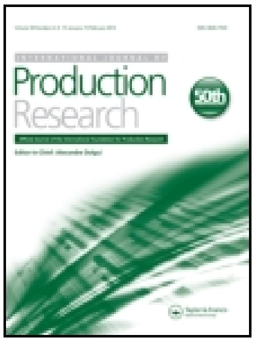

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Green product pricing decision analysis with application to personal computers

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This paper focuses on the pricing of reused personal computers that are discarded and sold on the secondary market. We first extract the main components affecting the performance of a reused computer. We then use quality function deployment to compare the weights of the main components against what reusable computer customers require. Third, we use TOPSIS to rank the selected reused computers. Finally, we price every reused computer according to relative monopoly power and perform an accumulated depreciation analysis on each one at various sale periods. The results show that each reused computer can be easily evaluated and priced on the secondary market.

Keywords: pricing; reused computer; TOPSIS; relative monopoly power; accumulated depreciation

1. Introduction

As our quickly exhausting natural resources surpass their regeneration capacity, environmental ecology becomes a crucial twenty-first century issue. In their supply chain environmental management, companies are being urged to lower their carbon emissions and choose non-toxic materials from their suppliers, which can improve product quality, enhance environmental performance and reduce their production risk (Purba 2002; Tsoulfas and Pappis 2008; Pigosso et al. 2010; Glew et al. 2012). Dowlatshahi (2000) proposes that a reverse logistics system be designed to manage the flow of products, including remanufacturing, reuse and recycling. Given the rapid development in the technology and computer industries, abandoning and replacing computers are easy, but their dismantling causes environmental damage. We should, therefore, seek to upgrade or reuse waste computers and treat their components. Braungart and McDonough (2002) propose the concept of 'cradle to cradle' for recycling computer waste products and parts at their end-of-life, thus reducing the mining of materials, the production of new products, the power consumed by production facilities and carbon emissions. Wang et al. (2011) propose that the convenience of recycling facilities and services, residential conditions, recycling habits and economic benefits are the four determinants in e-waste recycling. Giannetti, Bonilla, and Almeida (2013) have created strategies to reward or incentivise users of reverse logistics and help establish regulations by lowering taxes and stimulating innovation through the national policy on solid waste. Tsai (2010) shows that the main types of combustible waste in Taiwan's industrial sector include pulp sludge, scrap wood, sugarcane bagasse, textile sludge and scrap plastics, all of which he finds being reused as auxiliary fuel by utilities. Sheu, Chou, and Hu (2005) propose that the *government provide subsidies* to assist enterprises in selling their remanufactured product. Mitra and Webster (2008) propose that the government provide separate subsidies for manufacture and remanufacture to increase manufacturers' profits. Willis (2010) argues that the availability of storage space, the unpredictable volume of product returns and the insufficient incentives for users to return their items are all important issues for remanufacturers (Oktay 2008; Park, MacLachlan, and Love 2011). Wen, Lin, and Lee (2009) describe the Executive Yuan of Taiwan, established by the National Council for Sustainable Development, and observe that the Waste Disposal Act was substantially revised to promote the implementation of a recycling system using a 'polluter pays' model, in which the recycling duty is shared among the responsible enterprises, as they all pay a recycling subsidy fee to the resource recycling management fund (RMF). The RMF's financial report states that private recycling firms have the strongest incentive to recycle; their upstream, called 'private recovery stations,' collects and disposes of waste and recyclables from collectors, homes and businesses; recyclers are offered rewards when they collect and bring 3C waste products, waste papers, scrap metal, PET bottles and other recyclable products to recovery stations. Matsumoto (2009) provides a new perspective on the reuse businesses by discussing the independent reuse business companies that have grown rapidly in Japan; many have launched new types of second-hand shops and have developed strategies to guarantee a volume of collected used

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products and to stimulate demand for used products. Many reused or recycled products are not collected by manufactures through reverse logistics, but by recovery stations and retailers (Savaskan, Bhattacharya, and Van Wassenhove 2004; Wang and Hsu 2010). The reward offered for waste computers is less than 300 New Taiwan dollars, which might reduce computer owners' enthusiasm for recycling and lead to market failure. In addition, the black pricing of reused computers caused by information asymmetry usually makes green buyers hesitant to purchase a reused computer, since they compare the selling price against the degree of reusability.

The above discussion suggests that disposing of waste products is valuable. Reducing natural resource exhaustion and facilitating computer recycling requires the proper valuing of reused computers and offering reasonable prices to green buyers. Therefore, we will first define the main components and weights of each component supporting the functionality of reused computers; second, we will evaluate the order of reused computers using TOPSIS; finally, we will establish the residual value of each reused computer through the index of relative monopoly power. The flowchart of finding the price of the reused computers is defined as Figure 1.

