Selection of Notebook Personal Computers Using Data Envelopment Analysis

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Abstract

The decision to purchase one product rather than another becomes more difficult as the number of alternatives under consideration increases. Having to simultaneously evaluate a large number of product attributes among the alternatives can further complicate this decision process. Notebook personal computers are a good example of a product whose many attributes (e.g. price, performance, display type) make direct comparisons difficult. This research uses Data Envelopment Analysis (DEA) as a decision support tool to determine a desirable collection of notebook computers from a set of 146 evaluated. DEA simplifies comparisons among the competing alternatives by providing a single composite measure for each computer when all attributes must be considered simultaneously. This single measure informs the decision-maker which notebooks are *efficient*, or desirable, as compared to the others. The research shows that, of the 146 evaluated, nine are efficient, meaning they have a collective set of attributes that dominate those of the other 137 notebooks. Through sensitivity analysis it is also shown that these nine notebooks are reasonably robust with respect to unfavorable changes in their attributes.

Keywords: Data Envelopment Analysis, notebook personal computers, decision-making

Introduction

When an individual decides to purchase a notebook personal computer (PC), many attributes are typically considered, such as the type of processor (i.e., MMX or Pentium II), processor speed, amount of memory, hard disk size, video attributes, multimedia features, and certainly the price. Some buyers may wish to buy a system having the minimal necessary attributes and save money, while others may wish to spare little expense in exchange for a system that is quite powerful. The comparison of so many attributes makes the purchasing decision process far from trivial.

Publishers of personal computing magazines such as *PC World* (Fox, 1998) direct tremendous effort toward classifying which personal computers (both desktops and notebooks) are the "best." Typically, these studies evaluate issues pertaining to speed. For example, many tests involve determining how certain computers process a large spreadsheet, document, or database. While there is no denying the importance of such tests, other issues are treated entirely subjectively. For example, it is common for an evaluation of a notebook computer to contain language such as: "great sound, reasonable price, strong battery." Such language suggests that these rankings are largely subjective.

This type of decision-making problem can be thought of as multi-criteria because of the many attributes requiring attention — not least of all being cost. Typically, multi-criteria decision-making problem solution methods, like Analytical Hierarchy Process (AHP, [Saaty, 1980]), involve several phases. These phases are not necessarily complex, but they can be "clumsy."

DEA, on the other hand, reduces the effort necessary for interpretation by presenting a single score (a system's *efficiency*) which is the result of jointly considering all attributes of interest to the decision-makers. The efficiency is basically the objective function value of a linear programming model. If the system is found to be efficient, the decision-maker then knows that the PC has a collective set of attributes that is not surpassed by any other system. If this score of efficiency is found to be *inefficient*, the decision-maker then knows that the collective set of attributes for the PC of interest is surpassed by one or more of the other systems. Additional information also presented by

DEA is the necessary amount of favorable changes to the attributes such that they will become efficient. With regard to the *PC World* example above, it is also appropriate to note that DEA minimizes the dependence upon subjective assessments and is, in general, a more objective analytical multi-criteria decision-making approach.

Specifically, this research examines 146 popular notebook personal computers. Several attributes for each computer are considered. Each of these attributes are classified into four major categories which include performance, video, other features, and cost. The resulting efficient computers are further examined for robustness to unfavorable changes in their attributes. Also, several of the computers found to be inefficient (but nonetheless having reasonably desirable levels of attributes) are studied to see how much favorable change is necessary for them to be considered efficient. Practical observations from the study are made, and general conclusions are offered.

Data and Attributes

As stated, this analysis evaluates 146 notebook personal computers. The source for this data was the web-site of a mail-order company (New World Computers Direct, 1998) that specializes in the sale of notebook computers. Computers with missing data were not included in the analysis. For each of these computers, several attributes were considered, as listed in Table 1.

