Data gathered from press mentions in electronic databases has been used in a number of previous IS studies (Hess and Kemerer 1994; Kettinger et al. 1994; Pennings and Harianto 1992). Mentions from the three months prior to a product's introduction were added to the running total to account for the possible impact of pre-announcements (Farrell and Saloner 1986). Citations for a particular period were determined by adding all mentions of a product from three months prior to its introduction through the month prior to the time period of the observation. Because we investigated press mentions to gauge relative product awareness, the examined measures were calculated as the percentage of counted press mentions relative to the other products in the sample. This created a variable that reflects a scale of one's relative press mentions with respect to competitors and accounts for growth in awareness over time. While absolute measures of mindshare are impossible to calculate, this method should provide a greater degree of difference in the awareness of firms and products than the simple one/zero indicators for make that were used in prior studies.

Results and Interpretations

The indicated variables were regressed against the natural log of price. Table 3 presents the results. Model (1) is structurally most similar to that used to test network externalities in the computer spreadsheet market (Brynjolfsson and Kemerer 1996; Gandal 1994). By presenting this model, we examine whether our results are consistent with prior results. Model (2) examines the influence of mindshare and trialability. Model (3) examines the impact of browser share as a component of a two-sided market. Market two-sidedness is further explored through a factor analysis, with Model (4) considering browser and server share as a single factor related to server price. Model (5) attempts to measure the impact on priced products when a well-known firm has entered the market providing a free good.

Results are presented using the semi-log specification for several reasons. In many cases, transformed variables provide a more natural expression of the characteristics being studied (Johnson and Wichern 1993). This is likely the case in hedonic situations, since the aggregate of various factors may have a multiplicative impact on consumer value (i.e., the whole is worth more than the sum of its parts) (Fisher and Shell 1971). The semi-log specification is also consistent with previous network externalities studies. Although results are reported using the semi-log specifica-

Table 3. Estimation Results

		(1) Server Share		(2) Extended		(3) Two-sidedness		(4) Factor		(5) Shock	
	Variable	Coef	T-stat	Coef	T-stat	Coef	T-stat	Coef	T-stat	Coef	T-stat
	(Constant)	4.14	23.16***	4.06	28.73***	4.06	29.2***	4.57	35.1***	4.54	35.86***
H1	*Server Share*	0.172	7.85***	0.075	3.71***						
H2	*Browser Share*					0.009	4.53***				
H3	*Product Mentions*			0.02	3.65***	0.02	3.32***				
H4	*SSL Security*	0.47	3.07***	0.64	5.25***	0.50	4.00***				
	S-HTTP Security	0.33	2.23**	0.03	0.25	0.15	1.17				
	Database Linking	0.35	3.40***	0.35	4.30***	0.36	4.50***				
H5	*Trial Version*			0.76	11.05***	0.79	11.55***	0.75	12.09***	0.75	12.43***
Controls	*GUI Interface*	0.97	6.44***	0.59	4.87***	0.58	4.88***	0.66	6.25***	0.65	6.39***
	Remote Admin.	0.24	2.04**	0.37	3.74***	0.40	4.11***	0.33	4.01***	0.33	4.15***
	Scripting Support	0.52	6.15***	0.53	7.65***	0.48	6.98***	0.56	9.58***	0.55	9.69***
	Searchability	0.29	2.36**	0.18	1.82*	0.35	3.35***	0.39	5.61***	0.41	5.92***
	User Directories	0.55	6.01***	0.51	7.09***	0.50	7.05***	0.56	8.91***	0.56	9.21***
	Months on Market	-0.12	-8.76***	-0.13	-12.20***	-0.14	-12.94***	-0.15	-15.14***	-0.15	-15.84***
	Time in Months	0.06	4.26**	0.07	6.15***	0.07	6.62***	0.08	8.17***	0.12	9.26***
Factors	*Signal Factor*							0.42	9.99***	0.43	10.42***
	Standards Factor							0.41	13.41***	0.41	13.63***
Shock	*Free Product Entry*									-0.41	-4.28***
	Adj. R-sq.	0.63		0.78		0.78		0.78		0.79	
	Durbin-Watson	1.63		1.94		1.92		1.90		2.01	
	F	51.31		86.72		89.07		114.68		111.75	

