*ICIC Express Letters*
*Part B: Applications*
Volume **11**, Number **9**, September **2020**

ICIC International ©2020 ISSN 2185-2766
pp. **831–838**

# THE ECONOMICS OF CELL PHONE REMANUFACTURING: DIFFERENCES BY PRODUCT LINE, MODEL AGE, AND END-OF-LIFE QUALITY

Suah Kim and Minjung Kwak*

Department of Industrial and Information Systems Engineering
Soongsil University
369 Sangdo-ro, Dongjak-gu, Seoul 06978, Korea
suak210@soongsil.ac.kr; *Corresponding author: mkwak@ssu.ac.kr

Received March 2020; accepted May 2020

Abstract. *Remanufacturing used cell phones can be a sustainable solution to e-waste problems. To support planning and optimization of cell phone remanufacturing, this paper presents an empirical study on the economics of cell phone remanufacturing process. The study aims to assess the economic remanufacturability of a cell phone by collecting real-world data about the economic circumstances of three remanufacturing steps (i.e., buyback, reconditioning, and resale). More specifically, the study investigates the effect of three factors on the remanufacturability: product line (i.e., premium and mainstream models), model age (i.e., years passed from the market release), and end-of-life quality (i.e., the condition of a used phone). Samsung Galaxy S and Galaxy Note series released in 2015-2018 are chosen for the study, and extensive data collection is conducted about the models' remanufacturing economics as of 2019. Based on up-to-date real data, the study diagnoses the economic remanufacturability of cell phones and examines how it differs by the product line, model age, and the end-of-life quality. The study also discusses desirable conditions in which cell phone remanufacturing can achieve economic viability.*
**Keywords:** Remanufacturing, Refurbishment, Cell phone, Electronic waste

1. **Introduction.** Cell phones usually have a short lifespan of 2-3 years, and discarded cell phones are one of the fastest growing e-waste streams in the world, presenting a critical challenge to the global environment [1]. Remanufacturing cell phones can be a promising solution to the e-waste problem. It gives the second life to the discarded cell phones at only a small fraction of the original cost and the environmental impact [2-4].

Figure 1 shows the process of cell phone remanufacturing. It mainly consists of three steps: buyback, reconditioning, and resale. To succeed in the remanufacturing market, it is important to plan and optimize the overall remanufacturing process, and to this end, it is important and essential to understand the economic circumstances of the process. Although there have been some studies on the economics of cell phone remanufacturing, the focus has been on only a part of the process (e.g., the effect of model age or brand on the resale value [5,6]), and there has been a lack of studies covering the entire remanufacturing process (buyback, reconditioning, resale).

This paper presents an empirical study of the economics of cell phone remanufacturing that covers the entire remanufacturing process. By conducting data collection about the three steps of remanufacturing (i.e., buyback, reconditioning, and resale), the study assesses the economic remanufacturability of a cell phone. More specifically, the main purpose of the study is to investigate how following three factors affect the remanufacturability: *product line* (i.e., premium and mainstream models), *model age* (i.e., years passed from the market release), and *end-of-life quality* (the condition of a used phone). Based on real data, the study examines the effect of the three factors and discusses the conditions for

DOI: 10.24507/icicelb.11.09.831

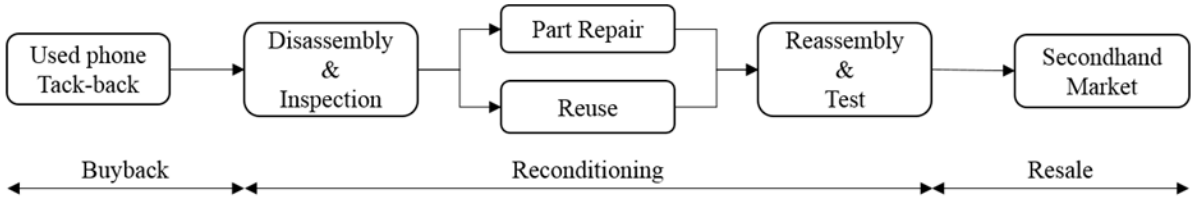



FIGURE 1. The process of cell phone remanufacturing

economic remanufacturability (or, positive profit). Following are the assumptions made in the study.

- A cell phone is remanufactured to the same phone of the original specifications.
- In reconditioning, parts are replaced with new ones. Refurbished or secondhand parts are not used for part replacement.
- Replaced leftover parts (battery and display) are sold to material recyclers.