Table 1. Description of Notebook Personal Computer Attributes

Attribute	Units	Attribute Example	General Category
Processor Type[a]	N/A	Pentium MMX	Performance (Output)
CPU Speed	MHz	166 MHz	Performance (Output)
Memory	MB	32 MB	Performance (Output)
Hard Drive	GB	3.2 GB	Performance (Output)
Screen Size	In	12.1 in	Video (Output)
Screen Type[b]	N/A	Dual Scan	Video (Output)
CD	Speed	20X	Features (Output)
Modem	KB/s	33.6	Features (Output)
Warranty	Years	3 years	Features (Output)
Price	$	$2499	Price (Input)

a. Pentium processors received a score of 0, Pentium MMX processors received a score of 1, while Pentium II processors received a score of 2. b. Dual scan matrix displays received a score of 0, while active-scan matrix displays received a score of 1.

The first three columns of this table are self-explanatory. The fourth column, "General Category," provides general classifications of the ten different attributes. This general "classification" falls into one of four groups. The four groups are Performance, Video, Features, and Cost. Processor type, processor speed, memory, and disk size describe general Performance attributes. The screen-size and display-type describe general Video attributes. Speed of the CD player and modem, in addition to the system warranty, are additional Features beyond performance and video. The general attributes of Performance, Video, and Features are considered *outputs* — benefits associated with having the notebook of interest. The decision-maker would like the values of these attributes as high as possible. The attribute of price is in a category by itself, and it is the only *input* — the level the decision-maker must sacrifice in order to obtain the notebook of interest — considered for this analysis. Obviously, the decision-maker would like to have cost as low as possible. One could easily argue as to the classification process of the chosen groupings, with the possible exception of price. It was decided here that attributes dealing with the speed and power of the notebook PC would be classied as "performance" measures, while the attributes related to the physical appearance of information on the PC screen would be classified as "video" measures. Other, less tangible attributes, but nonetheless important ones, such as the warranty life, would be classified as the more general "features" attribute.

To ease computation and interpretation, these ten attributes are reduced to four: Performance, Video, and Features as the three outputs, and Cost as the sole input. Notebooks without CD players had their values set to zero for the CD attribute. The same approach was used for the modem attribute.

Methodology

Data Preparation

The ten attributes presented above are in differing units (e.g. price is in dollars and memory is in megabytes). Obviously, composite measurements of these attributes cannot be interpreted in this form. Prior to analysis, the attribute values for each notebook must be converted into a standardized form. To explain the standardization process, the following definitions are provided:

X_{ij} = the value of attribute j for notebook computer i
$\overline{X}_j$ = the mean attribute value for attribute j across all i computers
$\hat{\sigma}_j$ = the standard deviation of the value for attribute j
Z_{ij} = the number of standard deviations notebook computer i is above or below the mean for attribute j (Z-scores).
RZ_{ij} = the Z-scores re-scaled from zero.
$Performance_i$ = System performance measure for notebook i
$Video_i$ = Video measure for notebook i
$Features_i$ = System features measure for notebook i
$Cost_i$ = Cost measure for notebook i

Determination of the mean and standard deviation across all notebooks for each attribute is straightforward. The values of Z_{ij} (the Z-scores) is determined by the following formula:

$$Z_{ij} = \frac{(X_{ij} - \overline{X}_j)}{\hat{\sigma}_j} \tag{1}$$

After these Z-scores are determined, they need to be re-scaled from zero for each attribute, so that the minimum Z-score for each attribute is zero. This is done by adding the absolute value of the minimum Z-score to each Z-score for each attribute:

$$RZ_{ij} = \text{Abs}(\text{Min } Z_j) + Z_{ij}, \text{ for each attribute j} \tag{2}$$

After these data are standardized and re-scaled from zero, they are organized into the four categories mentioned earlier: Performance, Video, Features and Cost. The Performance measure for each notebook PC is the mean of the first four attributes identified in Table 1:

$$\text{Performance}_i = \frac{1}{4}\sum_{j=1}^{4} RZ_{ij} \tag{3}$$

The Video measure for each notebook PC is the average of the next pair of re-scaled Z-scores:

$$\text{Video}_i = \frac{1}{2}\sum_{j=5}^{6} RZ_{ij} \tag{4}$$

The Features measure for each notebook PC is the average of the next three attributes from Table 1:

$$\text{Features}_i = \frac{1}{3}\sum_{j=7}^{9} RZ_{ij} \tag{5}$$

Because there is only one attribute, the Cost measure for each notebook PC is simply the re-scaled cost attribute (the last attribute from Table 1):

$$\text{Cost}_i = RZ_{i,10} \tag{6}$$

It is important to note that, for each of the three general attribute categories for outputs (Performance, Video, and Features), the mean calculations presented in equations (3)-(5) are not weighted. This reflects the assumption that all attributes make equal contributions to the measure of their general category. For example, processor-type, processor speed, system memory, and hard disk drive size all make equal contributions to the Performance measure for each notebook PC.