Significance: * p < .10, ** p < .05, *** p < .01

tion, estimations using alternative specifications (i.e., linear, and transformation of the dependent variable determined via the Box-Cox approach) are presented in the Appendix. The consistency of the main results is noted across the various models. All models were tested for multicollinearity using both the VIF and Belsley-Kuh-Welsch diagnostics (Belsley et al. 1980). In each model, the results indicated that the independent variables were not significantly confounded.[8] Residual plots for all models show that lack of normality was not a concern.

Network Effects in a Two-Sided Market

Model (1) considers the share of the server product. However, it does not take into account the role of the complementary component market, mindshare, or trialability. The positive significance of the server product's market share relative to the log of the server price supports the network externalities hypothesis (H1). The precise interpretation of the impact of network externalities is limited by the context of any given model and the explanatory power of included variables. Nonetheless, the 0.172 coefficient of server share suggests that during the time of the study, ceteris paribus, a one percent increase in server market share resulted in a 18.5 percent increase in price relative to competitors ($e^{0.172}$ = 1.185; or 18.5 percent).

Model (2) introduces two additional variables: mindshare and trialability. While server share continues to register a significant, positive impact on server price, the introduction of mindshare and trialability variables in the model offers more explanatory power. The adjusted R^2 is .78 as opposed to .63 in Model (1).

Model (3) examines the theoretical assertion that an externality runs across markets (in the current context, from browsers to servers). In this model, browser market share is positively related to the log of server price. During the time of the study, the coefficient of 0.009 suggests that a 1 percent increase in browser share resulted in roughly a .9 percent price premium. This indicates that the Web server market behaves as a two-sided market. It supports the contention that a larger installed base for one product in a two-sided market will provide price-related benefits to its complement (Parker and Van Alstyne 2000). Open standards may diminish a firm's exchange benefits from providing both server and browser. Nonetheless, consumers might still favor servers with a larger browser installed base in the presence of compatibility concerns. Consumers might also use the market share of the complement as a proxy for the viability and future success of the server (Katz and Shapiro 1986b).

In terms of adjusted R^2, Models (2) and (3) show that both the browser- and server-share variables have similar explanatory power. If both variables are included in a single model, however, the server-share variable becomes insignificant because of its high correlation (.89 in Table 4) with the browser-share variable.[9] The high correlation between the server share and the browser share means it is inappropriate to present results for both variables in the same model. Nonetheless, this correlation is expected. It is consistent with a two-sided market in which a larger browser share triggers a larger server share and higher server price. Additional analyses that further test the two-sided market hypothesis and offer additional insights are detailed later.

[8]The VIF values for all variables in all models presented fell well below the threshold of 10.0, and condition indexes in any of the models did not exceed the Belsley-Kuh-Welsch heuristic of 30.

[9]A model including both variables (not shown) provided results highly similar to those in Model (3). Aside from the insignificance of server share, variables in both models were consistent in terms of significance and direction of influence, and had roughly equivalent coefficients. Models also offered similar explanatory power. This behavior is to be expected, given the predicted association of the two share variables in a strongly two-sided market.