Table 1 shows the information about the subject of this study. Samsung Galaxy S and Galaxy Note series released from 2015 to 2018 (except the Note7 released in 2016 but discontinued due to battery explosion issue) are chosen for the study. Galaxy S and Note represent the mainstream and the premium lines, respectively, and the models in each product line represent different model ages from 1 to 4 years old (as of 2019).

TABLE 1. Product line and model information

| | Mainstream line | | | | Premium line | | |
|---|---|---|---|---|---|---|---|
| | S6 | S7 | S8 | S9 | Note5 | Note8 | Note9 |
| Release date | 2015.04 | 2016.02 | 2017.03 | 2018.02 | 2015.08 | 2017.08 | 2018.08 |
| Retail price | $721 | $703 | $786 | $804 | $812 | $920 | $1,054 |

The end-of-life quality of a used phone is classified into five types, i.e., Types 1 to 5 (Table 2), and the end-of-life quality determines the buyback class and the reconditioning step. Products with no functional or display problems are divided into either Type 1 or Type 2. Type 1 requires no part replacement and is just disassembled, cleaned, tested, and reassembled. Type 2, on the other hand, requires battery replacement. Type 3 indicates the phones with display problem and the display and battery should be replaced with new ones. Types 4 and 5 are the phones with functional failures that require mainboard replacement.

TABLE 2. End-of-life quality and the corresponding buyback class and reconditioning action

| End-of-life quality | Buyback class | Required part replacement |
|---|---|---|
| Type 1 | Normal | No replacement |
| Type 2 | Normal | Battery |
| Type 3 | Display failure | Display, battery |
| Type 4 | Functional failure | Mainboard, battery |
| Type 5 | Functional failure | Display, mainboard, battery |

The rest of the paper is organized as follows. Section 2 describes the data collection results following the sequence of the remanufacturing process: buyback, reconditioning, and resale. Section 3 discusses the economic remanufacturability of a phone and the effect of the three factors on it. Section 4 summarizes the findings and concludes the paper.

## 2. The Economics of Cell Phone Remanufacturing.

### 2.1. Buyback.

Buyback cost is the price paid to end-users for used end-of-life cell phones. This study assesses the buyback cost based on the price offered by the manufacturer's trade-in program (i.e., Samsung SmartChange). The buyback cost differs by the end-of-life quality and its corresponding buyback class (Table 2).

Table 3 shows the buyback cost of the subject phone models. For example, the buyback cost of Galaxy S6 with the normal condition is \$63.03. In other words, the remanufacturer should pay \$63.03 to take back one unit of S6. If the condition is changed to display failure and functional failure, the buyback price drops to \$58.82 and \$42.02, respectively. The average buyback cost of the three classes is \$54.62.

Table 3. Buyback cost (\$) as of 2019

| Buyback class/Model | S6 | S7 | S8 | S9 | Note5 | Note8 | Note9 |
|---|---|---|---|---|---|---|---|
| Normal | 63.03 | 88.24 | 210.08 | 243.70 | 67.23 | 239.50 | 327.73 |
| Display failure | 58.82 | 75.63 | 180.67 | 201.68 | 50.42 | 189.08 | 260.50 |
| Functional failure | 42.02 | 62.18 | 142.86 | 111.76 | 34.45 | 117.76 | 130.25 |
| Average | 54.62 | 75.35 | 177.87 | 185.71 | 50.70 | 182.11 | 239.49 |

Figure 2 illustrates how the average buyback cost changes by model age and product line, in both absolute and relative scales. Regardless of the product line, the buyback price tends to decrease with the model age. The great difference between the mainstream and premium lines is shown in the one-year-old phones, i.e., S9 and Note9. There is a difference more than \$50 per phone. However, such difference becomes insignificant if applying a relative scale (i.e., buyback cost in percentage of the initial retail price). The mainstream and the premium lines show similar patterns in terms of the buyback cost in ratio to the retail price, starting from 23% in year 1 to 6-7% in year 4.