This paper is organised as follows. Section 2 briefly introduces the QFD and TOPSIS methods. Section 3 proposes a pricing analysis for reused computers. Section 4 discusses the future values of reused computers. Finally, Section 5 presents a conclusion.

2. Methodologies

This section uses QFD to determine the weights of reused computers' main components and TOPSIS to evaluate the chosen computers.

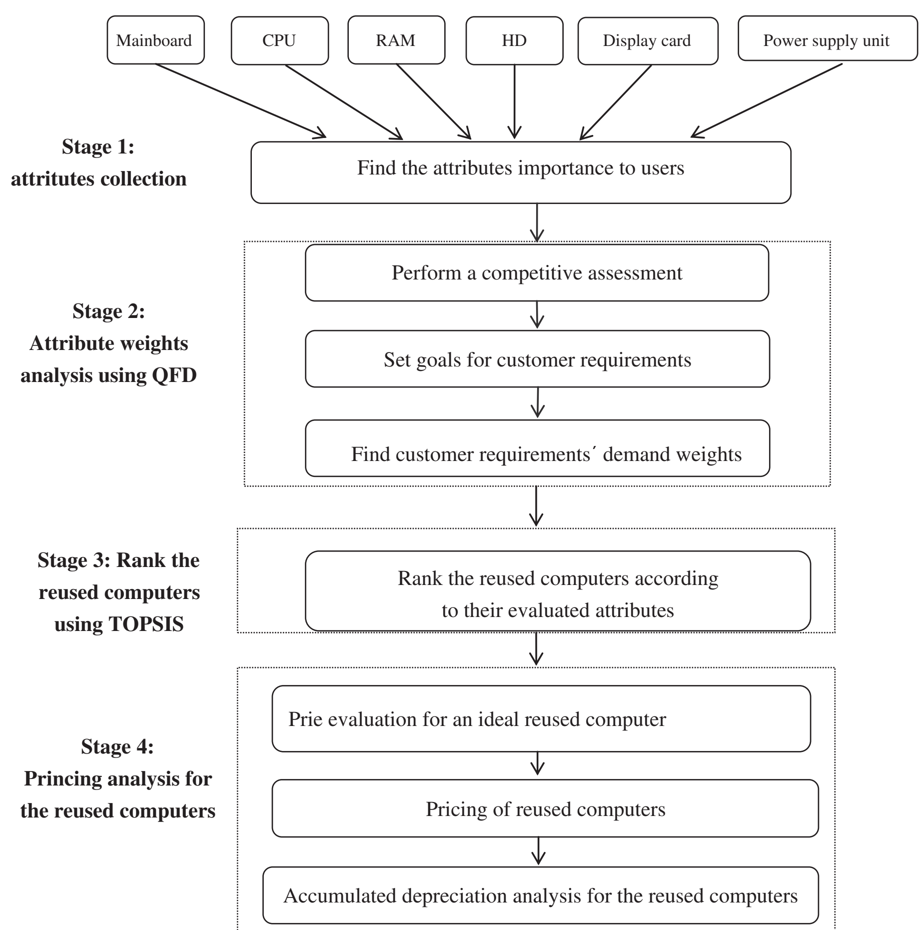

Figure 1. Flowchart for pricing of the reused computers.

2.1 *The QFD method*

The QFD method, introduced by Akao and Mizuno in 1972 (Akao 1990), is a successful engineering tool for finding customers' voices during product planning and design. Yang et al. (2011) stated that the basic QFD concept is to use a series of houses to translate qualitative requirements into quantitative specifications. Thus, QFD can be used to transform environmental requirements into quantitative indicators. As shown in Figure 2, QFD consists of four matrices: the customer requirement matrix, the relationship matrix, the planning matrix and the technical matrix. The house of quality (HOQ) is the fundamental and strategic tool in the QFD system; in this phase, the product's customer requirements are identified and – after being incorporated into the company's competitive priorities – are converted into the appropriate technical measures in order to fulfil those requirements.

We evaluate a reused computer's performance by defining its main components. We assume that most customers have limited knowledge and find it difficult to describe what used computer components are important, but that most computer experts are familiar with computer assembly and technical maintenance and are, thus, best able to evaluate reused computers. A reused computer should have attractive components that satisfy customer requirement; we use the HOQ to deploy the computer's attributes corresponding to its main components by following the steps below:

Step 1. Survey the customer requirements: in this step, literature reviews, focus groups and questionnaire surveys can be used to find the customer requirements.

Step 2. Structure the attributes of customer requirements: customer requirements are grouped into meaningful hierarchies or levels for analysis.

Step 3. Determine their importance to users: importance to users as perceived by customers is measured by using a five-, seven- or nine-point Likert scale.

Step 4. Perform competitive assessment: in this step, the performance of the company's product is compared with that of its competitor. A strong point with larger value is an important point against which the competitor is rated poorly. The scale for measuring these assessments is a five-point Likert scale.