Table 4. Correlation Matrix

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Browser Share	1																
2	Server Share	0.89	1															
3	% Prod. Mentions	0.68	0.74	1														
4	Database	-0.03	-0.05	-0.03	1													
5	SSL	0.20	0.19	0.21	0.57	1												
6	S-HTTP	-0.17	-0.15	-0.06	0.42	0.57	1											
7	Signal Factor	0.93	0.95	0.86	-0.04	0.24	-0.16	1										
8	Standards Factor	-0.02	-0.02	0.04	0.80	0.87	0.81	0.00	1									
9	Trialability	0.32	0.42	0.51	0.12	0.14	0.14	0.43	0.15	1								
10	GUI Interface	0.13	0.17	0.23	0.33	0.23	0.16	0.18	0.29	0.34	1							
11	Remote Admin.	0.26	0.34	0.40	0.11	0.54	0.32	0.37	0.40	0.19	0.49	1						
12	Scripting Support	0.28	0.19	0.04	0.25	0.24	-0.04	0.20	0.17	0.10	0.15	0.28	1					
13	Searchability	0.14	0.34	0.29	0.22	0.53	-0.02	0.32	0.30	0.17	0.23	0.48	0.18	1				
14	User Directories	0.30	0.19	0.26	-0.06	0.27	0.11	0.28	0.13	0.08	0.18	0.32	-0.06	-0.12	1			
15	Time	-0.13	-0.13	-0.23	0.00	0.06	0.01	-0.16	0.03	-0.03	-0.19	-0.17	-0.16	-0.06	-0.05	1		
16	Months on Mkt	0.47	0.52	0.32	0.12	0.44	0.17	0.48	0.29	0.35	0.22	0.38	0.14	0.32	0.23	0.58	1	
17	Free Prod. Entry	-0.11	-0.11	-0.21	-0.04	0.00	-0.02	-0.15	-0.02	-0.05	-0.19	-0.17	-0.17	-0.06	-0.05	0.81	0.43	1

Mindshare

To test Hypothesis 3, we introduce the mindshare variable in Model (2). While the positive impact of market share on server price remains after considering press mentions, *ceteris paribus* we found that those firms that received more mentions of their products than their rivals were able to command higher prices. The mindshare/price premium relationship continues to hold in Model (3) where browser share is used in the place of server share. Note that the significance of product mentions occurs without weakening support for (1) the influence of share or standards as identified by prior research, or (2) the impact of considering browser share in place of server share. These results suggest that mindshare has a significant influence on product price and that it extends the explanatory power of software market models.

Standards

Database connectivity continues to be significant across all models. However, it is more interesting to compare SSL and S-HTTP security standards. During the initial development of the commercial Web server market, industry leader Netscape pioneered the SSL Web security standard and made it available to industry consortia and rival vendors. Smaller players, such as Open Market, adopted a competing (although not mutually exclusive) standard known as S-HTTP. While S-HTTP was not significant in Models (2) and (3), the SSL standard appeared as significant in all models. This is consistent with the theory that consumers value the most widely adopted standard. Descriptive statistics (Table 2) indicate that the SSL standard was adopted by nearly 40 percent of all Web server products, while the S-HTTP standard was available in only 18 percent. The significant price premium placed on the most widely employed standard supports Hypothesis 4 and suggests that competition among security standards was influenced by network effects.

Trialability

Trialability has been shown to increase the likelihood of product adoption (Rogers 1995). Because the Internet allows trial versions of software to be distributed at virtually zero marginal cost (Negroponte 1995; Nejmeh 1994), the impact of trialability on product adoption is likely to be more important in markets for information goods. In all models where trialability was considered, results indicate that trial versions are associated with price premiums. In fact, *ceteris paribus*, firms offering a trial version enjoyed a price premium of roughly 110 to 120 percent.

Other Product Features Influencing Server Price

We included additional factors in the study both as controls and to reflect the current state of practice in hedonic modeling of software markets. Feature variables are included to offer a level of quality adjustment per product. All were positively significant across the models. Results also indicate that, *ceteris paribus*, a product is more likely to be offered at a lower price the longer it has been on the market. This is consistent with the assertion that many firms introducing new technologies are able to extract price premiums from eager early adopters (Shapiro and Varian 1998). After considering age-related price degradation, Web server prices show evidence of a slight price increase over time. This may reflect uncaptured time-based increases in product quality, inflation, and the general growth and importance of Web servers that paralleled the ascendance of the early Internet economy.[10]

[10]Although the variables measuring the months a product has been on the market and time period trend in the same direction, VIF measures do not suggest concern regarding possible confounding of the results. This is due to the fact that any two server products were most likely released at different times. As a further test, a model removing the time indicator was run, and although less descriptive than the presented models, this model did not alter the significance or direction of variables examined in the prior results.