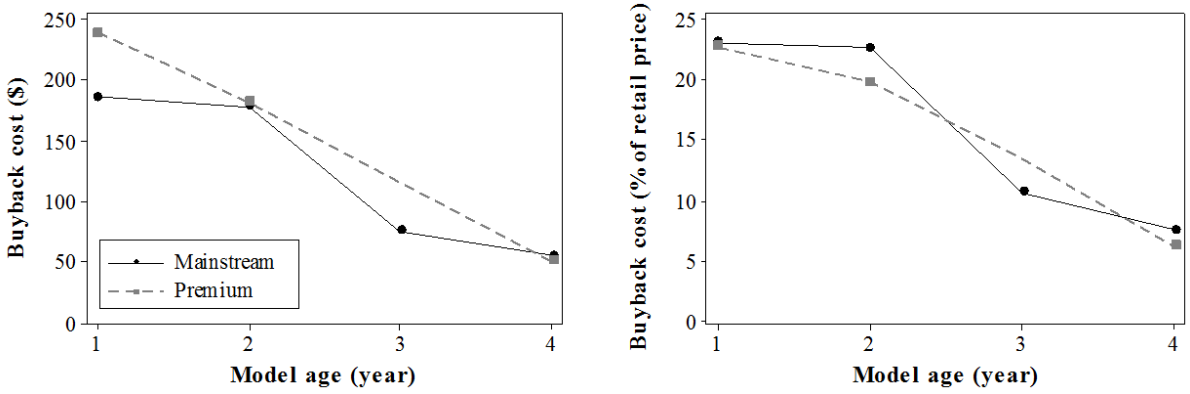



Figure 2. Average buyback cost in absolute (left) and relative (right) scales

### 2.2. Reconditioning.

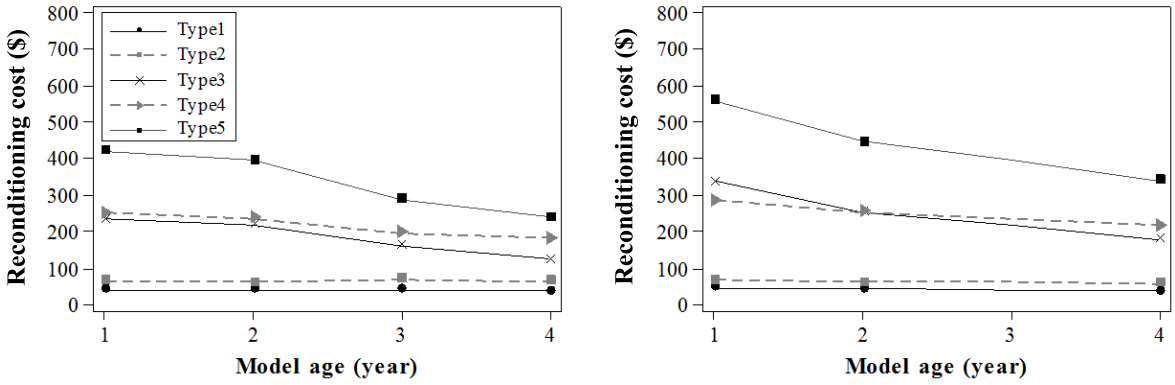
Reconditioning involves multiple operations, such as disassembly, cleaning, part replacement, reassembly, test, and packaging. In this paper, reconditioning cost is defined as the sum of the costs of disassembly, part replacement, and reassembly. Each cost is assumed referring multiple information sources, including the manufacturer's service center (Samsung service center https://www.samsungsvc.co.kr) and phone teardown reports (e.g., the reports from iFixit.com and TechInsights.com).

In this study, the disassembly cost is assumed to be \$21 for all phones including data scrubbing cost. The cost of part replacement (i.e., the new part cost) and the assembly cost (including the costs of assembly, test, and packaging) are different by the model. Table 4 shows the details about the costs and the total reconditioning cost of each model.

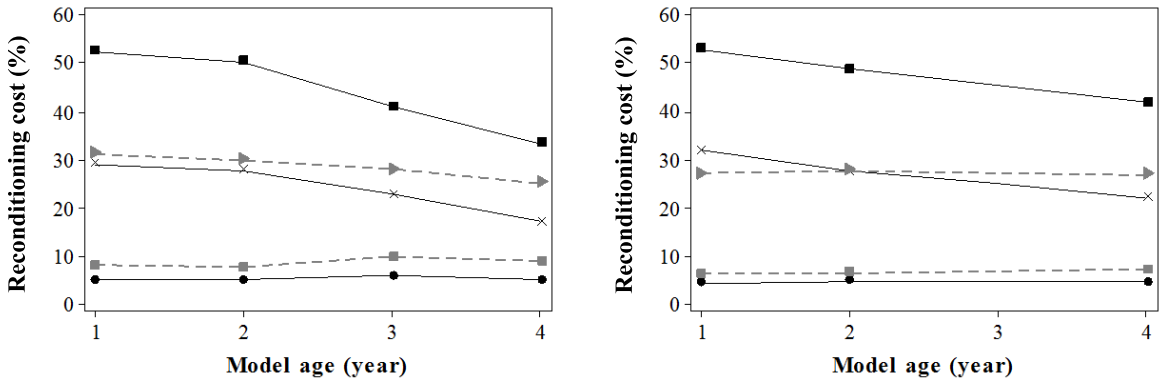
TABLE 4. New part cost ($) and reconditioning cost ($) as of 2019