Step 5. Set goal for customer requirement: the producing company sets a performance goal for each attribute or factor to satisfy customer requirements. The scale for measuring these goals is a five-point Likert scale.

Step 6. Plot the management point: a management point is a feature that will give the producing company a unique business position (Chan and Wu 2005). A 'strong' point is an important point against which the competitor is rated poorly. With a 'moderate' sales point, the importance rating or competitive opportunity is only fair. With a 'no' sales point, no business opportunity exists. Values of 1.5, 1.2 and 1 are assigned to 'strong', 'moderate' and 'no' management points, respectively.

Step 7. Find customer requirements' absolute weight: each absolute customer requirement weight is calculated as follows:

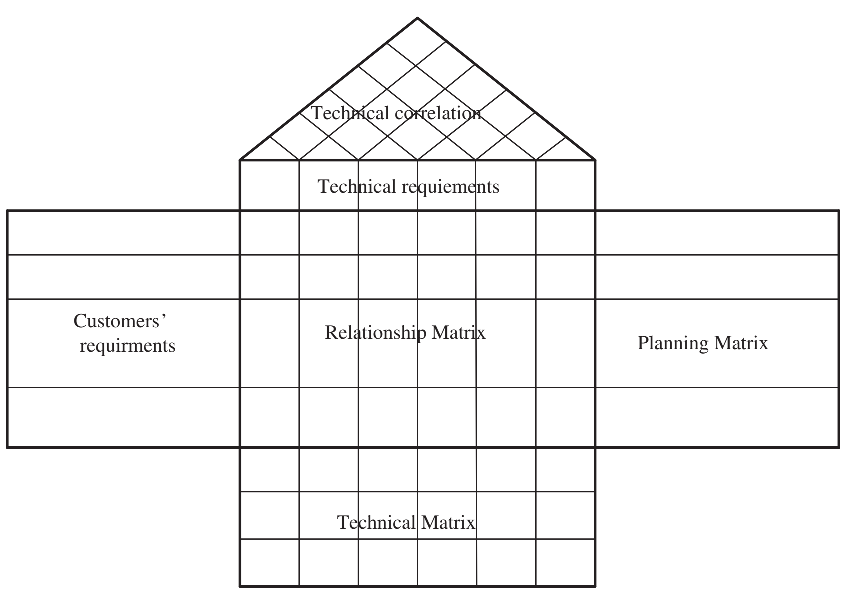

Figure 2. House of quality (Halog, Schultmann, and Rentz 2001).

$$\text{Absolute weight} = \text{importance to users} \times \text{improvement ratio} \times \text{management point}, \tag{1}$$

where improvement ratio equals goal performance divided by competitive assessment.

Step 8. Find the customer requirements' demand weight:

$$\text{Demand weight} = (\text{each attribute weight})/(\text{sum of the absolute weight}) \times 100\%. \tag{2}$$

2.2 *The TOPSIS model*

The TOPSIS method is a technique for ordering preferences according to their similarity to ideal solutions that maximise the benefits of criteria/attributes and minimise their costs; the negative ideal solution maximises their costs and minimises their benefits (Hwang and Yoon 1981). The best alternative is always the one closest to the ideal solution and farthest from the negative ideal solution. Suppose a MCDM problem has n alternatives, $A_1, A_2, \ldots, A_n$, and m decision criteria/attributes, $C_1, C_2, \ldots, C_m$. Each alternative would be evaluated with respect to the m criteria/attributes and each value assigned to each alternative with respect to each criterion forms a decision matrix denoted by $\mathbf{X} = (x_{ij})_{n\times m}$, as below:

$$\mathbf{X} = \begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1j} & \ldots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2m} \\ \vdots & \vdots & \ldots & \vdots & \ldots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \ldots & x_{im} \\ \vdots & \vdots & \ldots & \vdots & \ldots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nj} & \cdots & x_{nm} \end{bmatrix} \tag{3}$$

Let $W = (w_1, w_2, \ldots, w_m)$ be the relative weight vector for the criteria, satisfying $\sum_{j=1}^{m} w_j = 1$. The TOPSIS process would then follow the steps below:

Step 1. Calculate the normalised decision matrix: while some normalised TOPSIS methods are summarised by Shih, Shyur, and Lee (2007), Tsaur (2011) proposes a new one. We chose Tsaur's normalised method for analysis because it avoids criteria in greater numeric ranges dominating those in smaller numeric ranges and eliminates numerical difficulties during calculation. By defining the universe of discourse U_j, based on the range of all alternatives with respect to criterion C_j, we can obtain $U_j = [D^j_{\min} - D^j_1, D^j_{\max} + D^j_2]$, where D^j_1 and D^j_2 are two proper positive numbers; $D^j_{\min}$ and $D^j_{\max}$ are minimum and maximum values on the range of all alternatives with respect to criterion C_j. The normalised value n_{ij}, $i = 1, 2, \ldots, n$, $j = 1, 2, \ldots, m$, is calculated as

$$n_{ij} = \frac{x_{ij} - (D^j_{\min} - D^j_1)}{(D^j_{\max} + D^j_2) - (D^j_{\min} - D^j_1)} = 1 - \frac{(D^j_{\max} + D^j_2) - x_{ij}}{(D^j_{\max} + D^j_2) - (D^j_{\min} - D^j_1)} \tag{4}$$