Data Envelopment Analysis Formulation

Data Envelopment Analysis is employed to determine which notebook PCs are efficient. A notebook is considered efficient if its composite measure of output offsets its corresponding measure of input (Banker et al, 1984, and Charnes et al, 1978 and 1994). Recall that, for this analysis, Performance, Video, and Features are the three outputs, while Cost is the sole input. Performance, Video, Features, and Cost for notebook k will be represented by P_k, V_k, F_k, and C_k respectively, with weights of $(w_P)_k$, $(w_V)_k$, $(w_F)_k$, and $(w_C)_k$. Weights are simply multipliers that reflect the relative amount of contribution each output makes to the efficiency measure. Letting h_k represent the efficiency of notebook computer k, the objective is to maximize the efficiency of each notebook computer. Mathematically, this is expressed as follows:

$$\text{Max: } h_k = [(w_P)_k{*}P_k+(w_V)_k{*}V_k+(w_F)_k{*}F_k] + \mu_k, \text{ for each } k \qquad (7)$$

Subject to the following constraints:

$$(w_C)_k{*}C_k + \rho_k = 1, \text{ for each } k \qquad (8)$$

and:

$$[(w_P)_k{*}P_k+(w_V)_k{*}V_k+(w_F)_k{*}F_k] - [(w_C)_k{*}C_k] + \mu_k \leq 0, \text{ for each } k \qquad (9)$$

The values of μ_k and ρ_k are unrestricted slack variables that quantify the amount of inefficiency in each notebook computer. All weights are restricted to be at least zero. This analysis is performed for each of the 146 notebook PCs.

The objective function is intended to provide the maximum efficiency value for notebook computer k, given the weighting factors of each output. The two constraints (equations (8) and (9)) are intended to work in tandem to ensure that the efficiency of any notebook PC never exceeds unity.

In the most general terms, the objective is to show each notebook PC in its best possible light (maximization of h_k), while simultaneously adhering to the rules that preclude a notebook PC from having an efficiency exceed unity (equations (8) and (9)).

Weighting Issues

The issue of weighting needs additional consideration. Consider the values of the weights $(w_P)_k$, $(w_V)_k$, $(w_F)_k$, and $(w_C)_k$. The value of these weights must be greater than or equal to zero, but this restriction by itself is not adequate. Consider the following example: a notebook PC has strong Performance and Video attributes, its Cost is reasonable, but it has no Features to speak of (the warranty is inadequate, and there is no CD player or modem). Obviously, these features detract from the notebook's attractiveness. This notebook, however, would most likely be shown as favorable according to the above linear programming model simply because the Features weight, $(w_F)_k$, would be permitted to take on a weight of zero, thereby ignoring the relative importance of system Features. This condition does not allow a reliable gauge of efficiency for the notebook PCs.

To address this inadequacy, additional constraints need to be incorporated so that undesirable levels of certain output attributes are not ignored (Thompson et al, 1990, and Wong et al, 1990). Constructing pair-wise relationships of weights for the general output attributes does address this condition. These additional weighting constraints are as follows:

$$2 \le \frac{(w_P)_k}{(w_V)_k} \le 5 \tag{10}$$

$$2 \le \frac{(w_P)_k}{(w_F)_k} \le 5 \tag{11}$$

$$.5 \le \frac{(w_V)_k}{(w_F)_k} \le 2 \tag{12}$$

The first two constraints (equations (10) and (11)) essentially state that Performance must be considered at least twice as important as either Video or Features, but not more than five times more important. The third constraint states that neither Video nor Features is permitted to be more than twice the other. These weighting restrictions are, of course, subjective, but the authors nonetheless consider them reasonable. Weightings used for DEA which are acknowledged to be subjective, but considered reasonable nonetheless, have been addressed in prior research by McMullen and Strong (1998).