| Model | Part cost ($) | | | Assembly & test ($) | Reconditioning cost ($) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Battery | Display | Mainboard | | Type 1 | Type 2 | Type 3 | Type 4 | Type 5 |
| S6 | 27.71 | 58.79 | 117.18 | 16.00 | 37.00 | 64.71 | 123.50 | 181.89 | 240.68 |
| S7 | 27.71 | 92.39 | 127.76 | 20.00 | 41.00 | 68.71 | 161.10 | 169.48 | 288.87 |
| S8 | 19.31 | 159.59 | 175.76 | 19.50 | 40.50 | 59.81 | 219.40 | 235.58 | 395.17 |
| S9 | 23.51 | 169.85 | 187.06 | 20.44 | 41.44 | 64.95 | 234.80 | 252.01 | 421.86 |
| Note5 | 20.99 | 121.79 | 159.53 | 16.50 | 37.50 | 58.49 | 180.28 | 218.02 | 339.81 |
| Note8 | 16.79 | 193.19 | 194.12 | 23.50 | 44.50 | 61.29 | 254.48 | 255.41 | 448.60 |
| Note9 | 20.44 | 271.31 | 220.94 | 24.63 | 45.63 | 66.07 | 337.39 | 287.01 | 558.33 |

Figure 3 shows the reconditioning cost of the mainstream and premium lines, in both an absolute and a relative scales. Overall, the reconditioning cost decreases with the model age. Types 1 and 2 require the least costs, while Type 5 requires the highest cost. Although the absolute cost is significantly different between the mainstream and the premium lines, the relative cost shows a similar pattern, ranging from 4 to 52%.




(a) Reconditioning cost ($)




(b) Reconditioning cost (% of retail price)

FIGURE 3. Reconditioning cost of mainstream (left) and premium (right) models

2.3. **Resale.** Resale consists of two parts: the sales of scrap batteries and displays and the sales of remanufactured phones. Table 5 provides the recycling revenue from the sales of scrap batteries and the resale price of remanufactured phones, as of 2019.

The recycling revenue is assumed based on the price quotes by third-party recyclers (e.g., scrapmonster.com, webuylcds.co.uk) and the weight of the battery is assumed based on Bai et al. [7]. The price of remanufactured phone is assumed based on the price reports provided in the website SmartChoice.or.kr, a public information portal about

TABLE 5. Recycling revenue and resale price ($) as of 2019

| | | S6 | S7 | S8 | S9 | Note5 | Note8 | Note9 |
|---|---|---|---|---|---|---|---|---|
| Part recycling | Display | 31.50 | 37.80 | 50.40 | 63.00 | 1.26 | 63.00 | 75.60 |
| | Battery | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.06 |
| Phone resale | Top condition | 154.96 | 196.12 | 326.91 | 449.28 | 183.96 | 433.12 | 637.64 |
| | Normal condition | 132.63 | 175.02 | 305.17 | 420.60 | 165.64 | 415.36 | 604.24 |
| | Low condition | 110.11 | 143.99 | 270.33 | 393.18 | 139.84 | 379.38 | 575.32 |

mobile phones and services in Korea. The portal classifies the phone condition into three levels: top, normal, and low. Here, the top condition means that the product is a new or an unopened one; the low condition means that the product has problems in its cosmetic and/or functional quality. Thus, this study assumed that the remanufactured phone is sold at the price of normal condition and used the average price from January 2019 to May 2019.

Figure 4 compares the average resale price of the mainstream and the premium models. Unlike the previous cost results, results in the relative scale also show significant difference between the product lines. The average retail price ranges between 18-52% in case of the mainstream line and 20-57% in case of the premium line. This implies that the customers in the secondhand market prefer the premium line to the mainstream, and the premium line experiences slower value depreciation than the mainstream line.