An example is given to show the advantage for the proposed method. Suppose we have the following data on the range of all alternatives with respect to criterion $C_j = \{2551, 3742, 3312, 5309, 3709, 4884\}$. Clearly, we can find that $D^j_{\min} = 2551$ and $D^j_{\max} = 5309$, but two proper positive numbers D^j_1 and D^j_2 are chosen by a decision-maker. A key point in choosing the two proper positive numbers is to keep the derived full range $D^j_{\min} - D^j_1$ and $D^j_{\max} + D^j_2$ meaningful in which the right numbers on hundreds digit are set for 0; thus, the heuristics for D^j_1 and D^j_2 are chosen as 51and 91, respectively, to enlarge the simple full range $U_j = [2500, 5400]$.

Step 2. Calculate the weighted normalised decision matrix $\mathbf{V} = (v_{ij})_{n\times m}$.

$$v_{ij} = w_j n_{ij}, \qquad i = 1, 2, \ldots, n, \; j = 1, 2, \ldots, m, \tag{5}$$

where w_j is the relative weight of the jth criterion/attribute, and $\sum_{j=1}^{m} w_j = 1$.

Step 3. Determine the positive ideal A^+ and negative ideal solution A^- as below:

$$A^+ = \{v_1^+, v_2^+, \ldots, v_m^+\} = \{(\max_i v_{ij} | j \in \Omega_b), (\min_i v_{ij} | j \in \Omega_c)\} \tag{6}$$

$$A^- = \{v_1^-, v_2^-, \ldots, v_m^-\} = \{(\min_i v_{ij} | j \in \Omega_b), (\max_i v_{ij} | j \in \Omega_c)\} \tag{7}$$

where Ω_b is associated with benefit criteria and Ω_c with cost criteria.

Step 4. Calculate the separation measures, using the m-dimensional Euclidean distance: the separation of each alternative from the ideal solution (A^+) and the negative ideal solution (A^-) are given as below (respectively):

$$D_i^+ = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^+\right)^2}, \qquad i = 1, 2, \ldots, n \tag{8}$$

$$D_i^- = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^-\right)^2}, \qquad i = 1, 2, \ldots, n \tag{9}$$

Step 5. Calculate the relative closeness of each alternative to the ideal solution: the relative closeness of the alternative A_i with respect to A^+ is defined as

$$RC_i = \frac{D_i^-}{D_i^+ + D_i^-}, \qquad i = 1, 2, \ldots, n \tag{10}$$

The larger the RC_i value, the greater the relative closeness of the alternative A_i and A^+.
Step 6. Rank the alternatives according to the relative closeness to the ideal solution: the best alternative is the one with the greatest relative closeness to the ideal solution.

3. Evaluating the reused computers

When pricing reused computers, it is important to clearly evaluate their main components' degree of reliability. Thus, we select six reused computers from the secondary reused computer market for analysis. We then review the literature to find the main components that significantly affect reused computer performance; afterwards, we interview computer experts to identify the customer requirements. Finally, we obtain the attribute weights corresponding to the main components; then, we use TOPSIS to evaluate the order of the reused computers.

3.1 *The HOQ for reused computers*

The HOQ process that determines the attribute weights corresponding to the main components is described below:
Step 1. Survey the customer requirements: this step assumes that reused computer customers lack the knowledge required to identify a reused computer's main components. We, thus, review the literature to find customer requirements and the impact categories for reused computers. Reviewing the technical books of Computer DIY (Lu 2009; Li 2010; Shi 2010) reveals that the CPU, mainboard, random access memory (RAM), hard disc (HD), display card and power supply units are the main components of a computer. We, therefore, set those components at the first customer requirement level.
Step 2. Structure the attributes of customer requirements: from the first main component level obtained in Step 1, we can infer the second attribute level through literature reviews and expert interviews, which are used to construct the HOQ and the second column of Table 1.
Step 3. Find their importance to users: customer requirements are not equally important. We, therefore, extract the importance to users of each component attribute from the selected eight experts, as in the previous step. The importance to users of each main component attribute is, thus, obtained, as shown in the third column of Table 1.
Step 4. Perform a competitive assessment: this step measures the competition between reused computers and new ones. We obtain a competitive assessment by averaging the scores given by the eight experts after they compare the performance of reused computers with that of new ones using a five-point scale. The competitive assessment of each attribute is then obtained, as seen in the fourth column of Table 1.
Step 5. Set goals for customer requirements: this step sets the performance goals by which each attribute will satisfy customer requirements as effectively as a new computer can. The goals are set using a five-point Likert scale, as shown in the fifth column of Table 1.
Step 6. Plot the management points: the management point for each attribute is assigned. A strong management point is set as ◎ = 1.5; a 'moderate' point is set as O = 1.2 and a 'no' point is set as 1, with a blank space. The management point of each attribute is thus obtained, as shown in the seventh column of Table 1.
Step 7. Find customer requirements' absolute weights: the sixth column of Table 1 shows the improvement ratio, the goal performance divided by the competitive assessment. The absolute weight of customer needs is calculated by Equation (1). Thus, the absolute weight for each attribute is obtained, as shown in the eighth column of Table 1.
Step 8. Find customer requirements' demand weights: From Equation (2), we can obtain the demand weight for each attribute, as shown in the ninth column of Table 1. The weight of each component can be drawn from the attributes'

