Electronic product returns and potential reuse opportunities: A microwave case study in the United Kingdom

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Abstract

One route to reducing electronic waste, increasing product reuse, is dependent on the quality and functionality of discarded electronic goods (core), about which little is known or understood. This paper reports on the collection, testing, and classification of 189 discarded microwave ovens. We find that most had only minor, if any, issues and almost all were suitable for reuse and/or remanufacturing. It was also documented, in face-to-face interviews with 82 persons discarding microwaves, that consumers have little knowledge of disposal routes for end-of-life products other than public recycling facilities, and that a large proportion of consumers discarding microwaves intended to buy a similar product, calling into question the widely-held belief that e-waste is always driven by a desire for the latest technology. Based on these results, it is not unreasonable to argue that, for microwave ovens, the major impediments to reuse are neither the quality of discarded products nor the cost of electrical spare parts, but rather current product design and the incipiency of the market for second hand items. Using this information, minor changes in design that would significantly improve re-usability are proposed to OEMs.

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Key words: Sustainable supply chains, product take-back, electronic waste, recycling, remanufacturing, reuse, supply side of supply chains, and microwave ovens.
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1. Introduction

Discarded electronics constitutes one of the fastest growing waste categories in Europe (Cui and Forssberg, 2003).[1] In the United Kingdom alone, nearly one million tonnes of e-waste is generated per year (Huisman et al., 2007), and worldwide the volume is estimated at between 20 and 50 million tonnes, and to be growing at a rate of 4% per year. Because e-waste contains myriad toxic substances, such unfettered growth poses a serious threat to the environment.

Research on e-waste has increased significantly over the past two decades. But although generally attributed to short innovation periods and consequently short product life spans (Babbitt et al., 2009), little is known about the supply side of e-waste. More specifically, our knowledge of the quality of discarded products and the extent to which quality determines their reuse potential is scant.[2] More research is thus needed to assess the potential for reuse.

This paper (i) investigates the quality of, and costs of remanufacturing, microwave ovens discarded in the United Kingdom, (ii) assesses consumers' intentions and behaviours with respect to the disposal of microwave ovens, and (iii) proposes design changes intended to increase opportunities for reuse and remanufacturing.

The remainder of this article is organized as follows. The relevant literature is reviewed in Section 2; the cosmetic and functional quality levels of microwave ovens discarded in the UK are investigated in Section 3; and the antecedents of microwave oven disposal are considered in Section 4. In Section 5, based on the analyses performed in Sections 3 and 4, potential reuse opportunities and design modifications to facilitate remanufacturing are identified. The effects of increasing levels of manufacturing in terms of socio-economic development and environmental preservation are discussed in Section 6, and the main conclusions summarized and new avenues for research proposed in Section 7.

2. Literature review

We review in this section the literature relevant to this article, organised under three categories, (i) the literature on the importance of the quality of returned items (core) and barriers to acquisition, (ii) the literature on consumer intention and behaviour towards product disposal, and (iii) the literature on

[1] The terms e-waste, electronic waste, and WEEE are used interchangeably in this paper.
[2] We do not distinguish in this paper between microwaves repaired at home and those directed to second use.

design for remanufacturing.

2.1. The importance of quality core and barriers to its acquisition

Enhancing understanding of the quality of core, and more generally of the logistics of returned products, is important not only from an environmental standpoint. In recent decades, remanufacturing has become a billion-dollar industry as companies have learned to see product returns as a valuable income source rather that cost. Refurbishing and remanufacturing costs are for some products only a fraction of manufacturing cost, and the prices at which remanufactured products can be leased or sold approximate those of their new counterparts (Hesse at al., 2005; Geyer, 2009)

Previous studies have found the quality of core to be pivotal to the profitability and economic feasibility of supply chains for product recovery. Using analytical models, Ravi (2011) has shown the quality of computers returned for recycling to vary substantially and proposed a system for classifying them accordingly; Ferguson et al. (2009) have shown quality grading to reduce the overall costs of remanufacturing; and Guide and Van Wassenhove (2001) and Guide et al. (2003) earlier investigated the potential of quality grading in product recovery.

Other papers of an empirical nature have discussed the importance of core acquisition. Östin et al. (2008) discussed the difficulties and costs of obtaining core across the types of relationships that exist between manufacturers and users (e.g., ownership-based, service-contract); Östlin et al. (2009), using case studies, found core acquisition to be a fundamental input to remanufacturing, and Kerr and Ryan's (2005) case study of photocopier remanufacturing in Australia further emphasised the importance of suitable core; White et al. (2003), in a case study of personal computer remanufacturing, observed quality to be one of the main factors that determines whether a returned item is directed to the secondary market or dematerialized; and Ramzy and Williams (2009), one of the few studies to collect and analyze data on products returned for reuse, unlike our work, investigated the quality of products specifically for export. Geyer (2009), who investigates the re-usability and, indirectly, quality of returned mobile phones, finds a high percentage to be of good quality and most consequently to be re-directed to the secondary market.

