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# Urban mining potentials of university: In-use and hibernating stocks of personal electronics and students' disposal behaviors

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ABSTRACT

To evaluate the urban mining potentials of university, we characterize in-use and hibernating stocks of personal electronics possessed by university students in Jiangsu Province, China. Students' behaviors towards disposing of personal electronics are also explored, including obsolescence, hibernation and recycling. Mainly based on a questionnaire survey, the results firstly show that by per capita, in-use stocks of personal electronics owned by university students are basically higher than average household has in China. Average age of these in-use electronics is between 1.6 and 3.5 years, with mobile phones and tablet personal computers having the shortest in-use time. The lifespan of all personal electronics possessed by university students is shorter than by general residents, indicating their different consuming and disposal habits. Regarding the hibernating stocks, mobile phone has the highest hibernating level of 0.83 unit per capita, yet the level is half of that among university students living within the UK. In regard to disposal behaviors of university students, it is displayed that over a half of replacing practice happened because of the functional damage of old electronics. However, due to reasons like lacking recycling facilities and concerns for information security, 58% of the participants chose to keep these old electronics instead of reuse or recycling them, making university a potential distinct urban mine containing a large amount of valuable resources. We further find that university students have the intention of choosing online recycling platforms to dispose of their obsolete electronics so long as they are fully aware of the importance of recycling behaviors and the platform can provide nice user experience. Several suggestions are finally provided about how to exploit urban mines of university.

## 1. Introduction

Urban Mining (UM) concerns all the activities and processes of reclaiming compounds, energy and elements from products, buildings and waste generated from urban catabolism (Baccini and Brunner, 2012; Cossu and Williams, 2015). The concept has received common attention largely driven by resource availability concerns. To promote the implementation of UM, analyzing in-use stocks of materials/products in society and their discarding rates as a function of time has been an increasing research interest (Zhang et al., 2015). In recent years, hibernating stocks, referring to accumulations of obsolete materials in society that could be accessible for recovery, have also been a widespread concern in the context of sustainability, and become a focus of UM (Daigo et al., 2015; Krook et al., 2011, 2015), as they are a common and significant barrier to the effective and timely recycling. So far, research on hibernating stocks mainly focus on infrastructure as large material stocks are deposited in infrastructure networks (Krook et al., 2011, 2015; Lederer et al., 2016; Wallsten et al., 2013, 2015).

Among various categories of urban mines, personal electronics represent a typical, high-tech consumer device having a short lifecycle (usually less that 5 years) and containing substantial contents of valuable materials. Unused personal electronics are inclined to become idle or be discarded carelessly because of their relatively small size, making them constitute an important category of urban mines in recent years. Therefore, except for the emphasis on regular WEEE (i.e., waste electrical and electronic equipment) (Parajuly et al., 2017; Salhofer et al., 2016; Zhang et al., 2012) (Cucchiella et al., 2015; Milovantseva and Saphores, 2013), a series of published studies explore the issue of personal electronics waste (Saphores et al., 2009). For instance, Ylä-Mella et al. examine consumers' awareness and perceptions towards mobile phone recycling and re-use (Ylä-Mella et al., 2015); Wilson et al. also put attention on the issue of mobile phone in university, including

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its ownership, reasons for hibernation, and replacement motives (Wilson et al., 2017). Several research have estimated the generation of old mobile phones (Polák and Drápalová, 2012; Tanskanen, 2013) and computers (Rahmani et al., 2014), which have shown that only a very small percentage are returned for recycling. Bovea et al. explore potential reuse of small household WEEE (Bovea et al., 2016). Recently, Zhu et al. model in-use stocks and spatial distributions of electronic devices in household (Zhu et al., 2017), which includes some personal electronics such as mobile phones, tablets, laptops, and desktops.