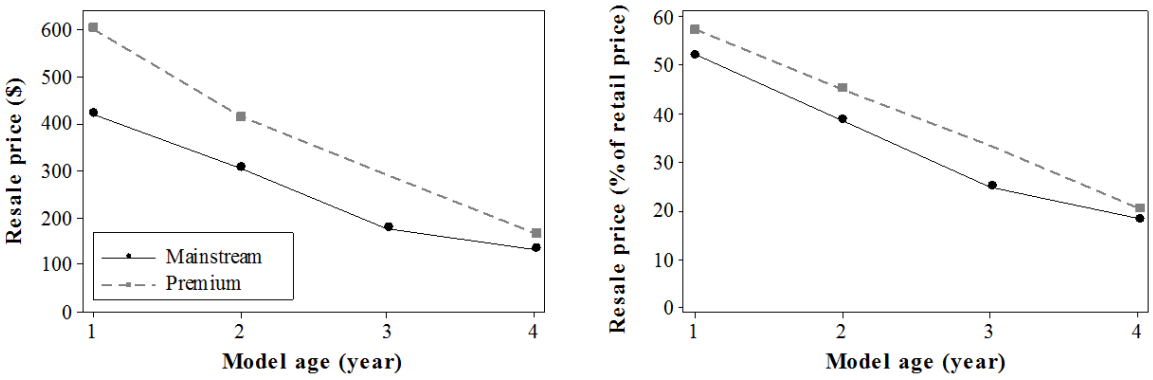


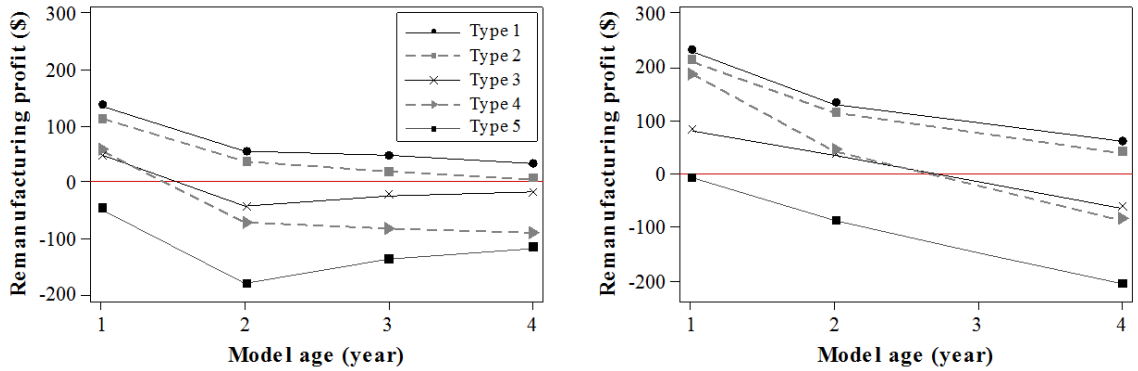

FIGURE 4. Average resale price in absolute (left) and relative (right) scales

3. **Remanufacturability Assessment.** The economic remanufacturability of a cell phone (or, the unit remanufacturing profit) is assessed by combining the results in Section 2. Figure 5 shows how the remanufacturability changes with the product line, model age, and end-of-life quality.

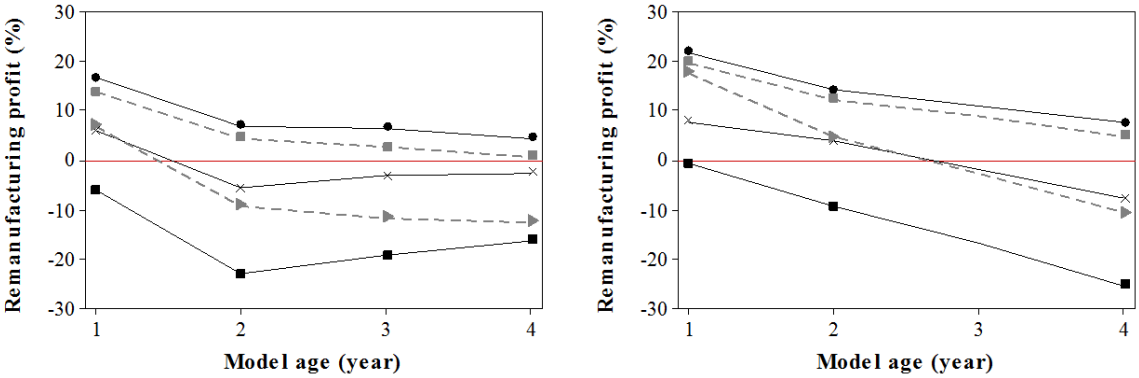
The graphs on the left side show the remanufacturability of the mainstream line. For Types 1 and 2, remanufacturing can be a profitable business regardless of the model age. Types 3 and 4 phones are profitable at first, but after one year from release, it cannot be profitable anymore. Remanufacturing Type 5 is not recommended as negative profit is expected regardless of the model age.