Table 5. Factor Analysis Standardized Loadings (λ)

Variable	Signal	Standards
Browser Share	**0.93**	-0.02
Server Share	**0.95**	-0.02
Product Mentions	**0.86**	0.04
Database Linking	-0.04	**0.80**
SSL Security	0.24	**0.87**
S-HTTP Security	-0.16	**0.81**

Further Analysis of Network Effects and Two-Sidedness

Because a single server market share variable would not account for the influence of both sides of the market (Farrell et al. 1998; Parker and Van Alstyne 2000; Rochert and Tirole 2001), we tested the impact of the browser share variable in Model (3) and found it to be positively related to the server price. This finding supports the idea that externality runs across markets from browsers to servers. Because of the high correlation between the server share and browser share variables, recall that it would be inappropriate to present results with both variables in the same model However, principal component factor analysis was used to examine more deeply the relationships among the variables studied.

Table 5 presents the loadings of factors identified using principle component analysis with Varimax rotation.[11] Two factors emerged. The first factor, labeled *signal*" includes the server market share, browser market share, and press-mentions variables. The presence of both market share variables offers further support for the idea that the market for Web software exhibits the characteristics of a two-sided market. The presence of press mentions is also consistent with theory. If consumers consider market share as a signal to determine both the viability and the extrinsic benefits of a network, then press mentions should also create mindshare that supports the network effect (Katz and Shapiro 1985). Overall, the results support the idea that consumers not only consider the size of a network today but also the network's likelihood of future success (Arthur 1994; Fichman and Kemerer 1993; Katz and Shapiro 1986a).

The second factor, labeled *standards*, is made up of the three indicators representing the standards considered in the study: support for the SSL security protocol, the S-HTTP security protocol, and support for linking to external database products. The rationale for considering these standards is grounded in earlier work (Brynjolfsson and Kemerer 1996; Gandal 1994). The fact that none of the other feature variables loaded on this factor are at or above $\lambda = .5$ suggests the appropriateness of conceptualizing standards variables apart from product features.

Model (4) in Table 3 shows the results of a regression using the two factors. The positive significance of the signal factor continues to support the existence of network externalities in the Web server market and the existence of a two-sided market. The positive significance of the standards factor offers further support for the idea

[11]All variables were standardized before being entered into the factor analysis. Cross-loading was not a problem with any of the variables used in the two factors (SSL, with a cross-loading in the signal factor at $\lambda = .24$, was the only variable showing a λ above .2). Both signa' and standards factors demonstrated an acceptable level of internal reliability with Cronbach's alpha of .909 and .766, respectively.

that consumers will place a higher value on more widely adopted standards.

The Market After the Entry of Microsoft's Free Servers

When modeling market behavior, it is also important to acknowledge, consider, and, when possible, test for additional factors that may be at work in the context explored. In this particular context, we wanted to ensure that the entry of a well-known, free-pricing firm mid-market did not distort the identified support for the hypotheses examined. Theory suggests that it is sometimes best for vendors to subsidize adoption in the presence of strong network externalities (Farrell and Saloner 1986; Parker and Van Alstyne 2000; Rochert and Tirole 2001). Giving away product can be considered an extreme form of subsidy aimed at rapidly acquiring market share. The practice may be motivated by a desire to control a standard, or the potential for encouraging the purchase of related products. The firm may also attempt to grow share for a product for which it eventually hopes to charge—a strategy known as penetration pricing (Church and Gandal 1992, 1993). Cusumano and Yoffie (1998) suggest that these reasons may have motivated Microsoft to enter the Web server market by providing its commercial-grade product free of charge. Eight months into the time period examined in this study, Microsoft entered the market with a free Web server. This entry may have damaged consumers' perception of the viability of the then market leader, Netscape.[12] One would expect such a move to have a negative impact on the price of commercial participants due to a reduction in consumers' willingness to pay. Alternatively, the shock may have had limited impact because of *excess inertia* or the reluctance among users to leave a mature network for an immature one (Farrell and Saloner 1985). Thus, it is unknown if Microsoft destroyed any network advantages that may have existed before its entry. To explore this issue, we perform an additional analysis of the impact of the entry of Microsoft's free servers.