Since 2010, the Chinese government has proposed the program of "demonstration urban mines" (National Development and Reform Commission (NDRC), Ministry of Finance of the People's Republic of China (MOF), 2010), and UM has been promoted as a strategy of alleviating China's mineral resource shortage and excessive dependence on foreign mineral resources (Wen et al., 2015). However, a relevant research shows that the current collection rate of WEEE is as low as 28% (Li et al., 2015a, b), and a non-negligible part of uncollected WEEE has been stored or abandoned directly, especially those small-sized electronics. Lately, Zeng et al analyze the recycling potential of WEEE in China by forecasting their generation till 2030 (Zeng et al., 2015); several scholars estimate obsolete cellular phones generation in China (Guo and Yan, 2017; Li et al., 2015a, b); and there are also studies discussing the stability and profitability of the informal WEEE collector in China (Gu et al., 2016). However, most of these studies adopt a top-down method and thereby do not take hibernating stocks of electronics into account., especially small-sized personal electronics. Moreover, little is known about the temporal status of these two kinds of stocks, including their lifespan/hibernating span and average age which is a crucial information for efficient UM in the future.

In the last few years, the "Internet + Recycling" has prompted the development of recycling industry in China, and a series of online platforms have been established. E-commerce giants such as JD.com and Alibaba Group have also joined efforts to promote e-waste recycling. JD.com is the leading investor of Aihuishou.com, one of China's largest personal electronics recycling platforms (Liao and Xu, 2018). Alibaba Group has invested in Huishoubao.com (Yang, 2018), which is another online recycling platform focusing on mobile phones, tablet personal computers, and other digital products. Using applications of these recycling platforms on mobile phones or computers, people can make appointments for unused electronics collection or trading. As the whole process is relatively convenient and not limited to traditional recycling channels, they are expected to bring new vigor to e-waste recycling industry. Although several studies have focused on recycling behaviors of Chinese consumers (Bai et al., 2018; Wang et al., 2018), people's behavior intentions towards online recycling platforms still remain unknown.

This research firstly characterizes in-use and hibernating stocks of personal electronics owned by university students in Jiangsu, China. Then we explore students' disposal behaviors towards obsolete, hibernation and recycling of personal electronics, with the last aspect focusing on students' behavior intention towards using online recycling platforms to handle their unused personal electronics. The results can explore the potential of UM, and provide potential instructions for a higher recycling rate. The topic is chosen for several reasons. Firstly, personal electronics are now ubiquitous among university students. Secondly, university students generally have higher concerns for global resource deficiencies and environmental problems, and are more willing to try new things (then they are supposed to easily accept newborn recycling platforms), thereby the collection rate of e-waste from them is expected to get improved more easily than from other social groups (Saphores et al., 2009). Finally, Jiangsu Province is chosen because of its role in higher education in China. To be specific, there are now 137 universities and colleges with about 1.7 million students in Jiangsu province (Jiangsu Statistical Bureau, 2016), encompassing approximately 7% of the total university students in China (National Bureau of statistics of China, 2016).

## 2. Methods

### 2.1. Questionnaire design

The major data source is a questionnaire survey. In order to design the appropriate survey questions, a preliminary exploratory research was conducted. The purpose of the preliminary research is to 1) screen the dominant types of personal electronics university students own, 2) identify the dominant answer categories of reasons for obsolescence/replacement and hibernation, and options of disposing of obsoleted electronics, and 3) understand attitudes of students to use online recycling platforms to handle their obsoleted electronics. Accordingly, the research includes three parts, the first part asks respondents to name the types of personal electronics they generally own; the second part involves three open-ended questions, i.e., 1) What was the major reason for your decision on laying the most recently used personal electronics aside? 2) What was the most common option for disposing of your obsoleted personal electronics? and 3) If you have kept any obsoleted personal electronics, for what reasons did you keep them? Finally, the third part asks whether they are willing to use online platforms to recycle their unused personal electronics, and what factors they consider when they make the decision.

The preliminary exploratory research is then conducted by randomly selecting respondents from several universities. Based on the answers of respondents, focal electronics in this study include five types, i.e., mobile phone (MP), laptop personal computer (LPC), tablet personal computer (TPC), digital camera (DC), and desktop personal computer (DPC). Although the entire inventory of personal electronics includes many more, these five types constitute dominant ones for university students. Then the questionnaire is structured into five main parts. The first part asks general questions on interviewees' socio-economic and demographic information. The second part gathers information about ownership of typical personal electronics, including quantity, in-use time, and general lifespan. The third part focuses on the condition of hibernating stocks of these five types of personal electronics, including quantity and hibernating years. The fourth part is to explore reasons for obsolescence of personal electronics, disposal preferences for discarded electronics, and reasons for hibernation. The fifth part provides a range of statements related to hypotheses concerning students' behavior intention towards using online platforms, and respondents are asked to indicate their level of agreement with these statements. These statements were scored on a 5-point Likert item scale ranging from 1 = completely disagree to 5 = completely agree. Explanations of questionnaire items in this part can be seen in Section 2.4. Details of the whole survey questions are displayed in Table S1.