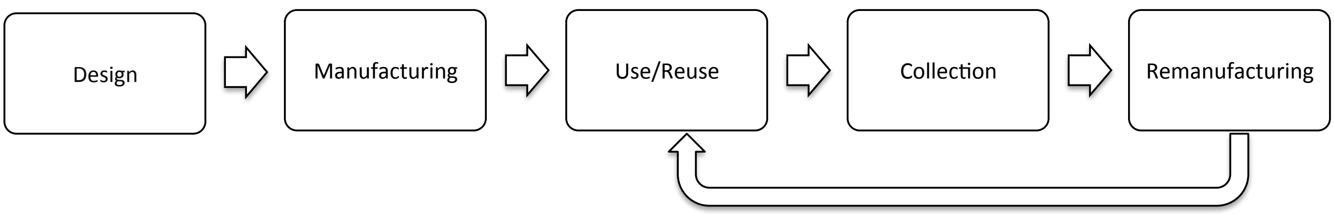
Yet other empirically oriented papers have examined barriers to obtaining high quality core. Hammond et al. (1998) argue that competition for high quality core affects manufacturers and remanufacturers alike, and Subramoniam et al. (2009) found local legislation in Brazil that prevented the import of used automotive parts to seriously impede the growth of a local car part remanufacturing industry. Further evidence of barriers to obtaining high quality core exists outside the realm of academic research. For example, legislation that resolves some of the environmental issues associated with e-waste may reduce the amount of core available for remanufacturing and reuse. The current WEEE directive, for instance, is alleged by some independent remanufacturers to have reduced the volume and quality of core by incentivising recycling, which competes directly with remanufacturing for core (interview with the CEO of a large remanufacturing organisation, October 2011). Product design can also impede refurbishment. For example, in 2002, Lexmark began fitting its toner cartridges with a computer chip that communicated with its printers via software for which the company holds copyrights, and without which its printers won't function (PCWord, 2003).

2.2. Consumer attitudes towards product disposal

The well-developed literature on consumer attitudes towards disposal includes the literature that investigates the antecedents of disposal behaviour, that is, factors that influence the decision whether to keep, donate, sell, dispose of, or recycle a product. Bayrus' (1991) investigation of replacement behaviour in the context of durable goods and the effect of demographic characteristics found high-income and low educational achievement to be positively correlated with early replacement of durable products, and Harrell and McConocha (1992) also found demographics (e.g., age) to affect disposal behaviour and, more superficially, disposal choice (i.e., whether to sell, pass along, or donate). Sego's (2010) investigation of mothers' disposal of toys found disposal behaviour to be affected by the personal meaning consumers attach to certain products, and in a similar vein, Mugee, Schifferstein, and Schoormans (2010) found three factors—attachment, utility, and appearance—to influence the decision of whether to dispose of a product. Finally, White et al. (2011) investigated the effect different types of messages have on intent to recycle. This paper relates to the literature on disposal behaviour, specifically with reference to microwave ovens.

Prior research also addresses the question of why consumers choose new over second hand products and consumers' appetite for reused and remanufactured products. Although we acknowledge the importance of investigating demand for such products, our focus is on the supply side of a reverse supply chain (e.g., *Collection* and *Remanufacturing*, as shown in Figure 1, which illustrates a closed-loop supply chain). For a review of the literature on demand and willingness to pay (WTP) for reused and refurbished products, we refer readers to Subramanian and Subramanyam (2011) and Quariguasi-Frota-Neto et al. (2012).

Figure 1: The phases in a closed-loop supply chain.



2.3. Design for remanufacturing

Improving product design to facilitate reuse and remanufacturing is part of design for remanufacturing, or DfRem (Shu and Flowers, 1999). Interest in DfRem has grown substantially in recent years, but badly needed is more case study type research on products other than the ones commonly investigated (e.g. photocopiers, by Hatcher et al. (2011)), such as the work of Sundin et al. (2009), which provides guidance in how to alter the layout to facilitate remanufacturing of three different products. The difficulty of implementing such changes in practice is also discussed, orginal equipment manufacturers (OEMs) of consumer goods, for example, being commonly less inclined than OEMs that manufacture capital goods to adopt what Sundin and Bras (2005) refer as functional sales (e.g., Rolls-Royce's Total Care system). Readers are referred to Hatcher et al. (2011) for an updated review of DfRem.

3. Quality of remanufactured products and economics of remanufacturing

We investigate here the functionality of microwave ovens discarded in the United Kingdom and costs of repairing them.

The following are among relevant research questions on e-waste that have not yet been empirically investigated in the literature are. (i) What are the functional and cosmetic quality levels of electronic products currently being discarded in the United Kingdom? (ii) What faults are principally responsible for these products being discarded? (iii) Is reuse and, consequently, life span extension technically possible for all returned products, that is, can all products be safety repaired? (iv) Is the quality of discarded products hindering reuse? (v) What opportunities exist for product reuse and how are they best exploited? (vi) What other factors may be hindering reuse of electronic devices?

3.1. Methodology

To investigate their functionality, we collected and tested for electrical and mechanical faults two batches of microwave ovens destined for disposal. The first part of the sample, 82 microwaves acquired between September and December 2010 from the Household Waste Recycling Centre (HWRC) site in Greater Manchester, was collected directly from consumers to avoid potential damage caused by manual transfer into recycling containers.[3,4] The collected items were tested and cosmetic imperfections and functional faults recorded. Tests were conducted *in loco* on six different occasions, each microwave being tested by at least one academic and one technician from the University of Manchester (UoM).

[3] Viridor Laing is the company responsible for managing the Greater Manchester HWRC sites. The disposal site is located on Longley Lane, which is part of the Greater Manchester area.
[4] Remanufacturers we interviewed indicated that damage is common in recycling centres owing to products being thrown into containers from up to two meters.

Site visits lasted a minimum of six hours due to the rate at which units arrived.

A second batch of microwaves was collected from Create UK, a Liverpool-based charity and social enterprise. Two shipments totalling 107 units were transported from Create UK to UoM for testing in March and June of 2011. At least one technician and one academic tested each unit. Altogether, 189 microwaves representing more than 40 different brands (including Bush, Toshiba, LG, Sharp, and Sanyo) were tested.