Table 1. The HOQ for a reused computer.

Demand quality		Importance to users	Competitive assessment	Goal	Improvement ratio	Management point	Absolute weight	Demand weight (%)	Total weight
Mainboard	Stability	4	5	5	1	◎	6	2.64	17.16%
	Operating temperature	4	3	5	1.7	◎	10	4.40	
	Transmission speed	5	3	5	1.7	O	10	4.40	
	Manufacturer's reputation	3	3	5	1.7		5	2.20	
	Future expandability	4	3	5	1.7	O	8	3.52	
CPU	Work performance	5	4	5	1.3	◎	9.38	4.13	16.89%
	Power consumption	3	3	5	1.7		5	2.20	
	Operating temperature	4	3	5	1.7	O	8	3.52	
	Stability	4	4	5	1.3	O	6	2.64	
	Transmission speed	4	3	5	1.7	◎	10	4.40	
RAM	Work performance	5	4	5	1.3	◎	9.38	4.13	14.76%
	Operating voltage needs	4	3	5	1.7		6.67	2.93	
	Manufacturer's reputation	3	3	5	1.7		5	2.20	
	Electronics warranties	3	3	5	1.7		5	2.20	
	Capacity size	4	4	5	1.3	◎	7.5	3.30	
HD	Transmission speed	5	4	5	1.3	◎	9.38	4.13	17.7%
	Heat dissipation ability	4	3	5	1.7		6.67	2.93	
	Shock *and vibration* resistance	5	3	5	1.7	O	10	4.40	
	Manufacturer's reputation	4	3	5	1.7		6.67	2.93	
	Hard disc capacity	5	4	5	1.3	O	7.5	3.30	
Display card	Memory capacity	5	4	5	1.3	◎	9.38	4.13	16.91%
	Display speed	5	4	5	1.3	◎	9.38	4.13	
	Operating temperature	4	3	5	1.7		6.67	2.93	
	Manufacturer's reputation	3	3	5	1.7		5	2.20	
	Power consumption	4	3	5	1.7	O	8	3.52	
Power supply unit	Sufficient for output power	5	5	5	1	◎	7.5	3.30	16.58%
	Operating temperature	5	3	5	1.7	O	10	4.40	
	Stability	4	4	5	1.3	◎	7.5	3.30	
	Manufacturer's reputation	4	3	5	1.7		6.67	2.93	
	Safety	3	3	5	1.7	O	6	2.64	

demand weights, as shown in the final column of Table 1. The result shows that the HD is the most important component of a reused computer, with a weight of 18.18%, and that RAM is the smallest weight component, with 15.16%.

3.2 *The order analysis for the reused computer sample*

Six reused computers were chosen from the secondary market, as shown in Figures 3–8, which identify their manufacturers and main components specifications. The computers have different manufacturers and specifications and, thus, different working performances. Eight experts selected among retailers evaluated the computers' main components on a scale from 1 to 10. The total scores are shown in Table 2, the last row presenting the ideal solution for each component. Next, we used TOPSIS to order the selected reused computers by following the steps below:

Step 1. Calculate the normalised decision matrix: this step uses the normalisation method proposed by Tsaur (2011). According to the discussion in the previous section, the full range of mainboard, CPU, RAM, HD, display card and power supply unit are selected as [30, 65], [20, 60], [20, 70], [30, 70], [10, 70] and [30, 70], respectively. The data collected for the evaluation of the reused computers in Table 2 were normalised as shown in Table 3.

Step 2. Calculate the weighted normalised decision matrix $\mathbf{V} = (v_{ij})_{n\times m}$: in this step, we first used the weighted value for each component derived from the QFD method in the final column of Table 1 and then multiplied them with the normalisation values in Table 3. The weighted values for the evaluation of the reused computers obtained are shown in columns 2–7 of Table 4.

Step 3. Determine the positive ideal A^+ and negative ideal solution A^-: the positive ideal solution for the reused computers was obtained by choosing the largest value of each main component, as shown in the eighth row of Table 4; the negative ideal solution for the reused computers was obtained by choosing the smallest value of each main component, as shown in the last row of Table 4.