### 2.2. Sampling and questionnaire distribution

The sampling method is determined after the questionnaire was designed. As we do not think there are obvious sampling units (usually called strata) that are internally homogeneous with respect to the research questions to be explored, we randomly choose a series of universities in Jiangsu Province, and distribute the questionnaire to students studying and living at the university. The surveyed sample involved 14 universities, which spread over different cities in the province. Besides, the interviewees of this survey are students living on campus, as in China the majority of students in higher education live on campus (Li, 2017).

The survey was conducted between July 2016 and October 2016. The questionnaire was administered by the interviewer, that is, the interviewer was responsible for administering the survey questions to the respondent and record responses in the questionnaire. In total, we sent out 400 questionnaires, and received 387 with valid responses. The number of valid questionnaires are sufficient in consideration of the population size of 1.7 million, as the ideal sample size is 385 assuming we chose a 95% confidence level, 0.5 standard deviation, and a margin of error of +/- 5%.

### 2.3. Definitions of key terms in the research

Regarding survey questions, we define key terms in this research as follows. How these terms can be extracted from the survey questions is also shown in Table S1.

Hibernating stocks: In contrast with “in-use stocks”, this term means personal electronics that are no longer being actively used but still kept by university students, regardless of whether the products still work or not. They are called “hibernating” because these stocks could in theory be reawakened from the perspective of resource recycling. They are also called “dead-storage stocks” in some research (Wilson et al., 2017).

Hibernating time: The term indicates the duration from the point of hibernation till the electronic goes to further disposal. It is also called “dead-storage period” or “the duration of hibernation” (Murakami et al., 2010). The exploration of hibernating time helps to understand the students' behavior related to sustainable consumption.

In-use time: This denotes how long a consumer has been using the electronics till the present.

Average age: for certain personal electronics, average age of this kind of electronic product is defined as Eq. (1) based on data set of in-use time. Compared to lifespan distribution of personal electronics, this indicator would give better insight into when these resource deposits are likely to enter the discard stream from an UM perspective.

$$Y_j = \sum_{i=1}^{n} (t_{i,j} \times \frac{Q_{i,j}}{Q_j}) \tag{1}$$

$Y_j$ refers to the average age of personal electronic $j$; $t_{i,j}$ is the in-use time (years) $i$ of personal electronic $j$ ($i$ = 0.5, 1.0, 1.5, 2.0, …); $Q_{i,j}$ is the amount of personal electronic $j$ that has been in use for time $i$ ; and $Q_j$ is the total amount of personal electronic $j$.

Lifespan: The term is defined for the owner (university students), not in terms of electronics, and denotes the duration of the period when the personal electronics is actively used by university students (Because hibernating product is not in use, the hibernating time is not included in the lifespan of the product). As the research focuses on urban mining of university, we deem the electronics reach their end of life (at least for the current stage) when they are obsolesced by university students. It is different with the definition of “total life span” in some studies (Polák and Drápalová, 2012). Although not clearly defined, the term of “lifespan” is often used in literature based on consumer surveys (Murakami et al., 2009), and it also refers to “duration of use” (Murakami et al., 2010) or obsolescence rate (Zhang et al., 2012). The estimate of lifespan can also help to understand progress toward sustainable consumption.

To calculate lifespan of electronics, we adopt the commonly used Weibull distribution functions (Melo, 1999) (Zhang et al., 2012). To determine the parameters of Weibull distribution, we use minimum, maximum and most likely value from the lifetime data set of personal electronics obtained from the questionnaire survey. The details of the method can be found in SI.