Microsoft's entry as a well-known, free pricer is modeled by indicating observations as zero during the first 8 months of the study when the firm did not offer a server, and as one during the last 11 months when it did. The results in Model (5), Table 3, show that a negative price shock, significant above and beyond the negative downtrend noted by the product age variable, is evidenced in the period after Microsoft's entry. The entry of this free product into the market seems to have lowered aggregate prices by roughly one-third. Nonetheless, network effects as indicated by the signaling and features factors were still significant.[13] Commercial firms lowered prices in response to threats, but they still maintained commercial products. These results suggest that market leaders were able to benefit from signaling-related price premiums despite the free alternative provided by a well-known competitor.

Limitations

Our research has several limitations. The investigation is constrained first by the time period examined and data available. Results may vary over time as competitive circumstances in the market change. Other important factors might not be adequately reflected in the model, perhaps because the data is too coarse. Despite the limitations, however, our results are consistent with and extend prior work on software and IT markets.

[12]In 1996, twice as many respondents named Netscape rather than Microsoft as the company that would be most important to their company's Web-based business. By 1998, Microsoft was 10 times more likely to be nominated as "strategically most important" to the success of corporate Web-based businesses (Cusumano and Yoffie 1998).

[13]These results also hold in models decomposing the factors into separate independent variables for share, press mentions, and standards. For brevity, these results are not presented in the results table.

Conclusions

With the emergence of the Internet and other low-cost, ubiquitous, IS supporting infrastructures, the topics of network externalities and two-sided markets are receiving increased attention among managers and IS researchers. Although some researchers believe that many, if not most, products subject to network externalities exist in two-sided markets (Parker and Van Alstyne 2000; Rochert and Tirole 2001), exploration of these topics in the literature has been dominated by theoretical or qualitative work. The lack of empirical work represents a gap in our collective understanding. A set of hypotheses was crafted for this study by leveraging literature in the domains of network theory, two-sided markets, multiproduct pricing, the economics of standards, and product adoption. These hypotheses were then used to develop a comprehensive, theory-driven model for considering the effects of network externalities and two-sidedness, as well as the impact of dueling standards, mindshare, and product trialability.

The positive relationship between server price and server market share offers empirical support for the network externalities hypothesis. In other words, we find evidence that significant positive network externalities exist in the Web server market. This finding, taken in the context of previous qualitative research, suggests that market share was the bulwark of price-based competitive advantage achieved during the course of this study. Support for network externalities in the Web software market is particularly interesting because it suggests that even in a market characterized by open standards, network effects are significant.

The relationship between browser share and server price has important strategic and theoretical implications. It suggests that the Web software market behaves as a two-sided market. Firms able to capture market share for the complement enjoy market share and price benefits for the other component offered (Schilling 2002). Cusumano and Yoffie (1998) point out that Netscape's strategy was based largely on supporting open standards, a sharp contrast to earlier dominant software firms. Open standards may diminish a firm's exchange-related lock-in benefits for providing both components. Yet, consumers may still fear compatibility problems and so favor servers with larger browser installed bases. This finding may be critical to understanding factors influencing future competition in software markets, because Internet and network adoption encourages the industry to continue embracing openness.

Extrapolating beyond the period studied, one might also conclude that Netscape's inability to secure ISP contracts for its browser was a watershed event (Cusumano and Yoffie 1998). By failing to lock up channels that could maintain and grow browser market share among new consumers, Netscape (now part of AOL/Time Warner) lost its dominant browser share, and with it an asset that had contributed to its profitability in the more lucrative server market.