Testing was done in five phases. Phase one consisted of a Portable Appliance Test (PAT), an electrical safety standard test that evaluates whether a particular electronic product is functionally safe for reuse. Products that failed this test were discarded. Phase two involved visual inspection of all items for cosmetic imperfections (e.g., cracks in the paint). In phase three, the microwaves were tested for leakage and power. The former test employed a microwave leakage detector; the latter involved heating a microwave oven proof cup containing 200 millilitres of water at a starting temperature between 19 and 21 Celsius (units able to elevate the starting temperature by 35 C in 60 seconds passed the test (ASISTM, 2009)). In phase four, the units were tested for electrical faults (e.g., damaged cords, magnetron failure), in phase five, for mechanical faults (e.g., faulty handles).

To establish the functionality of the microwaves at the point of disposal, we prepared a questionnaire to be completed for each unit. Sixteen units failed the PAT test and 33 units (17%), found to be in perfect working condition, could potentially be re-used without any servicing. The remaining 140 units presented cosmetic imperfections or exhibited electrical or mechanical faults. These were classified as follows. Electrical faults: E1. Damaged cord, mains lead, or plug or blown fuse (top or internal); E2. No voltage at the filter circuit input; E3. Voltage supply unavailable at the control circuit input; E4. Damaged high voltage (HV) transformer; E5. Damaged HV capacitor; E6. Defective magnetron. Mechanical faults: M1. Faulty handle or door locking mechanism; M2. Faulty or broken door; M3. Defective or damaged controls; M4. Out of order rotating base; M5. Damaged display; M6. Other faults including dirt, worn out inside coating, small cosmetic imperfections, and damaged case.[5]

3.2. Findings

Fault types were further classified according to gravity, that is, whether minor or major repairs were indicated. This classification was dictated by two criteria, time to repair and cost of parts. A repair was deemed minor if it could be accomplished with spare parts that retailed for less than £15 and would take no more than 15 minutes to complete (including disassembly, re-assembly, and testing). Prices used were those for spare parts available on the websites of specialized shops that cater to the repair industry; repair times were based on recorded average repair times and opinions of participating technicians.

[5] Category 6 mechanical faults refer to cosmetic imperfections.

Faults in categories E1, E3, E4, M2, and M4, and certain types of faults in M6, were considered minor, all others deemed major.

Results for the units tested were as follow. Half of the units required only minor repairs (e.g., replacing an internal fuse or external cable). Of these, 22 units (16%) had only minor cosmetic imperfections like external damage occasioned by transport or accumulated dirt. Major repairs required by the other half of the units included such repairs such as replacing a non-functional magnetron. Table 1 summarises the results.

Table 1. Quality of microwave ovens examined and sources of faults

Microwave oven fault categories			
	Minor repair	Major repair	Total
Electrical fault only	22 (16%)	17 (12%)	39 (28%)
Mechanical fault only	33 (23%)	34 (24%)	67 (47%)
Electrical and mechanical faults	15 (11%)	19 (14%)	34 (25%)
Total	70 (50%)	70 (50%)	140 (100%)

Note: Each of the 173 microwaves that passed the PAT test was tested for six different electrical and mechanical imperfections. This table shows the results for the 140 microwaves that presented electrical and/or mechanical faults. The other 33 microwaves were in perfect working order.

3.2.1. Types and frequency of electrical faults

The faults diagnosed by the electrical tests, classified according to the six categories identified above, are summarized in Table 2. The majority of electrical faults were missing plugs and leads (E1). In interviews, more than 20 consumers reported cutting the cables before transporting their products to the recycling centres to prevent re-use, fearing that they were still liable for the discarded products. Many of the microwaves in the E1 category were thus fully functional prior to disposal, and their reuse could be facilitated, at least to some degree, by simply making consumers aware that they are not liable for subsequent use of discarded items.

The second most common electrical fault in microwaves was failure of the principal component, the magnetron (E6), usually due to overloading or spillage (repeated heat exposure of food left in microwaves can burn the waveguide cover and damage the magnetron). The third most commonly diagnosed electrical fault was failure of the capacitor (E5).

Note that approximately two thirds of all electrical faults thus involve only three parts, cables, magnetrons, and capacitors.

Table 2 Major/minor electrical and mechanical faults in 140 microwave ovens

Category	Microwave ovens with electrical fault	Microwave ovens with mechanical fault
E1/M1	44 (31%)	3 (2%)
E2/M2	6 (4%)	13 (9%)
E3/M3	5 (4%)	14 (10%)
E4/M4	10 (7%)	8 (6%)
E5/M5	14 (10%)	5 (4%)
E6/M6	23 (16%)	71 (51%)

Note: As in Table 1, the 140 microwave ovens that passed the PAT test and were found to be defective are considered. Categories are the same as described in Section 3.2.

3.2.2. Types and frequency of mechanical faults

Cosmetic damage (M6), by far the most frequently recorded failure, encompasses missing rotating glass plate and peeled off, burned, or damaged internal coating as well as damage to the external casing incurred in handling and transport. Believing some of these imperfections to have resulted from transportation to the recycling centres, and in the case of products obtained from Create UK, between the charity and university, we suspect our estimation of the number of microwaves in perfect condition to be a lower bound. The most common internal faults were localized heating and thermal damage caused by food spillage and worn cavities, a result of the inferior quality of the painting process used by some manufacturers. Damaged doors being found only in items collected from Create UK suggests that this fault could be avoided by improving disposal and transport processes.[6] The cosmetic quality of microwave ovens collected from the HWRC was superior to that of units collected from Create UK because the former were received directly from consumers rather than retrieved from recycling containers.