### 2.4. Methods of exploring students' behavior intention towards using online recycling platform

To explore university students' behavior intention towards using online platform, we use the technology acceptance model (TAM) proposed by (Davis et al., 1989) as the theoretical foundation, and the service quality of the online platform is treated as the external variable. During the aforementioned preliminary research, we find that social influence will also affect students' attitudes via the impact from influential people surrounding them, as well as the effect of established social norms on environmental-friendly practice. Therefore, the extended TAM model is presented as Fig. 1, with the meaning of each construct displayed in Table 1.

Related hypotheses are summarized as follows, and the structural equation model (SEM) is employed to explore the interrelations among constructs.

**Hypothesis 1 (H1).** SQ of the online recycling platform has a positive effect on PEOU of university students.

**Hypothesis 2 (H2).** SQ of the online recycling platform has a positive effect on PU of university students.

**Hypothesis 3 (H3).** PEOU of university students has a direct positive effect on PU of university students.

**Hypothesis 4 (H4).** SI has a direct positive effect on university students' ATT.

**Hypothesis 5 (H5).** PU of university students has a direct positive effect on university students' ATT.

**Hypothesis 6 (H6).** PEOU of university students has a direct positive effect on university students' ATT.

**Hypothesis 7 (H7).** SQ of the online recycling platform has a positive effect on university students' ATT.

**Hypothesis 8 (H8).** University students' ATT has a positive effect on the BI of the online recycling platform.

**Hypothesis 9 (H9).** PU of university students has a positive effect on the BI of the online recycling platform.

## 3. Results

The demographic characteristics of the participating university students are depicted in Table 2. Of the 387 participants, 42% are female and 58% are male, which correlates relatively well with the statistics published by Jiangsu Statistical Bureau which states that 49% of university students in Jiangsu in 2015 were female, and 51% male (Jiangsu Statistical Bureau, 2016). The ratio between the undergraduates and the graduates (9:1) in this questionnaire survey is also nearly in accordance with that from official statistics (11:1) (Jiangsu Statistical Bureau, 2016). Besides, most of the respondents (74%) in this survey spend 1000–2000 RMB for living each month, which is consistent with other investigations on university students in China (Wang, 2017). It is thereby believed that results in this survey can be utilized to roughly represent the entire university student population of Jiangsu Province.

### 3.1. Characteristics of in-use stocks of personal electronics

#### 3.1.1. Quantity of in-use personal electronics

The results for quantifying in-use stocks of personal electronics are presented in Table 3. It can be concluded that MP, with smartphones quickly substituting traditional mobile phones and becoming the dominant type, has the highest ownership rate (1.19 per capita) of all small electronic types. As one of daily necessities, smartphones are widely used in China, especially among young people. The amount of in-use computers among university students, including TPC, LPC and DPC, are also non-negligible, with an aggregate ownership rate of 1.80 per capita. With the development of social and educational informatization, computers (especially LPC) have penetrated into daily lives of university students. DC has the lowest ownership rate, because its functions are partly replaced by smartphone whose camera can match most of common photography demands. If we take the ownership rate as a proxy for all university students in Jiangsu Province, and extrapolate the figure upwards accordingly, this would suggest a projected quantity of 2.04 million MP, 0.72 million TPC, 1.66 million LPC, 0.70 million DPC, and 0.45 million DC, respectively.

The national data on possession of small electronics per household, is shown in the third column of Table 3. Considering 3–4 people living

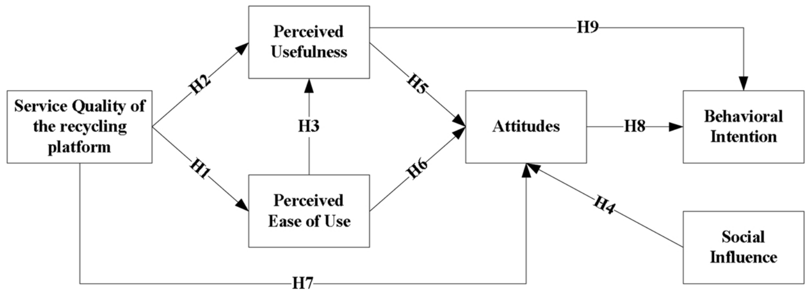


**Fig. 1.** Research framework for exploring students' behavior intention towards using online recycling platform.

in a Chinese household on average, the results on university student are obviously higher than common residents. This could be understood in a way that families with a member attending university own more electronics such as computers and cameras. Or, it can also be translated that university students tend to be more likely to own such kinds of electronics than other people. In view of the fact that the nationwide data does not differentiate in-use electronics and hibernating ones, the mentioned gap between university students and average household will be more pronounced. Comparing ownership rate in this result with that in Australia (Zhu et al., 2017), it is also found on a per capita basis, university students own more in-use stocks of personal electronics than Australia residents in 2015. This has interesting implications that from the perspective of designing more effective e-waste collection schemes, university students and universities may deserve more attention.