Results

DEA-Efficiency Issues

Of the 146 notebook PCs analyzed, nine were found to be efficient in the context of the Data Envelopment Analysis. Hereafter, notebooks found to be efficient will be referred to as *DEA-efficient*, while those not found to be efficient will be referred to as

DEA-inefficient. Table 2 shows a listing of the nine DEA-efficient notebooks with their associated attribute values.

Table 2. Listing of DEA-efficient Notebooks with Associated Attribute Values

Model	CPU Type	Speed (MHz)	RAM (MB)	HDD (GB)	Screen (in)	Type	CD	Modem (baud)	Warranty (yrs)	Price ($)
Compaq Presario 1070	Pent.	133	16	1.05	12.1	D	10	0	1	1099
Compaq Presario 1650	II	266	64	4	12.1	A	24	56	3	2999
Compaq Presario 1655	II	266	64	4	13.3	A	24	56	3	3299
Compaq Presario 1680	MMX	200	32	2.05	12.1	A	20	56	1	1499
CTX EZBook 777 MSFK	MMX	200	72	2	12.1	D	20	56	1	1749
CTX EZBook 777 MTFK	MMX	200	72	1.95	12.1	A	20	56	1	1899
Hitachi Vision Book 4150X	MMX	150	16	1.41	12.1	A	10	33	1	1099
Toshiba Satellite 205CD	Pent	100	8	0.81	11.3	D	6	0	1	1099
Toshiba Tecra 780CD (8 GB)	II	266	64	7.91	13.3	A	20	56	3	5499

What sets these nine notebooks apart from the DEA-inefficient ones is that they possess a set of attributes that collectively dominate the remaining 137. There are some other notebook PCs that, while found to be DEA-inefficient, nonetheless have a collective set of attributes that are formidable. Table 3 lists these notebooks and their associated attribute values.

Table 3. Near-Efficient Notebooks with Associated Attribute Values

Model	CPU Type	Speed (MHz)	RAM (MB)	HDD (GB)	Screen (in)	Type	CD	Modem (baud)	Warranty (yrs)	Price ($)
Tosh. Satellite 430 CDT	Pent.	120	16	1.23	11.3	A	10	0	3	1499
Tosh Satellite 460 CD	MMX	166	32	1.97	12.1	D	10	33	3	1399
Toshiba Tecra 780 CD (5 GB)	II	266	64	4.98	13.3	A	20	56	3	5099
Fuj.Lifebook 755 TX	MMX	150	32	2	12.1	A	20	56	3	1699
AMS Roadster 3035 EC	MMX	266	32	3.03	13.3	A	24	56	3	2995
AMS Roadster 3040 EC	MMX	266	64	4	14.1	A	24	56	3	3895
AMS Roadster 5020 EC	MMX	233	64	4	14.1	A	20	56	3	3767
AMS Roadster 5030 EC	MMX	266	64	4	14.1	A	20	56	3	3995
Compaq Presario 1681	MMX	233	48	3.13	12.1	A	20	56	1	1999
CTX EZBook 772 MSMK	MMX	200	24	1.95	12.1	D	20	33	1	1299
CTX EZBook 774 MTFK	MMX	200	40	2	12.1	A	20	33	1	1749

The decision as to which of these notebooks are “near-efficient” is subjective, but this decision process is assisted by the output in Table 4. This table shows, for these notebooks which are classified as “near-efficient,” how much adjustment to the outputs and the input of cost is necessary for them to be classified as DEA-efficient. The first column is the notebook PC classified as “near-efficient.” The second column lists the required input reduction for the notebook of interest to become DEA-efficient. For example, for the AMS Roadster 5020 EC to become DEA-efficient, its cost must be reduced to 65.506% of its current level, or to: \$3767*.65506 = \$2467.61. The third column lists the amount of augmentation to the outputs necessary for the notebook of interest to become DEA-efficient. Using the same notebook PC as an example, the AMS

Roadster 5020 EC could also become DEA-efficient if all of the output attributes were increased to 113.281% of their current levels, or 13.281% *above* their current levels. It is imperative to note that *either* this amount of input reduction or output augmentation can make a DEA-inefficient notebook DEA-efficient, but changes to both are not necessary. It is also important to note that notebooks that are DEA-efficient require neither input reduction nor output augmentation.

