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HEDONIC PRICE ANALYSIS OF THE SERVER APPLIANCE MARKET

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Abstract

Electronic commerce is becoming more and more critical for the modern business. As such, the issue of how to invest wisely in the infrastructure and required facilities for electronic commerce operations demands attention from the management. In this paper, we examine the product attributes that are important in deciding the purchasing price of the multipurpose server appliances—a central piece of hardware for the electronic commerce infrastructure. The application of a hedonic model to a cross-sectional data set of 48 server appliance products reveals that the deciding factors for price are main memory, cache memory, brand name, CPU speed, and hard disk capacity. Also found in the study are the existence of network externalities of brand name and the absence of Grosch's law for economies of scale in computing power. Managerial implications are then derived from the results obtained.

Keywords: Electronic commerce infrastructure, hedonic model, server appliance market, network externalities, Grosch's law

Introduction

Electronic commerce over the Internet provides a firm with new opportunities for conducting business. It is expected that electronic commerce can improve efficiency, enhance customer service, reduce costs, increase sales, streamline production process, etc. According to an estimate by OECD, the worldwide sales of electronic commerce will reach a figure as large as $1 trillion in year 2003 to 2005 (OECD 1999). As a consequence, it is not surprising to witness the enormous spending firms have been making for various business-to-business (B2B) and business-to-consumer (B2C) activities in the hope of leveraging these promised opportunities.

The Internet economy has been described as consisting of four layers: electronic networks, applications, intermediaries, and online transactions (Barua et al. 2000, 2001). While the higher two economic activity layers define the character of the Internet economy, the lower two infrastructure layers constitute the enabling technologies. Currently, within the infrastructure layers, hardware (PCs, routers, servers, etc.) is estimated to have the largest sales at $10 billion to $30 billion (OECD 1999). The hardware suppliers that provide the infrastructure are among the first that have benefited from the increasing demands for electronic commerce. Two prominent examples are Cisco's router sales and Dell's sales of PCs and servers. This paper focuses on the multipurpose server appliances, which are a central piece of hardware for the infrastructure layers of electronic commerce.

The server appliances are one emerging market that becomes a response to the costly and time-consuming web server setup endeavors (Pipex 2000). Server appliances are usually designed to carry out a specialized set of tasks. Some examples of these specializations are web caching, file serving, network attached storage (NAS), firewall, and web hosting. The multipurpose server appliance, on the other hand, combines a critical set of these specialized capabilities to provide full yet streamlined electronic commerce functionality within one server unit. Typical server appliances come pre-loaded and pre-configured for specific functions and consequently require considerably less time and efforts to set up. IDC forecasts that the server appliance market
will grow from $740 million in 1999 to $11.5 billion in 2004 (Jacobs 2000). A number of prominent computer and software vendor companies have also been signaling their commitment to serve this market (Kovar 2000).

The vibrant and competitive nature of the Internet economy puts considerable pressure on server appliance vendors and their customers to make informed decisions when business opportunities arise and growths occur (Gantz 2000). The capacity of buyers to order economical but powerful server appliances and the ability of vendors to deliver them can enhance a particular business opportunity, which in the aggregate can improve market efficiency. An important aspect of this market is the price determination mechanism. Given the importance of the server appliances within the infrastructure layers for the Internet economy, a search for effective pricing mechanisms in the dynamic environment is thus motivated. Besides, the underlying technologies for the server appliances are subject to rapid change. Therefore, we can expect higher rates of quality change, which make conventional price index either difficult to construct or readily obsolete once constructed. This paper intends to address both pricing issues by employing a hedonic pricing model.

**Previous Research**

### Hedonic Model

The multipurpose server appliances are intricately bundled systems. There are a myriad of ways to build them, and consequently there can be countless variations of them. As such, a complete specification of a server appliance would make it difficult for potential buyers to fully understand its aggregate value or for its manufacturers to charge its offerings in a realistic and reasonable manner.

Hedonic models have been proposed to address this issue by determining product characteristics that can help measure the value of the product. In order for a hedonic model to be effective, the selected characteristics should represent the salient aspects that contribute to the customer's utility or pleasure. Moreover, the same characteristics should capture the features that significantly contribute to the manufacturer's costs. The criterion for including product features into a hedonic model is these features should explain the customer's willingness to purchase a product and the manufacturer's willingness to offer it.

### Network Externalities

Network externalities is the economic concept that the value of a product perceived by a customer increases as the number of users of the product increases. The positive extra utilities derived from a larger user base may come from a variety of sources. They include the physical installation effect, standard/compatibility, easier information gathering, market share, and simply the bandwagon effect, among others.