**Table 2**
Demographic characteristics of respondents in the sample.

| Characteristic | Category | Ratio (%) |
|---|---|---|
| Gender | Male | 57.8 |
| | Female | 42.2 |
| Level of study | Undergraduate | 90.3 |
| | Postgraduate | 9.7 |
| Monthly living expenses (RMB) | ≤1000 | 16.9 |
| | 1001-1500 | 54.0 |
| | 1501-2000 | 19.9 |
| | 2001-2500 | 6.5 |
| | > 2500 | 2.7 |

**Table 3**
Ownership of in-use personal electronics among university students in Jiangsu and comparisons.

| Personal electronics | Units in-use per capita (university students in Jiangsu) | Units in-use per household in China [a] | Units in-use per capita in Australia [b] |
|---|---|---|---|
| MP | 1.19 | 2.24 | 1.18 |
| TPC | 0.42 | – | 0.38 |
| LPC | 0.97 | (LPC + DPC) = 0.55 | 0.61 |
| DPC | 0.41 | | 0.36 |
| DC | 0.26 | 0.20 | – |

a: data obtained from (National Bureau of statistics of China, 2016).
b: data calculated based on (Zhu et al., 2017).

### *3.1.2. Average age of in-use personal electronics and their lifespans*

Table 4 presents in-use time of personal electronics owned by university students. Concretely, the range of the in-use time covers minimum and maximum in-use time of personal electronics, and the mode is the value that occurs most often within the set of in-use time data. It is surprising and also interesting to find the maximal in-use time of DPC and DC are up to 8 and 10 years, respectively. This means university students, in their 20 s, have been using the same DPC or DC since they were about 10 years old, with the electronics shared by family members or purely attributable to themselves then. One possible explanation is that for some university students, there is no need to update DPC and DC as frequently as other personal electronics, since some of the targeted functions can be replaced by other electronics (e.g. DPC's functions can be replaced by TPC/LPC, and DC by MP).

Generally, MP and TPC have been in use for less than two years on average, and 40% of both types have been owned for no more than one year. In-use LPC has an average age of two years, with one year and two years accounting for 30% and 36%, respectively. In-use DPC has an average age of three and a half years, and it is interesting to note that 51% of DPC currently in use have been owned for 2–3 years. Finally, DC has been in use for two and a half years on average, with the value of two years appears most frequently. The mode of in-use time for MP is one year, while for all other four kinds of electronics, two-years occurs most frequently.

Based on lifetime data obtained from the questionnaire survey, the Weibull distribution of 5 types of personal electronics are estimated as shown in Fig. 2. It is displayed that personal electronics are generally discarded at the age of 2–4 years. Compared to the residents of Taizhou

**Table 1**
Meaning of constructs in the research framework.

| Constructs | Meaning | Reference |
|---|---|---|
| Perceived Usefulness (PU) | The degree to which people believe that using a particular system will enhance their job performance. It reflects user perception of performance improvement by using online recycling platform. | (Venkatesh and Davis, 2000) |
| Perceived Ease of Use (PEOU) | The degree of ease associated with the use of the system. When users feel that online platform are easy to use and do not require much effort, they will have a high expectation toward acquiring the expected performance. | (Venkatesh and Davis, 2000) |
| Service Quality of the recycling platform (SQ) | Including the convenience and security of the transaction process provided by the platform. It can be partly reflected by the reputation of the recycling platform. | (Venkatesh and Davis, 2000) |
| Social Influence (SI) | The person's perception that most people who are important to him think he should or should not perform the behavior in question and social norms about environment-friendly recycling behavior. | (Venkatesh et al., 2003) |
| Attitudes (ATT) | People's positive or negative evaluation or assessment of specific behaviors. | (Venkatesh and Davis, 2000) |
| Behavior Intention (BI) | People's intention of conducting specific behaviors. More stronger the intention, more likely they are to behave. | (Venkatesh and Davis, 2000) |