Table 4. Changes Necessary for Near-Efficient Notebooks to Become Efficient

Model	Required Input Reduction	Required Output Augmentation
Toshiba Satellite 430CDT	0.53411	1.06656
Toshiba Satellite 460CD	0.67750	1.09965
Toshiba Tecra 780CD5	0.67089	1.07283
Fujitsu LifeBook 755T	0.69685	1.07929
AMS Roadster 3035 EC	0.65994	1.18969
AMS Roadster 3040 EC	0.68513	1.09096
AMS Roadster 5020 EC	0.65506	1.13281
AMS Roadster 5030 EC	0.65027	1.11181
Compaq Presario 1681	0.90725	1.02762
CTX EZ Book 772 MSM	0.94034	1.01264
CTX EZ Book 774 MTF	0.67464	1.10769

The collection of all DEA-efficient notebooks comprises what is referred to as the efficiency frontier — analogous to the production possibilities frontier in economics. The “x-axis” is referred to as the virtual inputs — the weighted sum of all inputs. Since there is only the input of cost here, the virtual inputs are as follows:

$$(w_C)_k * C_k, \text{ for each notebook } k \tag{13}$$

The “y-axis” for this efficiency frontier is referred to as the virtual outputs — the weighted sum of all outputs. The virtual outputs are as follows:

$$[(w_P)_k * P_k + (w_V)_k * V_k + (w_F)_k * F_k], \text{ for each notebook } k \tag{14}$$

Figure 1 shows an approximation of the efficiency frontier, which includes all DEA-efficient notebooks, in addition to the notebooks that are classified as near-efficient.