Some items had multiple faults including both electrical and mechanical ones. Seven of the microwaves presented two faults, and two had three mechanical faults.

In summary, the quality of discarded microwaves being high and cost of replacement electrical parts low, the potential for reuse and, consequently, product life span extension is good. Conspiring to prevent reuse, however, are an incipient second hand market, design issues, and weak government legislation.

4. Consumer behaviour and e-waste disposal

In this section, we shed light on the question of why consumers discard electronic products.

[6] Ten units collected from Create UK, and none of the units collected directly from consumers at Viridor, had damaged doors. Although we cannot establish this difference to be statistically significant, interviews with individuals working at the disposal sites confirm this finding.

4.1. Methodology

A simple questionnaire was prepared and administered to consumers discarding microwave ovens at the Longley Lane, Sharston and Manchester HWRC. Each questionnaire had a unique number, which was associated with a particular discarded microwave oven. Although the interviews were semi-structured, because they were short (due to the circumstances under which it was administered, the questionnaire was designed to be completed in less that 4 minutes), only a few questions per interview could be answered.

The questionnaires were completed by a researcher who approached members of the public as they arrived at the recycling sites. Prior to the first visit to the sites, the researchers and managers of the facilities agreed to some rules that the researchers were required to follow, for example, pertaining to locations where members of the public could be approached (the questionnaires were administered either at the entrance of the recycling sites or in front of the containers used for disposal).

4.1.1. Methodological justification for the interviews

Face-to-face interviews have a number of advantages over other methods of data collection, such as mail-in questionnaires, including higher response rates, greater confidence that data collection instructions have been properly followed, and flexibility to answer new questions generated by respondents' answers (Forza, 2002). In the case of our research, we believe that face-to-face interviews assured more accurate answers. Had we constructed our sample based on a less focused audience, it is not unlikely that some of the reasons underlying disposal decisions may have been forgotten by respondents, microwave disposal being hardly a memorable event and occurring infrequently.

4.2. Analysis and discussion

The overall response rate for face-to-face interviews was greater than 50% (see Table 3). The interviews revealed the age of the discarded appliances to range from one to 25 years, average age, approximately six years. This result confirms our intuition that the life span of microwaves is relatively short. Moreover, most of those disposing of microwave ovens were between 35 and 60 years old, owned cars, and were of middle to high income.

Only a small fraction of interviewees were aware of alternative end-of-life destinations for their unwanted products (e.g., charities and reuse organizations).

The interviewees did not know why their microwaves had failed. Some could identify the problem with their microwaves in very general terms (e.g., sparks inside the microwave), but most were unable to effectively repair or even identify the source of the problem (e.g., some stated that their microwaves were making strange noises, but were unable to identify the source thereof). Failure to start up, unexpected noises, sparking when powered on, non-working turntables, and rust were the main defects cited.

To gauge attitudes towards the latest innovation and technology upgrades, we asked whether the interviewees intended to replace their discarded products with similar or updated versions. More than half of those disposing of defective items planned to purchase replacement products with the same functionality, and most of those disposing of products in working condition to purchase updated products. Our results, which are summarized in Table 3, thus call into question the widely-held belief that e-waste is caused by a desire for the latest technology.

Table 3 Face-to-face survey of consumer behaviour related to recycling of e-waste at the Greater Manchester HWRC

	Yes	No	Not Answered	Total
Q1.	41 (50%)	39 (48%)	2 (2%)	82 (100%)
Q2.	16 (41%)	5 (13%)	18 (46%)	39 (100%)
Q3.	21 (54%)	N.A.	18 (46%)	39 (100%)
Q4.	31 (72%)	2 (5%)	10 (23%)	43 (100%)
Q5.	19 (23%)	55 (67%)	8 (10%)	82 (100%)

Note: Five questions were asked of 82 consumers who disposed of microwave ovens at the HWRC in Greater Manchester. Q1- Could you please tell us whether your discarded microwave oven is working (Yes)/not working (No)/Not Answered?; Q2- If the item is not working, are you able to pinpoint what is wrong with the product? Yes/No/Not Answered; Q3- If the item is not working, are you replacing or updating this item with a more modern product? Yes/No/Not Answered; Q4- If the item is working, are you replacing or updating this item with a more modern product? Yes/No/Not Answered; Q5- Are you aware of other disposal options for your unwanted working items besides HWRC (e.g., donating, reuse organizations)? Yes/No/Not Answered. Note that Q2 and Q3 were posed only to consumers whose answer to Q1 was negative, Q4 only to consumers who answered otherwise.

5. Recommended measures for facilitating reuse and life span extension

Based on the results reported in Sections 3 and 4, we propose ways to facilitate reuse and thereby extend the life span of microwave ovens. We also propose modifications to improve the durability of the product, which would also contribute to longer life spans.

All recommendations are aimed at OEMs. We acknowledge that governments play a pivotal role in promoting reuse, and that more research is therefore needed to investigate how legislation can encourage better design for manufacturing, but this is outside the scope of the present paper. We refer to Oakdene Holling (2008) for a discussion of policy options for promoting remanufacturing in the United Kingdom. For our part, we elaborate seven design changes, although we believe there to be other equally important changes that are not included for the sake of brevity.