Network externalities can be either direct or indirect. Direct network externalities represent the direct physical effects of the number of users on the quality of the goods. The number of users connected to a cellular phone system is a good example of direct network externalities. On the other hand, indirect network externalities occur when complementary goods become more plentiful as the users of a product grow. The complementary nature of a computer system and the software programs that run on the system can be regarded as an instance of indirect network externalities (Katz and Shapiro 1985).

The server appliances have certain characteristics that suggest the market would demonstrate network externalities. The market should be subject to both types of externalities. It is a composite good of hardware, software, and some level of service from the suppliers. The capabilities of suppliers to deliver products and services after sale are linked to their volume sales. For example, brand name may imply higher quality to the potential buyers, and hence the manufacturer may be able to charge a premium on the extra value implied.

### Grosch's Law

Grosch's law (Grosch 1953) is one of the first attempts to relate computer power to economic value. Grosch proposed that the use of computers would afford a unit cost reduction proportional to the square root of its speed. Subsequent research obtained mixed results. Knight (1966) tested Grosch's law and confirmed it. Cale et al. (1979) claimed with their findings that it did not apply any more. Sicar and Dave (1986) obtained results suggesting Grosch's law was still valid only if it is applied within computer classifications.
The cost defined in previous studies was actually price (i.e., the user’s purchasing cost of the computer system). If the price is a measure of value, then one should observe that both buyer and seller jointly determine the price. Our understanding of the relationship between computer power and value can become clearer through some economic analysis, which in the current study is the hedonic pricing model.

Model Specifications

To apply a hedonic model to the server appliance market, we first have to specify the functional forms. Oftentimes the functional specifications depend mainly on the researcher’s subjective assumptions or empirical intuition. Two of the most frequently used ones are the linear and double log forms. Box and Cox (1964), however, proposed a generalized approach to alleviate the problems of unsystematic model selection and arbitrary data transformation. The Box-Cox transformations basically allow the data to speak for itself, so that the researcher can choose the most appropriate specification by looking at several criteria, including the $R^2$, $F$-statistic, and significance of coefficients estimated, simultaneously. Both the linear and double log forms are the special cases of the generalized Box-Cox transformations.

The generalized Box-Cox model transforms the data through the use of a parameter $\lambda$:

$$
\frac{Y^\lambda - 1}{\lambda} = \beta_0 + \beta_1 \frac{X_1^\lambda - 1}{\lambda} + \beta_2 \frac{X_2^\lambda - 1}{\lambda} + \cdots + \beta_n \frac{X_n^\lambda - 1}{\lambda}
$$

where $\lambda$ is determined by a maximum likelihood function, $L_{max}$. The maximum likelihood value is calculated for different values of $\lambda$, based on the following equation:

$$
L_{max} = -\left(\frac{n}{2}\right) \ln\left(\frac{\text{Residual}}{n} \frac{\text{SS}}{1} + (\lambda - 1) \sum_{i=1}^{n} \ln(Y_i)
$$

where $n$ is the total number of observations, and SS represents the sum of squares. The value of $\lambda$ that maximizes $L_{max}$ in eq. (2), denoted by $\lambda^*$, is used to transform the data in the Box-Cox transformation (1).

It can be easily shown that when $\lambda = 1$, the Box-Cox transformation (1) is equivalent to the linear specification:

$$
Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n
$$

and when $\lambda = 0$, the Box-Cox model (1) reduces to the double log functional form:

$$
\ln( Y ) = \beta_0 + \beta_1 \ln( X_1 ) + \beta_2 \ln( X_2 ) + \cdots + \beta_n \ln( X_n )
$$

The advantages of applying the generalized Box-Cox methodology, along with the linear and double log models, are as follows (Lynch et al. 1990). First, the transformations are based on the estimation results, not on subjectivity held by researchers. Second, the Box-Cox transformations include most of the commonly used ones like the linear and double log forms. Third, the estimation process generates $L_{max}$ values that can help differentiate the effectiveness of alternative models.

Data Description

The data was collected from the web sites of the appliance suppliers in February 2001, supplemented by the product information available in a PC Magazine article (Derfler 2001). The cross-sectional data was used in order to rule out the effects of price inflation and quality changes due to time-based technology advance. The cross-sectional nature of the data set ensures the hedonic model capture only the influential effects of different bundles of product features on the price, not other time-related effects. There are 48 server appliance products included in the data set. The price of a server appliance (PRICE) is used as a proxy to represent the value a potential buyer perceives and a manufacturer delivers when a transaction is made.
A typical multipurpose server appliance offers several common capabilities such as Internet sharing, Web server, firewall, e-mail, and FTP file-transfer services. Therefore, a server appliance provides a business with a powerful but cost-effective set of tools. The capacity of a server appliance is to provide numerous services to a large number of users with highly irregular rates of demands. To accomplish this task, a server appliance needs high processing speed.