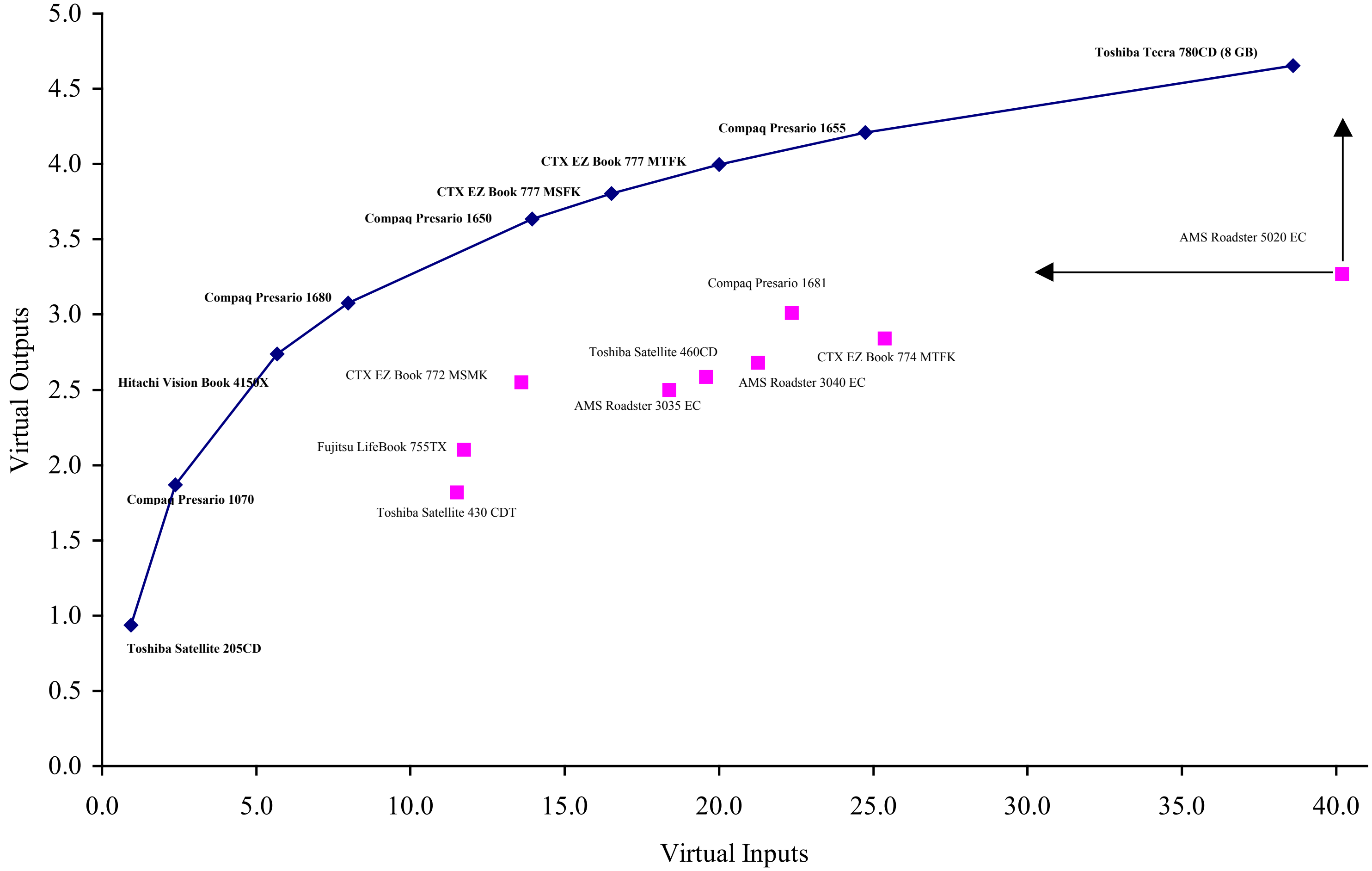

Figure1. Efficiency Frontier

Notice from Figure 1 that the DEA-efficient notebooks (in bold) are actually on the efficiency curve, while the near-efficient notebooks are somewhat to the "southeast" of the frontier. A distinctive feature of this efficiency frontier is its convexity (Banker et al, 1984). The concept of input reduction and output augmentation can be further illustrated by the location of the AMS Roadster 5020 EC with respect to the efficiency frontier in Figure 1. The horizontal arrow pointing to the left shows the necessary input reduction (decrease in virtual inputs) for this notebook to be considered DEA-efficient. The vertical arrow pointing upward shows the amount of output augmentation (increase in virtual outputs) necessary to make this notebook DEA-efficient. Due to scaling issues, the Toshiba Tecra 780 CD (5 GB) and the AMS Roadster 5030 EC were omitted from Figure 1, despite the fact that they were subjectively considered to be near-efficient in the context of DEA.

Sensitivity Analysis

Given that nine of the 146 notebooks were found to be DEA-efficient, it is also prudent to examine the efficiency-status of these nine notebooks if they are subjected to unfavorable change. The output attributes of these nine notebooks are reduced by an adjustment factor (AF) and the input of Cost is increased by this same factor. In essence, these "adjustments" make the efficient notebooks less attractive. DEA is repeated for each adjustment to determine just how robust these notebooks are to unfavorable changes.

$$X_{ij} = \frac{X_{ij}}{(1+AF)}\text{, for all outputs (j = 1 through 9)} \tag{15}$$

$$X_{ij} = X_{ij}*(1+AF)\text{, for input (j = 10)} \tag{16}$$

After these adjustments are made to the attributes for the DEA-efficient notebooks, standardization, re-scaling, and data-preparation are performed according to equations (1)-(6). After the data set is prepared, the DEA is performed to determine whether-or-not the DEA-efficient notebook has remained in the set of DEA-efficient notebooks. The adjustment factor ranged from 1% to 12% in increments of 1%. The results of this sensitivity analysis are presented in Figure 2.