We further consider whether the proposed changes in DfRem contradict the principles of design for manufacturing (e.g., whether a change in design makes the microwave oven more difficult to manufacture). All recommendations were evaluated by colleagues at UoM for feasibility, and by Create UK, a large, independent UK remanufacturer, for their usefulness in facilitating remanufacturing. The changes are classified according to RemPro-matrix (Sundin and Bras, 2005) and summarised in Table 4. A request made to one large OEM to discuss the proposed changes was declined.

Table 4: Change in design according to the RemPro-matrix

N.	Recommendation	RemPro classification
1	Reduce the complexity of how printed control boards (PCBs) are assembled	Ease of access, separation, and securing
2	Facilitate access to internal parts	Ease of access and securing
3	Redesign how magnetrons are fitted to make them more easily accessible	Ease of access, separation, and securing
4	Change painting of internal cavity material	Wear resistance, ease of cleaning*
5	Change material in wave-guide cover to plastic	Wear resistance
6	Change the design of mains cables and plugs	Ease of separation and securing
7	Reduce the number of different designs of mechanical parts	Affordable parts*

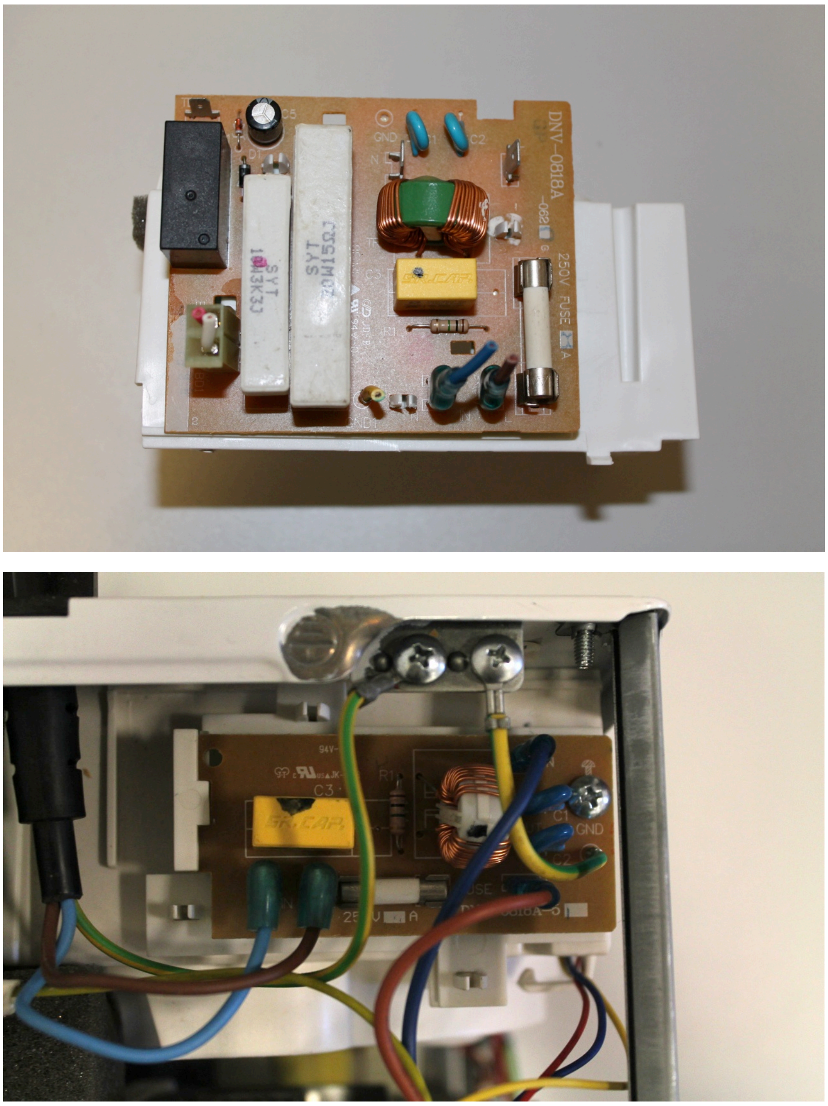
Note: * "Ease of cleaning" and "Affordable parts" are not included in the Rempro matrix.

5.1. Reduce the complexity of how printed control boards (PCBs) are assembled

The way PCBs are fitted was found to vary substantially across microwave models and manufacturers. Manufacturers used screws (of different types and sizes), snap-fits, or plastic supports, and in many cases a combination of these, to mount PCBs. This complicates retrieval of the control boards, as every removal is unique. That electrical circuit diagrams, usually affixed to the inside of the case unit, were found in very few of the microwaves inspected rendered repair/remanufacture even more challenging. In summary, replacement of printed circuit boards is time consuming, requiring careful dismantling of the board and other components as well as connector cables.

Of the microwaves investigated, the two mountings that rendered PCB removal the least time consuming were the snap-fit and plastic support. Utilizing these over screw mountings would reduce failure and facilitate reuse/remanufacturing of the E2 and E3. Picture 1 illustrates a PCB board mounted with snapfits.

Picture 1: Fittings of PCBs.