The graphs on the right side show the profit margin for the premium line. Overall, it seems that the premium line has better remanufacturability than the mainstream line, although there exist some exceptions (e.g., Type 5 in year 4). Types 3 and 4 phones remain profitable until year 2.

Although premium line shows higher economic remanufacturability, it seems that the remanufacturability needs to be improved for both product lines considering the average cell phone lifespan of 2-3 years. Using refurbished part can be an option to this end. It




(a) Remanufacturing profit ($)




(b) Remanufacturing profit (% of retail price)

FIGURE 5. Remanufacturing profit of mainstream (left) and premium (right) models

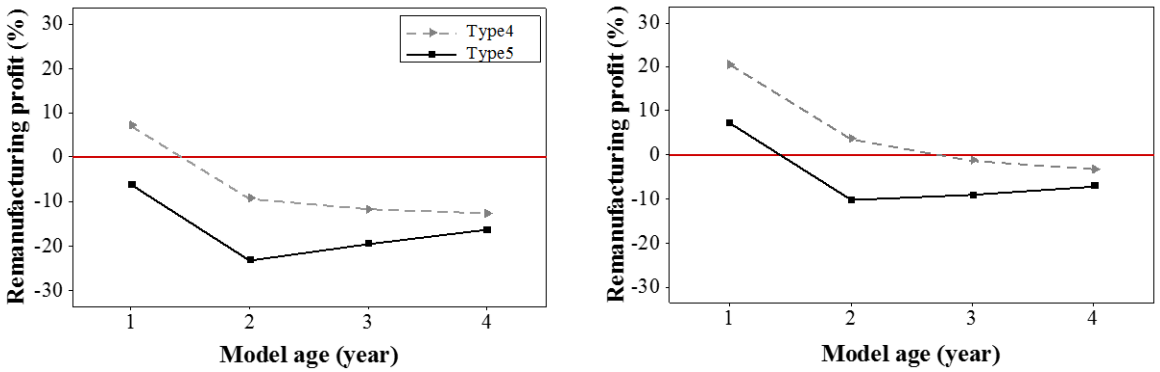
is expected that the refurbished parts enable a significant reduction in the reconditioning cost, the major cost element of the remanufacturing process. For example, if refurbished mainboards are used in remanufacturing, the remanufacturability of Types 4 and 5 phones can be significantly improved, as shown in Table 6 and Figure 6.

TABLE 6. Change in remanufacturability (fraction) by adopting refurbished mainboards