The clock speed of central processing unit (CPU), cache memory capacity (CACHE), and the size of random access memory (RAM) jointly determine the execution speed of a server appliance, each through its own way of doing things. The CPU’s own speed is defined through the cycle rate of its internal clock, measured in mega Hertz. This measure is closely related to the number of million instructions executed per second (MIPS). The executed instructions also have to be stored and fetched from memory. There are three levels of memory. L1-Cache is the memory that resides internally inside the CPU and does not vary once the CPU is installed. L2-Cache, which is slower than L1-Cache but faster than RAM, is often simply referred to as Cache. The size of L2-Cache represents the capability of the server appliance to process frequently executed code without having to wait for a slower RAM access. More L2-Cache memory is desirable because studies have shown that significant time saving can be achieved through L2-Cache usage. The third level of memory is RAM where all programs must reside when they are initially loaded. Its size is another factor affecting how fast the programs can be accessed and processed, since RAM is faster than the magnetic storage media.

The size of a hard disk capacity (HD) is another important product characteristic for a server appliance. The hard disk acts as a secondary storage mechanism to support other functions. For example, it is the place where web content resides, where the information of customer accounts and the data derived are stored, and where the diverse applications are permanently retained. It also provides the slack capacity that the server appliance utilizes to absorb irregular rates of activity. As such, a hard disk with higher capacity is preferable to the buyers.

Finally, in order to examine the effects of brand name on the pricing of the server appliances, we analyzed the network externality potential of them. All of the products of the data set carry strong potential weights. However, the Dell brand, has two characteristics not present nor easily replicated by the other brands. First, according to business news and market reports, Dell appears as the current or emerging leader in several fronts including the closely related global server market (E-Week 1998; McCall 1999; Lah 2000; CadInfo.Net 2001). Second, Dell has been vocal regarding the firm’s focus and commitment to this market, above the other firms represented in the data set (InfoWorld 2001).

Consequently, we included a dummy variable, DLL, to represent the server appliances produced by Dell Computers. Among the 48 products in the data set, ten are manufactured by Dell. If the brand name dummy variable is found to be significantly positive, we are provided with empirical evidence to claim network externalities exist in the server appliance market, and buyers are willing to pay more for a brand name product.

Table 1 shows the descriptive statistics of the dependent and independent variables that will be incorporated into our hedonic pricing models.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRICE ($)</td>
<td>3394.04</td>
<td>2452.22</td>
<td>995</td>
<td>12059</td>
</tr>
<tr>
<td>CPU (MHz)</td>
<td>597.23</td>
<td>242.63</td>
<td>200</td>
<td>1000</td>
</tr>
<tr>
<td>RAM (MB)</td>
<td>191.33</td>
<td>157.80</td>
<td>32</td>
<td>512</td>
</tr>
<tr>
<td>HD (GB)</td>
<td>9.19</td>
<td>8.09</td>
<td>0</td>
<td>40.8</td>
</tr>
<tr>
<td>CACHE (KB)</td>
<td>245.13</td>
<td>383.39</td>
<td>0</td>
<td>2048</td>
</tr>
<tr>
<td>DLL (0, 1)</td>
<td>0.208</td>
<td>0.410</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Results and Implications

The empirical results are obtained by applying the three hedonic models—linear, double log, and the Box-Cox transformation—to the cross-sectional data set and are presented in Table 2. In the double log model, the values of zero for HD, CACHE, and DLL are approximated by a number close to zero (0.000001), as suggested in (Lynch et al. 1990; Rao and Lynch 1993). The criteria used to judge the overall appropriateness of the hedonic model are the $R^2$, $F$-statistic, $L_{max}$, and the significance levels of coefficient estimates. Based on these criteria, it can be said the linear hedonic model provides the best results and should be chosen over the other two for interpretations. The linear hedonic model generates the highest $R^2$ (0.75) and $F$-statistic (24.87), and also all the coefficients estimated are significantly positive at the 0.05 level at least. Only its $L_{max}$ value is not the highest among the three
models. The choice of the linear model over the double log model and the Box-Cox transformation is not unique and has been reported in previous work (Rao and Lynch 1993).