The relationship between the share variables and press mentions identified in the factor analysis is also an important finding because it supports the claim that signaling fosters network effects (Tam and Hui 2001). Consumers want to join a network that leads now and that will continue to do so in the future. In the absence of perfect information, consumers may have to use a number of proxies to gauge a network's future viability and associated externality benefit. This study's results suggest server share, browser share, and mindshare are such proxies. In addition, these results point to research opportunities to further develop theory and to investigate more deeply the dynamics between signaling and network effects. By identifying the benefits of press mentions, this study also lends credibility to the strategy of targeting public relations efforts at raising a firm's press profile.

In the competition for publicly available standards, the price premium for the more popular SSL security standard implies network effects. This price premium, when compared with the lack of one for S-HTTP, may support the assertion that dominant products in network markets are not

always the highest quality. During the time of the study, Open Market's CEO stated, "Merchants will use our software because it offers the most comprehensive security." Clearly Open Market felt that by supporting S-HTTP in addition to SSL, it was offering a better security standard. However, despite the quality advantage perceived by Open Market, the S-HTTP standard failed in the marketplace. This happened while Netscape's dominance of both browser and server markets allowed it to champion the SSL standard. It is also worth noting that Netscape developed, embraced, and publicly offered the SSL standard while excluding the S-HTTP standard from its product line. In this case, the dominant firm seems to have inhibited the diffusion of the rival standard in open standards competition.

The reported relationship between trialability and price is also a key finding. This relationship underscores the importance of offering trial versions of software products. Trial versions help seed initial markets and jumpstart bandwagons by fostering experimentation. This experimentation prompts further signaling through use and feedback conveyed to others, and improves a consumer's willingness to pay (Agarwal and Prasad 1997; Bandura 1977; Katz and Shapiro 1994; Nejmeh 1994; Padmanabhan et al. 1997).

The significant and dramatic price drop caused by the entry of a free product by a well-known producer may provide an important point of reference for other industries and contexts. An increasing number of businesses in markets as diverse as finance, retail, and consumer electronics have adopted the free or reduced pricing strategy. Depth of product line has been suggested as influencing IT adoption decisions (Tam and Hui 2001). Firms without scope in a product line may see their market invaded by firms willing to loss-lead in one market in order to generate sales or lock consumers into another revenue stream.

In addition to the managerial implications outlined above, this research offers several interesting contributions for the researcher. From a methodological perspective, this work has developed a modeling approach for studying the important case of two-sided information goods. This approach has also leveraged prior research to extend and enhance modeling techniques used to study pricing in software markets. Finally, it provides empirical support for earlier theoretical work on network economics, two-sided markets, software standards, and trialability.

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Appendix

Comparing Results Across Specifications

One of the difficulties in performing hedonic pricing tests lies in selecting the appropriate model specification. The selection of an appropriate form can be particularly challenging because theory does not suggest a clear functional relationship among variables. For example, in discussing the interpretation of hedonic models, Triplett (1986) argues that other functions may often be appropriate. The semi-log form used in this work is justified based on the increased normality of the dependent variable versus ransformations, its consistency with prior approaches, and the likely multiplicative impact of several features on a product's valuation (Fisher and Shell 1971). However, by exploring additional specifications, one can examine if the results in the selected model are an artifact of the specification itself or are robust across alternative methods. It is common practice in econometric studies to present the results of alternative specifications that consider other possible transformations of the dependent variable (Brynjolfsson and Kemerer 1996; Gandal 1994). We extend this practice by introducing the more precise Box-Cox methodology as one appropriate to use when seeking optimal models describing markets of network goods. Table A1 presents results examining alternative specifications. Model (ii) offers the linear form using these same independent inputs against the non-transformed server price in dollars. Model (iii) presents the results according to an optimal transformation of the dependent variable suggested by the Box-Cox technique.