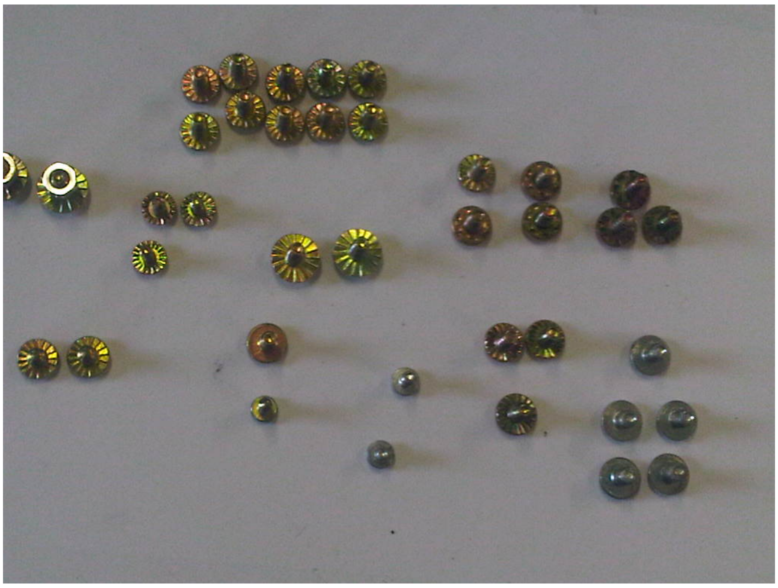


Note: Picture 1 shows two types of PCB assemblying: top, mounted using snap-fits, and bottom, connected to the chasis by plastic mount (bottom, left) and Phillips screw (bottom, right).

5.2. Facilitate access to internal parts

The problem of component accessibility, alluded to in Sundin (2001), persists in some of today's home appliances (Sundin et al, 2009). To open a microwave oven case involves removing several screws (typically between six and eight), often of different types and sizes. Screws of different types and sizes may necessitate changing tools, which is time consuming, and screw removal in older machines can be complicated by rust and corrosion. These problems are exacerbated during the reassembly process because the technician needs to keep track of the right position of each screw and screws and screw holes may have been damaged during the disassembly process. A sample of different screws collected from a single microwave oven is shown in Picture 2.

Picture 2. Screws of different shape and sizes collected from a single microwave oven

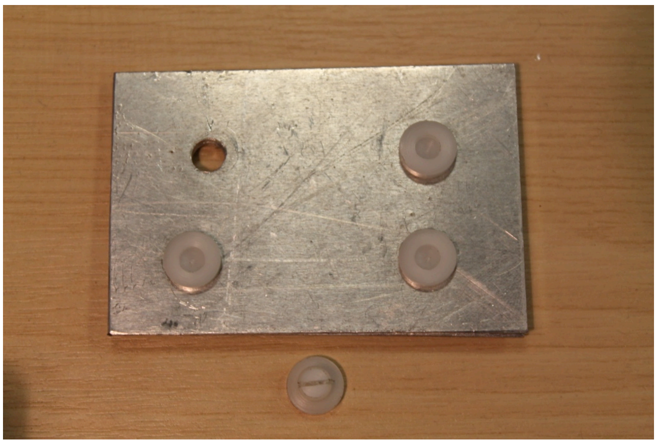


Note: In total, this microwave contained 38 screws of 12 types and sizes.

There are two solutions to this problem. The first is to design the product with fewer screws all of the same size, the second to eliminate the use of screws altogether. An alternative solution is the use of plastic screws. Picture 3 shows plastic screws produced at UoM that require little effort to remove, don’t rust, and are as solid and secure as metal screws.

With respect to DfM, we don't believe that reducing numbers and types of screws increases manufacturing complexity or cost, although introducing plastic screws may.

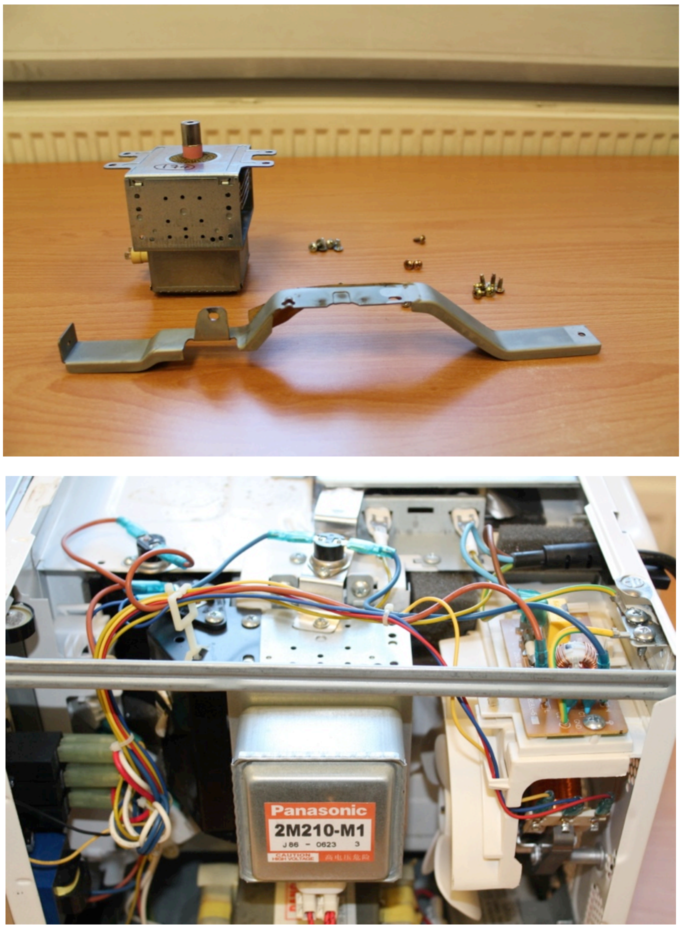
Picture 3. Plastic screws developed at UoM



5.3. Redesign how magnetrons are fitted to make them more accessible

That magnetrons, the second most common source of electrical faults, are produced by only a handful of manufacturers also facilitates the reuse of parts. For a number of units investigated, however, removal of the magnetron was complicated by, among other factors, the need to remove a large number of screws to open the microwave case. In fact, the magnetron was in most models one of the most difficult parts to remove. Making magnetrons more accessible would facilitate their replacement or reuse. Sundin et al. (2009) show that small changes in design can facilitate access to parts, and propose changes in the design of, among other home appliances, washing machines and refrigerators. Picture 4 shows (on the bottom) the position of a magnetron within a microwave oven with connecting cables and screws and (on the top) the magnetron disassembled, and the screws of six different types that needed to be removed to extract the magnetron from the case. We suggest fixing the magnetron with less screws of fewer types.