Step 4. Calculate the separation measures: using Euclidean distance, we obtained the D_i^+ of the distance between reused computer i and the positive ideal solution and the D_i^- of the distance between reused computer i and the negative ideal solution, as shown in the eighth and ninth columns of Table 4.

Step 5. Calculate the relative closeness: each reused computer's relative closeness to the ideal solution was obtained, as shown in the 10th column of Table 4.

Step 6. Rank the alternatives (RC_i): using the RC_i value in Table 4, we ranked the order of the values of the reused computers. Computer II was shown to be the best, followed by Computer IV.

MB：MSI 661FM3-L
CPU：Intel Pentium 4 3.06 Ghz
RAM：Kingston 512MB (PC-2700/DDR333/E)
HDD：Hitachi 80GB (Deskstar 7K250/SATA)
Display Card：MSI 661FM3-L, SIS 661FX,32M
Power supply unit：X-PRO 300W

Figure 3. The reused computer of sample 1.

MD：GIGABYTE EP41-UD3L
CPU：Intel® Core™2 Quad Processor Q8400
RAM：Apacer 2G DDR2 *2
HDD：Samsung 500G/Spinpoint T166/SATAII/8M (HD500LJ)
Display Card：NVIDIA GF9600GS 512M
Power supply unit：Cougar 400W

Figure 4. The reused computer of sample 2.

MB：ASUS P5GD1-PRO
CPU：Intel Pentium 4 3.0Ghz
RAM：Kingston 1GB (PC-3200/DDR400/E)
HDD：Western Digital WD800BB(80G)
Display Card：NVIDIA 7300GS 256M
Power supply unit：Seventeam 300W ST-300BKV ATX2.0

Figure 5. The reused computer of sample 3.

In Steps 1–6, we derived the order of the chosen reused computers. Retailers can easily identify the best computer and rank the rest, but we still do not know how to price them. We, thus, propose the pricing process described below.

4. Pricing of the reused computers

We assume that the better a computer's main components perform, the higher is its price. As Table 4 shows, the larger the RC_i value, the greater the relative closeness of the reused computer i with respect to the ideal reused computer. Thus, the reused computer with the largest value of RC_i has the greatest competitive power and dominates the other

MB：ASUS M3A78
CPU：AMD Phenom*4 9650 (4M Cache)
RAM：ADATA 2GB (PC2-6400/DDR2 800/E-R)
HDD：Hitachi 250GB (Deskstar T7K250/SATAII)
Display Card：ASUS 9600GT 1G
Power supply unit：Acbel iPower 420w

Figure 6. The reused computer of sample 4.

MB：Foxconn 945PLAE
CPU：Intel® Pentium® D Processor 935 (4M Cache)
RAM：Apacer 1G DDR2 800*2
HDD：Seagate 160G/7200.9/2M
Display Card：PowerColor X1950 PRO 256MB DDR3
Power supply unit：X-PRO 400W

Figure 7. The reused computer of sample 5.

reused computers. The *Lerner Index* (Hope 1999) identifies the degree of monopoly, by which a wider gap between product price (P) and marginal cost (MC) indicates greater monopoly power, as defined as Equation (11):

$$Lerner\ Index = \frac{P - MC}{P} \tag{11}$$

Therefore, a perfect competition market $P = MC$ derives *Lerner Index* = 0, which reaches the social optimum, whereas a natural monopoly indicates an MC approximate to zero and derives a *Lerner Index* approximate to 1: obviously, then, a profit-maximising firm's power varies between 0 and 1. In our ranking of the chosen reused computers, the greater the relative closeness to the ideal reused computer, the greater the monopoly power it exerts on the other reused computers.

MB：intel D915GEV
CPU：Intel® Core™2 Duo Processor E8300 (6M Cache)
RAM：Transcend 1G DDR2 800*2
HDD：Western Digital 160G/ Caviar SE/SATA/8M
Display Card：intel D915GEV with Intel GMA900
Power supply unit： hec 300w 300VN-2RX

Figure 8. The reused computer of sample 6.

Table 2. Evaluation of the reused computers by the experts.

	Mainboard	CPU	RAM	HD	Display card	Power supply unit
Computer I	36	32	26	36	21	44
Computer II	60	55	68	67	52	61
Computer III	47	29	36	33	47	39
Computer IV	49	52	55	57	64	62
Computer V	44	47	56	47	51	49
Computer VI	43	57	57	48	19	42
Ideal solution	60	57	68	67	64	62

Table 3. Normalisation of the collected data.