The Box-Cox methodology can assist in evaluating and selecting an optimal data transformation. Rao, Lynch, and Lin (Lynch et al. 1990; Rao and Lynch 1993) are largely responsible for introducing this methodology to price-related IS research. We offer it here as a worthy technique for those seeking a systematic identification of the optimal transformation to be used in models of network goods. While there are several approaches to utilizing the Box-Cox methodology, this paper follows the maximum likelihood method outlined by Draper and Smith (1981). This technique examines a family of power transformations of the form

$$Y' = Y^{\lambda}$$

for a number of λ occupying a frontier of potential candidate transformations. The optimal transformation is that which identifies the maximum likelihood estimator of λ. In this approach, transformation W is chosen as:

$$W = \begin{cases} (Y^{\lambda} - 1)/\lambda, & for\ \lambda \neq 0 \\ (\ln Y), & for\ \lambda = 0 \end{cases}$$

where

$$L_{\max}(\lambda) = -\frac{1}{2} n \ln (RSS/n) + (\lambda - 1)\sum_{i=1}^{n} \ln Y_i$$

Applying the Box-Cox technique for this data set yields a suggested optimal transformation where $\lambda = 0.18$. As such, the results in Model (iii) are arrived at after each server price observation has been transformed

Table A1. Comparsion of Functional Specifications

	(i) semi-log		(ii) linear		(iii) Box-Cox l=.18	
Variable	**Coef**	**T-stat**	**Coef**	**T-Stat**	**Coef**	**T-Stat**
(Constant)	4.06	29.2***	-193.53	-2.27**	5.55	14.51***
Browser Share	0.009	4.53***	3.88	3.14***	0.0187	3.37***
Product Mentions	0.02	3.32***	17.51	5.59***	0.06	4.20***
SSL Security	0.50	4.00***	314.88	4.15***	1.67	4.90***
S-HTTP Security	0.15	1.17	33.34	0.43	0.31	0.89
Database Linking	0.36	4.50***	186.52	3.83***	0.99	4.52***
Trial Version	0.79	11.55***	259.78	6.19***	2.17	11.51***
GUI Interface	0.58	4.88***	91.19	1.25	1.43	4.37***
Remote Admin.	0.40	4.11***	126.20	2.11**	1.09	4.06***
Scripting Support	0.48	6.98***	153.60	3.62***	1.34	7.01***
Searchability	0.35	3.35***	385.91	6.08***	1.16	4.08***
User Directories	0.50	7.05***	264.64	6.11***	1.40	7.18***
Months on Market	-0.14	-12.94***	-78.19	-11.95***	-0.41	-13.79***
Time in Months	0.07	6.62***	46.39	6.92***	0.23	7.51***
Adj. R-sq.	0.78		0.695		0.788	
Durbin-Watson	1.92		1.728		1.908	
F	89.07	***	57.190	***	92.564	***

Significance: * p < .10, ** p < .05, *** p < .01

as (Y^λ1)/l. Residual plots of the presented models do not demonstrate concerns regarding normality. While the adjusted R^2 value of the model using the Box-Cox transformation is slightly higher than the semi-log form, results are similar enough that we chose to focus on the easier-to-interpret semi-log form in our earlier results interpretation. Such a practice is common when results are roughly similar, when transformations are within one half to one quarter point of more "interpretable" values such as 0 (log transformation) and 1 (no transformation), and when skewness in the error terms is not a concern (Draper and Smith 1981). A variation of the Box-Cox technique can apply the transformation to independent variables as well. This technique was inappropriate in this context, however, because models using the dual-transformation raised concerns regarding the distribution of error terms. Used here, the Box-Cox technique has validated the appropriateness of our choice of the semi-log form for results explanation, even though the $\lambda = .18$ transformation explained slightly more variance in the data.

An examination of the results in Table A1 suggests that there is consistent evidence supporting the major conclusions of this study across all three functional specifications. The three sets of results show a significant, positive relationship between browser share and server price. All models also show a price relationship with the use of dominant standards, the ability to link to external databases, and the availability of trial versions. The positive relationship between price and product mentions holds across the various

models as well. It should be noted that unlike Models (i) and (iii), there were some concerns with the linear Model (ii) with respect to the normality of the distributed error terms; however, this underscores the appropriateness of considering the Box-Cox affirmed semi-log specification. Taken in aggregate, these results indicate a highly consistent degree of hypothesis support across the functional specification considered.