Picture 4: Microwave magnetron and connections



Note: The picture at the top shows the magnetron dismantled. In total, 18 screws of 6 types had to be removed to retrieve the magnetron. The picture at the bottom shows the magnetron assembled.

5.4. Change the painting of the internal cavity material

The most common of the purely cosmetic mechanical faults was rust, the result of the internal cavity paint peeling off and the exposed surface becoming oxidized. This was often caused by the turntable wheels wearing down and lifting the floor surface. To reduce this fault, manufacturers need to (i) change the design of the stirrer belts and wheels, (ii) improve the painting in the internal cavity, or (iii) use stainless steel.

With respect to changing the design of stirrer belts and wheels, it has been observed that older models that used fixed wheels did not present this problem. We do not recommend reverting to the older design, however, as it increases the complexity of the manufacturing process and makes cleaning more difficult.

This problem can also be mitigated by changing the material and/or colour of the internal cavity. Peeling was most frequently observed in cavities painted with light colours and infrequently observed in cavities without paint or painted in dark colours. Picture 5 illustrates the problem (on the left) and a on more detail (on the right).

Picture 5: Microwave oven with rusted internal cavity.

Note: Picture 5 shows cavity rust caused by the turntable wheels wearing down and lifting the floor surface.

The number of types of failures being small, and some failures being preventable in the home, a simple system for testing cables, magnetrons, capacitors, and power fuses would afford a nearly complete diagnosis without disassembly.[7]

[7] Nor would visual inspection, which would suffice for most other types of failure, require disassembly.

5.5. Change of material in wave-guide cover to plastic

Most recent, especially low-end, microwave ovens use a removable paper type in lieu of a plastic plate type wave-guide cover. Food grease and food spillages adhere more readily to paper, which, when heated, can be more easily damaged. Microwaves with a fixed plastic form of wave-guide cover have been observed to be easier to clean and to have longer life spans. We hesitate to extrapolate these findings to all microwaves, however, believing more research to be needed to establish whether plastic are more durable than paper wave-guide covers. Figure 6 illustrates the deterioration of a paper type wave-guide cover (on the right) and an intact plastic wave-guide cover (on the left).

Picture 6: Plastic and mica wave-guide cover

Note: Picture 6 shows on the left an intact plastic type wave-guide cover, on the right a broken mica type wave-guide cover.

5.6. Change the design of the mains cables and plugs

Consumers frequently dispose of microwaves because of defective cables, which, although affordable, cannot be easily removed. Picture 7 shows a microwave oven with a fixed cable.

Picture 7: Microwave with fixed cable (broken).

This could be remedied by a simple design change, namely, making cables removable (like a kettle's).[8] Consumers could either buy a replacement cable or have one installed for a small fee, no specialist labour being required. Utilizing moulded cables like the 13A UK main plugs, which are generally available and retail for less that £2, would further improve effectiveness by enabling independent remanufacturers to reuse cables from machines de-manufactured for spare parts.[9]

Picture 8: Removable microwave cable

Note: The cable on the right is an example of the current design of a typical microwave power cable. The cable on the left is an example of moulded cable with 13A UK main plugs.

5.7. Reduce the number of different designs of mechanical parts

The most common sources of mechanical faults, defective controls, doors, and locks, because their design is used to achieve brand differentiation, are significantly less homogeneous than the parts responsible for most electrical faults. Whereas, for example, only a few models of magnetron exist, the number of doors is nearly equal to the number of different microwave models. Making components interchangeable across different product types and brands is thus more difficult for mechanical than for electrical parts. Reuse of mechanical parts by independent remanufacturers is thus largely restricted to same product substitution.

[8] Currently, non-removable "cloverleaf" cables are used.

[9] Our experience suggests that independent remanufacturers commonly hold inventories of parts removed from returned products.

5.8. Further considerations

As well as the technical possibilities for increasing reuse, that is, the "how" question, it is important to analyse the question of why OEMs are only marginally engaged in design for reuse and remanufacturing. Although we do not directly investigate this issue in this paper, we speculate that design changes that could potentially reduce e-waste are not implemented for the following reasons.

One, manufacturing and remanufacturing, of microwaves as well as of many other electrical appliances, are generally carried out by OEMs and independent remanufacturers, respectively, two different types of organizations with different incentives. Design for reuse will benefit only remanufacturers, and may even hurt OEMs to the extent that it leads to an increase in the number of products being remanufactured, which will compete with new products. Unlike other environmentally friendly initiatives like improvements in energy efficiency, which consumers do consider when purchasing new products, there is no direct incentive for microwave manufacturers to design their products to be re-usable. The misalignment of incentives between manufacturers and remanufacturers, and consequent lack of engagement of OEMs in DfRem, was recently documented by Hatcher et al. (2011).