	Mainboard	CPU	RAM	HD	Display card	Power supply unit
Computer I	0.1714	0.3	0.12	0.15	0.1833	0.35
Computer II	0.8571	0.875	0.96	0.925	0.7000	0.775
Computer III	0.4857	0.225	0.32	0.075	0.6167	0.225
Computer IV	0.5429	0.8	0.7	0.675	0.9000	0.8
Computer V	0.4000	0.675	0.72	0.425	0.6833	0.475
Computer VI	0.3714	0.925	0.74	0.45	0.1500	0.3

Applying the concept of relative closeness, we define the relative monopoly power in Equation (12) between the *i*th reused computer and the ideal reused computer. In Equation (12), P' is the evaluation price for an ideal reused computer, estimated by reviewing the best performance of the reused components and the sum total of their prices; P_i is the unknown price for the estimated reused computer and MC_i is the recycling cost, which includes the purchase, maintenance and handling costs involved when a retailer collects the *i*th reused computer from a consumer. If P_i equals MC_i, implying that the *i*th reused computer is in perfect competition with a zero monopoly power value, the reused computer is not sellable in the secondary market and should have its main components dismantled for recycling into secondary materials; by contrast, when $P_i = P'$, implying that the reused computer has a strong monopoly power equal to that of

Table 4. TOPSIS analysis results for the reused computers.

	Mainboard	CPU	RAM	HD	Display card	Power supply unit	D_i^+	D_i^-	RC_i	Rank
Computer I	0.0294	0.0507	0.0177	0.0265	0.0310	0.0580	0.2818	0.0282	0.0911	**6**
Computer II	0.1471	0.1478	0.1417	0.1637	0.1184	0.1285	0.0351	0.2844	0.8901	**1**
Computer III	0.0834	0.0380	0.0472	0.0133	0.1043	0.0373	0.2469	0.1000	0.2883	**5**
Computer IV	0.0932	0.1351	0.1033	0.1195	0.1522	0.1326	0.0824	0.2393	0.7439	**2**
Computer V	0.0687	0.1140	0.1063	0.0752	0.1155	0.0787	0.1458	0.1698	0.5380	**3**
Computer VI	0.0638	0.1562	0.1092	0.0796	0.0254	0.0497	0.1950	0.1676	0.4622	**4**
Positive ideal solution	0.1471	0.1562	0.1417	0.1637	0.1522	0.1326				
Negative ideal solution	0.0294	0.0380	0.0177	0.0133	0.0254	0.0373				

Table 5. The price evaluation for the ideal computer.

	Mainboard	CPU	RAM	HD	Display card	Power supply unit	The sum total
The ideal reused computer	1900	2500	900	800	1250	850	8200
A new computer	2490	5550	1200	1560	3090	1500	15,390

the ideal reused computer, RC_i = 1. The reused computer can, thus, be evaluated for its relative monopoly using RC_i value, which varies between 0 and 1:

$$RC_i = \frac{P_i - MC_i}{P' - MC_i} \tag{12}$$

Based on Equation (12), the steps below are taken to price the chosen reused computers.

Step 1. Price evaluation for an ideal reused computer: we investigate the main components to obtain their prices and then integrate them with the sum total of an ideal reused computer. In Table 5, the ideal reused computer is compared with a similar but new computer; the sum total of an ideal reused computer is evaluated to be less than that of a new computer. The P' is evaluated as NT 8200.

Step 2. Pricing of reused computers: first, we rewrite Equations (12) and (13) using the RC_i value for the ith reused computer, as shown in Table 4, as well as the price of the ideal reused computer P' evaluated in Step 1 and shown in Table 5 and the MC_i in column 2 of Table 6 as the recycling price for the ith reused computer. The prices of the reused computers are, thus, obtained as shown in column three of Table 6. As Table 6 shows, Computer II has the highest price value (NT 7, 958), while Computer V has the largest profit value (NT 2, 798), because it has a better ranking and a smaller recycling price (MC_V):

$$P_i = RC_i \times P' + (1 - RC_i)MC_i \tag{13}$$

As seen, the proposed method can easily derive prices for reused computers. The most profitable one might not be the most expensive, as the collection costs imposed by retailers on the customers must be taken into account.

Step 3. Accumulated depreciation analysis for the reused computers: the secondary market pricing of reused computers should consider accumulated depreciation over time. The dynamic depreciation of a reused computer depends on how long it is in the market. The longer a reused computer spends in the secondary market, the larger its depreciation

Table 6. The pricing of the reused computers.

The chosen reused computer	MC_i	Pricing for the reused computers	Profit for each reused computer
Computer I	2300	2837	537
Computer II	6000	7958	1958
Computer III	2500	4143	1643
Computer IV	5300	7457	2157
Computer V	3000	5798	2798
Computer VI	2800	5296	2496

Table 7. The practical discount rate.