**Table 4**
In-use time of personal electronics owned by university students in Jiangsu (unit: years).

| Personal electronics | Range of in-use time | Mode of in-use time | Average age |
|---|---|---|---|
| MP | [0.5,6] | 1 | 1.6 |
| TPC | [0.5,5] | 2 | 1.7 |
| LPC | [0.5,5] | 2 | 2.0 |
| DPC | [0.5,10] | 2 | 3.5 |
| DC | [0.5,8] | 2 | 2.5 |

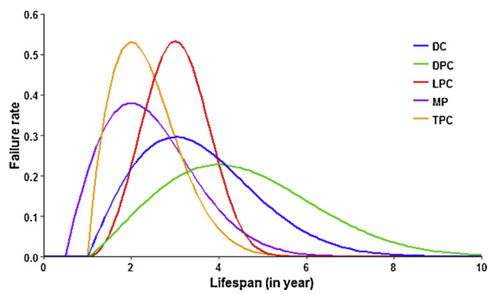


**Fig. 2.** Lifetime distribution of personal electronics possessed by university students.

City in Zhejiang Province (Chi et al., 2014), the lifespans of all personal electronics possessed by university students are shorter, in viewing of the mode of lifetime probability distribution. The difference in the discarding rate indicates that students' electronics consumption/disposal habits are different from average household. When we consider the lifespan of MP in particular, which has been frequently investigated within the context of recycling, although the lifespan in different studies varies between 1.57 to 3.63 years (Murakami et al., 2009; Polák and Drápalová, 2012; Tan et al., 2018; Yin et al., 2014; Bai et al., 2018), our results is close to that of university students in the UK (Wilson et al., 2017), and shorter than most of residential consumers in different regions among the world. For Computer (including DPC and LPC), the comparison between university students and residential consumers shows similar pattern despite less empirical data (Chung et al., 2011; Rahmani et al., 2014).

### 3.2. Characteristics of hibernating personal electronics

The numbers of hibernating personal electronics are presented in Table 5. By and large, the hibernating amount per capita for all 5 categories of personal electronics shows a lower level than in-use stocks. Among the 5 categories, MP has the highest hibernating level of 0.83 unit per capita, while the other 4 categories appear a level of lower than 0.2 unit per capita. Likewise, when taking this as a proxy for all university students in Jiangsu Province, this would suggest a projected quantity of 1.42 million MP, 0.10 million TPC, 0.24 million LPC, 0.33 million DPC, and 0.12 million DC.

However, the average hibernating level of MP is just half of that among university students living within the UK (Wilson et al., 2017). One possible reason is that in China, a considerable part of university students do not own their first MP until they enter the university, and thus there are not so many MP replaced. The hibernating amount of DPC and LPC per student in this research are close to that of Hong Kong per household (Chung et al., 2011), indicating a higher hibernating level of students, given 3–4 people of average household size in Hong Kong.

**Table 5**
The size and duration of hibernating personal electronics.

| Personal electronics | Hibernating units per capita | Average hibernating years till now |
|---|---|---|
| MP | 0.83 | 1.7 |
| TPC | 0.06 | 1.4 |
| LPC | 0.14 | 2.0 |
| DPC | 0.19 | 2.3 |
| DC | 0.07 | 2.6 |

Results on hibernating time show that all types of personal electronics have been retained for less than 3 years, with the longest retaining time close to 3 years (for DC) (Table 5). When presented with the question "when will you dispose of these electronics?", most of participants responded with "I have no idea" or "maybe sometime convenient", indicating they have no direct incentives to reuse or recycle these items instead of accumulating them. Wilson et al. show that the average hibernation span of MP is 3 years for university students across the UK (Wilson et al., 2017). It is thus important to understand what factors affect the students' behavior, and activate these hibernating stocks flowing into recovery systems. Otherwise, the hibernating electronics will probably be discarded by students with their graduation from universities.