Two, a weak market for used, refurbished, and remanufactured microwaves further contributes to the large number of microwaves being recycled or discarded rather than re-used.

Our focus being on the supply part of the supply chain, definitive solutions to these problems must remain an avenue for future research. We believe that governments can play an important role in addressing these impediments to higher levels of reuse. The interests of manufacturers and independent remanufacturers could be brought into alignment by, for example, rewarding, as with tax breaks, manufacturers that produce products that are can be easily remanufactured and thereby diverted from landfills to the reuse markets. The weak market for remanufactured products could be addressed by creating mechanisms for including remanufactured products in government procurement strategies. The United Kingdom, for instance, has for a long time had in place mechanisms that favour SMEs in public procurement. Remanufactured products might be similarly favoured, although we believe that the requisite mechanisms would rely on extensive analysis.

Other ways surfaced by this investigation for increasing the life span and improving the re-usability of products are, for the sake of brevity, not discussed here.

6. Social and environmental benefits

Increasing the life span and reuse opportunities for microwave ovens would have an impact on both socio-economic development and environmental protection.

With respect to social-economic development, remanufacturing, being a labour intensive activity, has generated numerous jobs in the United Kingdom and elsewhere. Moreover, that its potential has not been yet fully exploited means that more jobs might be created in the sector if governments and manufacturers work together to support product reuse (Lund, 1998; Chapman et al., 2009).

Moreover, the remanufacturing industry annually produces products worth billions. In the United Kingdom, alone, the industry is worth £5 billion per year. In the same way that remanufacturing can create many more jobs than it does today, we argue that it can generate even more value for the UK economy (Walson, 2009).

Moreover, remanufacturing commonly employs a layer of society, the long-term unemployed, for which permanent jobs are difficult to secure. A local charity located in the northwest of England, for instance, has trained nearly 500 long-term unemployed and placed them in permanent jobs with local and multinational manufacturers, such as Jaguar. According to the local police, the number who committed criminal offenses after finding a permanent job was but a small fraction of what would be expected from a group with the same profile (interview with the CEO of the charity engaged in training, September 2011).

Reusing and extending the life span of microwave ovens also reduces the amount of e-waste that needs to be processed. E-waste has become an increasingly serious concern in the United Kingdom largely due to the limited capacity of landfills and concerns about the release of toxic materials.

With respect to global emissions, although measuring emissions savings that might accrue to remanufacturing is beyond the scope of this paper, we speculate that remanufacturing consumes substantially less energy than manufacturing and accounts for lower emissions per microwave oven. It is difficult to say, however, whether the cumulative energy demand (CED) through the entire life cycle of the product is lower for remanufactured products, as new products tend to be more energy efficient. A thorough investigation is needed to show whether this is (or is not) the case.

7. Conclusions and further research

We investigate in this paper the quality of microwave ovens discarded in the United Kingdom and consumer attitudes regarding the disposal of this product. We found many discarded items to either be in perfect working order or have only minor faults, and a high percentage to be candidates for repair or remanufacture. We further found the cost of spare parts needed to repair most of these items to be, on average, small, and few parts to be responsible for most of the, in many cases repairable, electrical and mechanical failures.

We argue that despite its significant potential, re-usability is seriously hindered by designs that do not fully embrace the concept of manufacturing for reuse. Redesigning microwaves to accommodate repairs of simpler faults and make repair of more complex faults by specialized shops economical could substantially increase product life spans and re-usability. The lack of engagement with design for reuse is, we believe, partially explained by non-alignment of interest between manufacturers and remanufacturers. As they do not profit, at least directly, from reuse, the former have little incentive to design products in ways that facilitate reuse. We also find, however, that even with existing designs it is technically (but not necessarily economically) viable to safely reuse most of the items being discarded. We further find the lack of a strong secondary market to conspire against reuse.

We document as well that few of those disposing of microwaves had knowledge of how electronic appliances could be re-used apart from being recycled, and that most who were discarding defective products intended to purchase similar products and most who were discarding operational units planned to upgrade. Whereas the latter's decisions would likely not be affected by improved re-usability and better components, given the opportunity to perform DIY repairs or conveniently obtain shop repairs at an attractive price, others may well not have discarded their microwaves.

We consequently propose changes in design to facilitate reuse and extend product life spans, and advocate dissemination of information on reuse to promote implementation of our recommendations. We further encourage recyclers to engage in triaging of products being discarded at the point of disposal to avoid cosmetic or other damage to otherwise re-useable units in recycling containers or during handling or transport.

If e-waste is to be reduced, microwaves need to be re-designed to last longer and with reuse in mind, and inventories of spare parts made available at affordable prices.

Among its limitations is that the reported study investigates only the supply side. As one potential direction for future research, we encourage the undertaking of more demand side investigations, which are just beginning to appear in the literature. For example, how do consumers perceive remanufactured products and what affects consumers' willingness-to-pay for these products? These questions and others equally timely and relevant to marketing for reuse remain, to date, only partly answered.

Finally, this paper documents the opportunities that exist for reuse and remanufacturing of microwaves in the United Kingdom and proposes ways that re-use can be facilitated by OEMs. As mentioned throughout, other technical and strategic issues have not been addressed, but deserve attention in future research. These include the antecedents of participation in product take-back, for example, why do some organisations engage in reverse logistics and other not? Equally important is to investigate why, given the low cost of and, looked from a demand side, strong financial business case for remanufacturing microwaves, aren't OEMs currently engaging in such activity (e.g., fear of cannibalisation or image damage?), and how might governments make the business case even stronger? These are some of the questions that warrant further investigation.

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