Suggested interval	Discount rate (%)	Sale periods
$RC_i \geq 0.8$	1.5	24 weeks
$0.5 \leq RC_i < 0.8$	5	20 weeks
$0.2 \leq RC_i < 0.5$	8	16 weeks
$RC_i < 0.2$	10	12 weeks

should be calculated to be. Interviews with reused computer retailers revealed that reused computers are usually sold within three to six months. We can, therefore, use a depreciation factor for the ideal reused computer; Equation (13) is revised as Equation (14) for the discounted value of the ideal reused computer at the period of time n:

$$P_i = RC_i \times \frac{P'}{(1+r)^n} + (1 - RC_i)MC_i, \qquad \forall n = 1, 2, \ldots \tag{14}$$

where r is the depreciation rate and n is the time elapsed until the reused computer is sold. We assume that a reused computer with the worst ranking (the smallest RC_i value) is usually sold in 12 weeks, that the most highly ranked one (the largest RC_i value) usually sells within 24 weeks, and that the others sell within 12–24 weeks or are used for secondary materials. In practice, the relation among RC_i value, discount rate and sale periods is as shown in Table 7. Discount rate r_i is obtained by assuming that the reused computer will be recovered for secondary materials when the residual of the ith reused computer is smaller than its MC_i at its end-of-sales period. Drawing from Table 7, the accumulated depreciation analysis for reused computers is as shown in Figure 9.

Figure 9 shows that each reused computer depreciates according to the discount rate and, thus, that retailers can price their computers at various time points. We usually assume that many green customers are glad to purchase reused computers in the secondary market, but retailers may suffer net losses if their reused computers are not sold by the end-of-sales period. Therefore, after pricing reused computers, marketing strategies designed to increase the number of green customers should be considered. In contrast to Mitra and Webster's model (2008), they defined an industry comprised of a manufacturer producing a new product and a remanufacturer. After the product reaches the end of life and is abandoned, a remanufacturer enters the market and competes with the manufacturer. The government takes responsibility for collection and disposal, and collected units in suitable condition for remanufacturing are sold to the remanufacturer at a price that recoups some fraction of the cost. Our proposed method could be proceeded without government's support, where a business model for the reused computers can be proposed as similar as taobao.com's model. If any seller would like to dispose his old computer, then our proposed method can be used to fit a reasonable price for the seller and buyer, and then their transaction can be matched successfully.

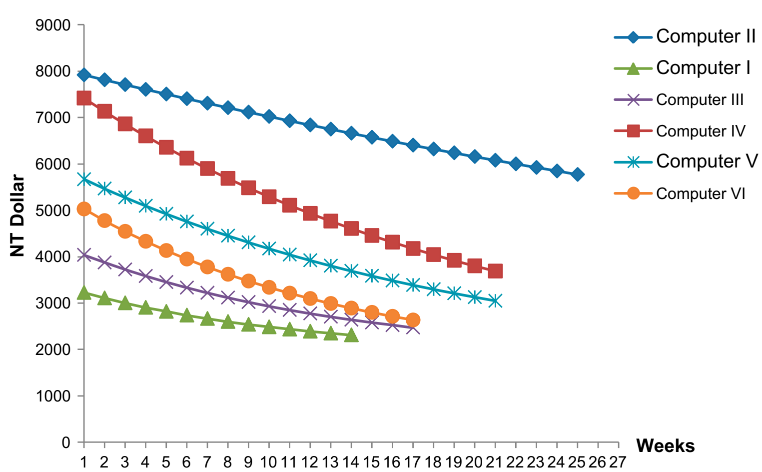

Figure 9. Accumulated depreciation analysis for reused computers.

5. Conclusion

This paper has proposed a pricing method for reused computers involving the evaluation of their main components, including the mainboard, CPU, RAM, HD, display card and power supply unit. We weighted the customer requirements and then calculated the weights of the reused computers' main components. We then used the weights for the main components in the TOPSIS method to evaluate computer attributes and rank the selected reused computers. From the RC_i values obtained in TOPSIS, a pricing equation was obtained indicating the relative monopoly powers of the selected reused computers. Most importantly, we tested the sample through a sensitivity analysis using an accumulated depreciation assessment, which showed that the proposed method can be easily applied to derive the sale prices of reused computers at various points in time. Clearly, the proposed method appears to be the most appropriate tool based on the following two primary advantages: (a) it gives the decision-makers both the best possible pricing and the worst possible depreciation assessment to the selected reused computers; (b) the number of required observations is limited. If this pricing method meets expectations, it will be important in the secondary market for reused products.

However, this study has examined only a few reused computers, and a larger sample might affect the efficiency of the proposed method. Therefore, future research should establish an open e-business system, where customers can transact in it for reused computers and then enlarge the sample size. Besides, the sensitivity analysis to the attribute weights in the TOPSIS method should be further examined from subjective weights by decision-makers, objective weights by entropy method or hybrid weights by subjective and objective method, and then find their differences to make a robust analysis. Finally, more experiments on other kind of reused products (i.e. smart phone, wearable device, LCD TV and so on) using the proposed method, and then an integrated method are future topics for pricing reused 3C products.

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