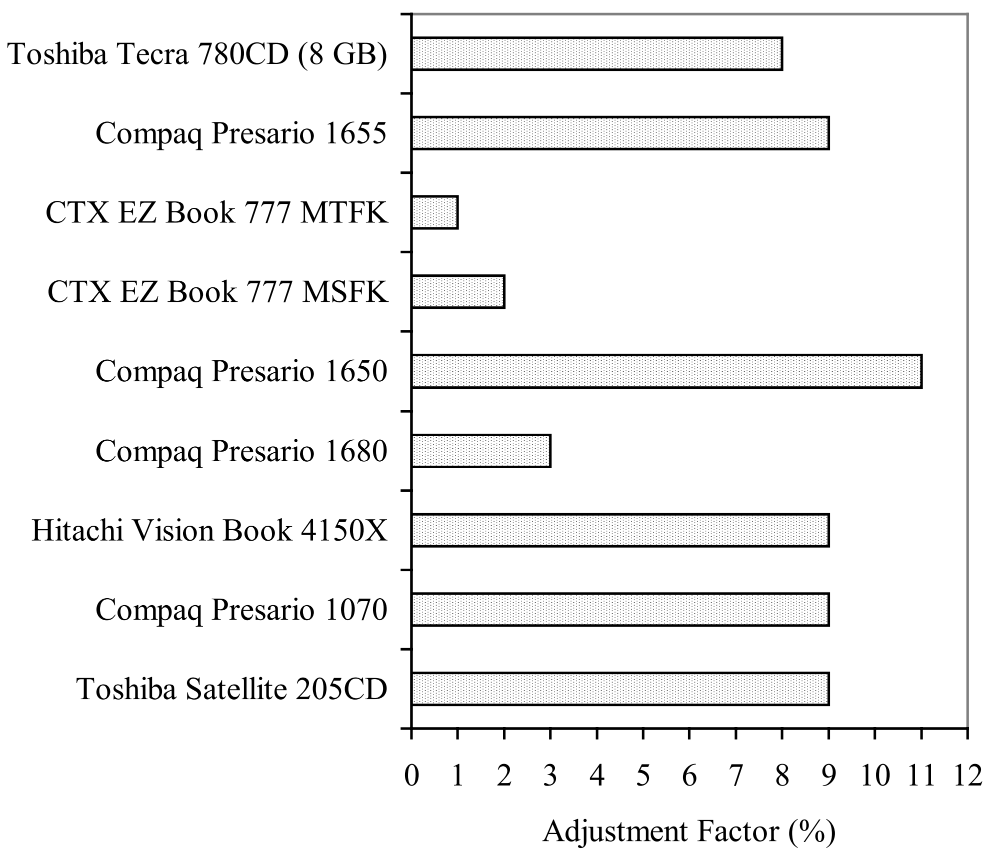

Figure 2. Sensitivity Analysis for DEA-Efficient Notebooks

The “x-axis” for Figure 2 is the level of the adjustment factor. The horizontal bars describe the amount of robustness each of the DEA-efficient notebooks exhibit with regard to the level of unfavorable change. For example, the Toshiba Satellite 205 CD remains DEA-efficient through unfavorable changes of 9%. Beyond 9% unfavorable changes, this particular notebook becomes DEA-inefficient. Of course, once a notebook "departs" from the set of DEA-efficient notebooks, it will not return to the efficient set as the adjustment factor is increasing.

Discussion of Results

General Discussion

The notebooks presented in Table 2 that comprise the efficiency frontier have characteristics that essentially dominate the DEA-inefficient notebooks. Of this group, the Compaq Presarios are well represented. Four of the nine DEA-efficient notebooks and one of the eleven near-efficient notebooks are Compaq Presarios. The CTX EZ Books also show a strong performance by being present twice along the efficiency frontier and twice in the group of near-efficient notebooks. The AMS Roadsters also show a formidable performance by being in the group of near-efficient notebooks four times. IBM Thinkpads are noticeably absent from the efficiency frontier and the group of near-efficient notebooks.

An important thing to notice from the efficiency frontier is its general orientation. At its "southwest" end, both virtual inputs and virtual outputs simultaneously have their lowest values. At its "northeast" end, both virtual inputs and virtual outputs have their highest values. Consider the Toshiba Satellite 205 CD. This notebook PC has minimal Performance, Video, and Features attributes, while simultaneously having minimal Cost. Consider, on the other hand, the 8 GB Toshiba Tecra 780 CD. This notebook has very high values of Performance, Video, and Features attributes, while being simultaneously quite expensive. The Toshiba Satellite 205 CD can literally be thought of as a "low-end" machine, while the Toshiba Tecra 780 CD can quite literally be considered a "high-end" notebook PC. Despite their differences, however, what these two notebooks have in common is that their collective outputs (benefits) offset their cost. This phenomenon applies to all notebooks residing on the efficiency frontier.