Table 2. Estimated Results

<table>
<thead>
<tr>
<th>Model</th>
<th>Coefficient Linear</th>
<th>Coefficient Double Log</th>
<th>Coefficient Box-Cox</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
<td>2.599** (0.946)</td>
<td>0.203 (0.223)</td>
<td>0.291 (0.346)</td>
</tr>
<tr>
<td>RAM</td>
<td>6.689*** (1.480)</td>
<td>0.449*** (0.090)</td>
<td>1.194** (0.459)</td>
</tr>
<tr>
<td>HD</td>
<td>61.784* (25.481)</td>
<td>0.014* (0.007)</td>
<td>0.859 (1.012)</td>
</tr>
<tr>
<td>CACHE</td>
<td>2.114** (0.610)</td>
<td>0.012 (0.009)</td>
<td>0.365 (0.273)</td>
</tr>
<tr>
<td>DLL</td>
<td>1468.66** (473.27)</td>
<td>0.007 (0.009)</td>
<td>1.373 (2.449)</td>
</tr>
<tr>
<td>R²</td>
<td>0.75</td>
<td>0.67</td>
<td>0.74</td>
</tr>
<tr>
<td>F</td>
<td>24.87</td>
<td>16.88</td>
<td>23.99</td>
</tr>
<tr>
<td>λ</td>
<td>1</td>
<td>0</td>
<td>0.367</td>
</tr>
<tr>
<td>Lmax</td>
<td>-409.25</td>
<td>-398.87</td>
<td>-396.84</td>
</tr>
</tbody>
</table>

***p < .001, **p < .01, *p < .05, standard errors in parentheses

The results suggest that the deciding factors for pricing the server appliances are RAM, cache memory, brand name, CPU speed, and hard disk capacity, ranked in that order. These results are consistent with our a priori expectations. What is interesting in our findings is that brand name has exerted positive network effects on the value perceived by the potential buyers. Dell products, including Intel-based servers, desktops, laptops, and notebooks, have been consistently ranked among the best in terms of quality, customer satisfaction, and revenue sales, as reported by a number of surveys in the trade magazines (e.g., Goh 1999; Oullette 1999). This favorable image of Dell brand name is found carried over into its server appliance segment and allows it to charge a premium for the implicit extra value.

To validate Grosch’s law in our data set, a formulation similar to Mendelson’s model (1987) is estimated:

$$\ln\left(\frac{\text{PRICE}}{\text{CPU}}\right) = \alpha_0 + \alpha_1 \ln(\text{CPU})$$

(5)

The coefficient of $\alpha_1$ is estimated to be -0.193 with a t-statistic equal to -1.219, not significant at the 0.11 level. Therefore, the server appliances included in the data set demonstrate the constant returns to scale and do not support Grosch’s law. The constant average cost per CPU MHz may be attributed to the commodity status of server appliance market, similar to the findings by Mendelson on hardware cost and computing power measured in MIPS (Mendelson 1987). This may also explain why the variable of CPU is only the fourth important factor among the five examined. If Grosch’s law applied and the server appliances showed economies of scale, then buyers would get more bang for the buck on the CPU speed and hence would put more weight on its significance for the purchasing decision.

Managerial implications derived from our empirical results are two-fold. For the manufacturers of server appliances, they have to realize the salient factors in deciding potential buyer's willingness to purchase are the features bundled together into their products. As a consequence, the conventional pricing mechanism based solely on material costs, labor expenses, and marginal profits attached to a single unit may not be as useful and meaningful as they should. Sometimes it may even lead to unrealistic pricing decisions that fail to capture the market dynamics. The hedonic pricing model employed in the study can serve as an ideal supplementary mechanism for determining better prices. Also, for a new product about to be marketed, the hedonic model can serve as a price-forecasting tool to evaluate its competitive position in the current market. With the fierce competition typically associated with IT products, this capability may become even more crucial to a supplier’s long-term survival.

Potential buyers of server appliances are facing an equally important resource allocation problem: how to get the most benefits from the product features subject to a given budget constraint. With the help of a hedonic model, they can have a better understanding of the possible options available in the market, or even come up with a customized specification to meet their own...
particular requirements for laying out the infrastructure for electronic commerce. Overall, the hedonic pricing model can help promote product differentiation and cost differentiation, which in the end may enhance the market efficiency.

Conclusions

The infrastructure of electronic commerce is an essential prerequisite for a firm to conduct business over the Internet. Such an investment can be costly and should be examined discreetly in order to make an informed and economically sound decision. This paper employs a hedonic model to examine the salient characteristics that decide the purchasing prices for the server appliances. The results show that the deciding product attributes for price are main memory, cache memory, brand name, CPU speed, and hard disk capacity. Also confirmed are the effects of network externalities due to brand name and the absence of Grosch's law in the market.

Some interesting topics can be suggested for future research. First, only the relationship between hardware features and price is analyzed in the study. We didn't consider the software aspect of this market. As such, future research can incorporate software capabilities into the hedonic model and analyze the interrelation between hardware attributes and software attributes on the pricing mechanism. Second, the server appliance market is only one segment in the electronic commerce infrastructure. Other markets like network service providers, traffic carriers, electronic payment systems, etc. should also be examined, so that suppliers and buyers in those markets can achieve pricing equilibrium. Finally, the hedonic model is mainly designed for a cross-sectional analysis. A more advanced theoretical model thus should be sought to inspect the time-series or panel nature of product features.

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Lah, D. "Dell Takes The Lead In PC Sales," The View, January 26, 2000.