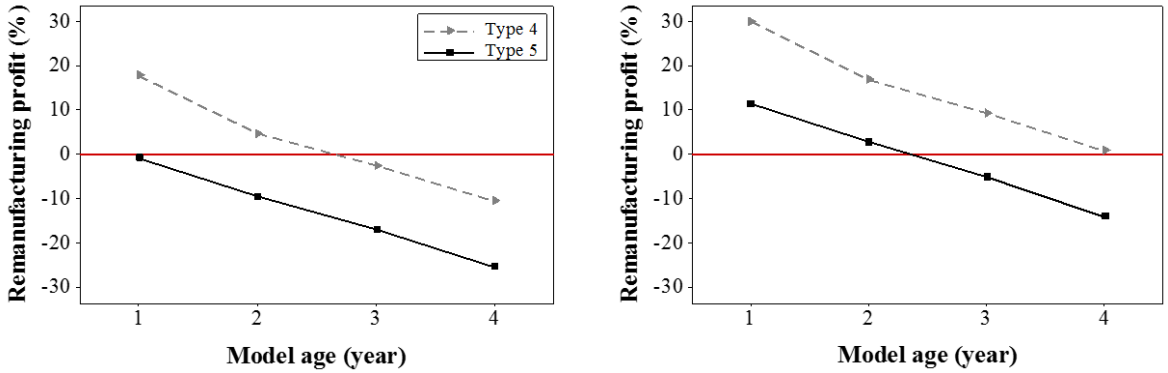
| Model age | Mainstream | | | | Premium | | | |
|---|---|---|---|---|---|---|---|---|
| | New part | | Refurbished part | | New part | | Refurbished part | |
| | Type 4 | Type 5 | Type 4 | Type 5 | Type 4 | Type 5 | Type 4 | Type 5 |
| 1 | 0.07 | −0.06 | 0.21 | 0.07 | 0.18 | −0.01 | 0.30 | 0.11 |
| 2 | −0.09 | −0.23 | 0.04 | −0.10 | 0.05 | −0.10 | 0.17 | 0.03 |
| 3 | −0.12 | −0.20 | −0.01 | −0.09 | −0.03 | −0.17 | 0.09 | −0.05 |
| 4 | −0.13 | −0.16 | −0.03 | −0.07 | −0.11 | −0.26 | 0.01 | −0.14 |

4. **Conclusions.** To assist in a better understanding of the economics behind cell phone remanufacturing, this study analyzed the economics of cell phone remanufacturing considering three factors: product line, model age, end-of-life quality. Taking Samsung Galaxy S and Galaxy Note series as the subjects, an empirical study was conducted based on up-to-date real data.

The results show that cell phone remanufacturing can be an economically viable business if a returned phone meets certain conditions. For example, remanufacturing 1-year-old phones can always be profitable except the Type 5 case. If the phone is a premium




(a) Mainstream line: new mainboard (left) and refurbished mainboard (right)




(b) Premium line: new mainboard (left) and refurbished mainboard (right)

FIGURE 6. Change in remanufacturability by adopting refurbished mainboards

model, 2-year-old phones are also good for remanufacturing. Overall, the premium line shows better remanufacturability than the mainstream line, owing to higher resale values.

This study, however, pointed out that the economic remanufacturability of cell phones needs to be improved regardless of the product line. Considering the fact that the average cell phone lifespan is 2-3 years, the chances of economic profitability seem to be very limited. The economics of cell phone remanufacturing should be improved by taking account of the average life of a cell phone, and manufacturers should either reduce the remanufacturing cost or increase the market value of remanufactured phones. In this paper, using refurbished parts was suggested as a potential solution.

This study can be used as a basic information source for remanufacturing planning or optimization. Also, when improving remanufacturability, the current study can help set the improvement target for the cost or revenue. One limitation is that the current study considered only one brand. Also, the variability of cost/revenue data over time was not taken into account. Addressing these issues can be future work.

**Acknowledgment.** This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (Ministry of Science and ICT, MSIT) (No. NRF-2019R1F1A1041099). The authors also gratefully acknowledge the helpful comments and suggestions of the reviewers, which have improved the presentation.

## REFERENCES

[1] P. Sarath, S. Bonda, S. Mohanty and S. K. Nayak, Mobile phone waste management and recycling: Views and trends, *Waste management*, vol.46, pp.536-545, 2015.

[2] W. L. Ijomah, *A Model-Based Definition of the Generic Remanufacturing Business Process*, Ph.D. Thesis, University of Plymouth, Plymouth, UK, 2002.

[3] M. Kwak, Optimal line design of new and remanufactured products: A model for maximum profit and market share with environmental consideration, *Sustainability*, vol.10, no.11, 2018.
[4] D. R. Cooper and T. G. Gutowski, The environmental impacts of reuse: A review, *Industrial Ecology*, vol.21, no.1, pp.38-56, 2017.
[5] R. Gyer and V. D. Blass, The economics of cell phone reuse and recycling, *Advanced Manufacturing Technology*, vol.47, pp.515-525, 2010.
[6] T. Makov, T. Fishman, M. R. Chertow and V. Blass, What affects the secondhand value of smartphones: Evidence from eBay, *Industrial Ecology*, vol.23, no.3, pp.549-559, 2019.
[7] H. Bai, J. Wang and A. Z. Zeng, Exploring Chinese consumers' attitude and behavior toward smartphone recycling, *Journal of Cleaner Production*, vol.188, pp.227-236, 2018.