The level of robustness is also worth noting. All nine DEA-efficient notebooks remain efficient after a 1% unfavorable adjustment in their attributes. After that, the two CTX notebooks leave the efficiency set as the adjustment factor increases to 2% and 3%. With larger increases in the adjustment factor, most notebooks remain robust through unfavorable changes of 9%, at which point most notebooks lose their status as being DEA-efficient. The most robust notebook is the Compaq Presario 1650, which remains robust through unfavorable changes of 11%. In general, the DEA-efficient notebooks found in this study remain reasonably robust when subjected to unfavorable changes.

Other Things to Consider

Prior to putting these findings into some sort of rational perspective, there are some other issues regarding the data and model assumptions that require some explanation.

Only one supplier for notebook PCs was used. The purpose of this analysis is not to find the best supplier, but to find out which notebooks have attributes which exceed others. The only one of these attributes that should vary across suppliers is the cost. Since mail-order PCs are becoming more and more like commodity items, the price variation across suppliers was not a concern. Furthermore, work was done to collect data from multiple suppliers, but it was quickly discovered that attributes other than price also varied. For example, the Compaq Presario 1655 may have had a 4 GB hard disk drive from one supplier, while having a 2.3 GB hard disk drive from another. These types of things make a convincing argument for gathering data from a single supplier. It was also discovered that New World Computers Direct had the largest selection of notebook PCs, which provided for a rich data set.

Another thing to consider is that "quality" of the notebook PCs is ignored in this study. It is worth repeating that none of the IBM Thinkpad notebooks made the list of DEA-efficient or near-efficient notebooks (eighteen of the 146 notebooks analyzed were IBM Thinkpads). Despite the fact that none of these eighteen notebooks were considered desirable in the context of DEA, most people consider products made by IBM to be of high quality. Quality assessment is a very subjective endeavor. The authors, while realizing that perhaps ascertainment of notebook quality could be obtained via survey research, consider it beyond the scope of this paper.

Unlike other attributes, CPU type and screen type are not continuous variables — they have been encoded to take on numerical values. This limits the decision-maker's ability to precisely state the level of output augmentation necessary for DEA-inefficient notebooks to become DEA-efficient.

Physical weights of the notebook PCs are also not addressed. Heavier notebooks might be considered burdensome. Weight, like cost, could be treated as an input attribute. Convenience, like money, can be something the decision-maker sacrifices to obtain the notebook of interest. Weight was excluded from the current study because the information was not readily available.

Something else which needs to be considered is that fact that the notebook PC market is dynamic — system features seem to continually improve, while the price of these systems seems to continually drop. This analysis can therefore be considered a "snapshot" in time.

Conclusions

In order to support the decision process of selecting a suitable notebook PC from a large group of alternatives, Data Envelopment Analysis has been utilized to find the "best" notebooks based upon several criteria. This method permits a decision-maker to interpret a single measure obtained from several attributes to determine whether-or-not a notebook PC is "efficient," and is simpler to use than other types of multi-criteria decision-making techniques which force the decision-maker to interpret large amounts of data. The analysis showed that nine of the 146 notebooks studied were found to have a collectively dominant set of attributes, while eleven others were found to be relatively desirable as compared to the other notebooks. The nine DEA-efficient notebooks were also evaluated for sensitivity to unfavorable changes with respect to their attribute values. This test for robustness showed that all nine notebooks remained robust through small (1%) unfavorable changes, while most remained robust through larger unfavorable changes (9-11%).

An important general consideration to make with regard to this analysis is its general intent. The authors are not trying to present a compelling case for which notebook PCs should and should not be purchased. Instead, they are presenting a technique, which reflects the utility function of a decision-maker, to assist in making educated decisions when considering many alternatives across several attributes.

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