### 3.3. Reasons for obsolescence/replacement and hibernation

When university students decide no longer to use an electronic product, their demands for electronics' functions would not disappear. Consequently, the decision is usually accompanied by the replacement of obsoleted electronics with new one. To understand university students' behavior towards obsolescence/replacement and hibernating of personal electronics, respondents are asked three questions as shown in Table S1. The answers of questions are displayed in Figs. 3–5, respectively.

Fig. 3 shows the decision of obsoleting electronics and replacing them with new ones was primarily driven by functional damage (53.2%) of the product. That is, university students buy new electronics mostly because some part of or the whole functions of the electronics have stopped working (They could be repaired but cost too much money). By contrast, the rate of obsolescence of MP due to "functional damage" is lower among university students in the UK (Wilson et al., 2017). Besides, near 30% of respondents claimed that the newly bought electronic products have more functions/features compared to previous ones. To sum up, the overwhelming majority of obsolescence/replacement behavior happened due to the objective inability of the electronics to meet the functional needs of the owner. The option of "out of date in appearance" mostly indicates some electronics are obsoleted for reasons independent of functional or performance issues. Although this category only accounts for less than 20%, it is still noteworthy that these electronics still have usable functions, and have the potential to be reused.

As shown in Fig. 4, among the five disposal options for obsoleted electronics by university students (①selling to individual scrap peddlers; ②giving to others; ③throwing away; ④keeping in the residence; ⑤selling to formal recycling companies), over half of the participants chose to keep them, creating a large amount of hibernating stocks as Section 3.2

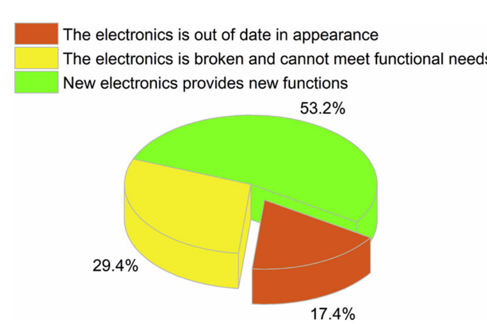


**Fig. 3.** Reasons for obsolescence/ replacement of personal electronics.

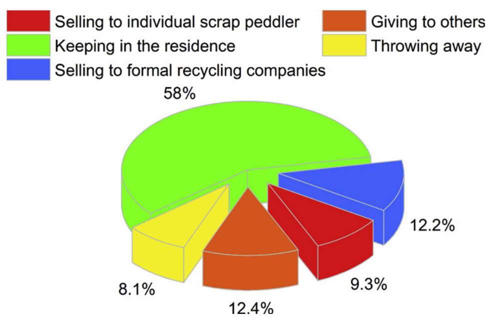


**Fig. 4.** Disposal options for obsoleted personal electronics.

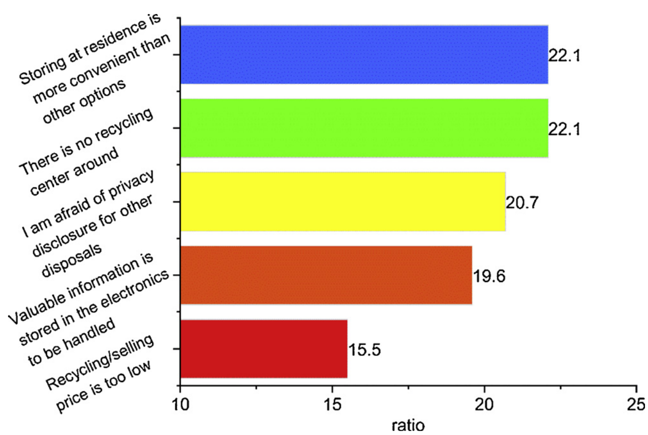


**Fig. 5.** Reasons for hibernating personal electronics.

presented. The ratio of hibernation option is in consist with a research on disposal of MP among university students in the UK (Ongondo and Williams, 2011), but obviously lower than that of total Chinese consumers (79.3%) (Bai et al., 2018). Apart from disparities in survey methods (e.g. different option categories), the contrast may indicate a different attitude of university students towards keeping old electronics. Besides, just 12.2% of university students sold the discarding electronics to formal recycling sectors, slightly higher than informal sectors (9.3%), and 12.4% of respondents chose to give unused electronics to family or friends for second use. Finally, it is found that 8.1% threw their obsolete electronics into general wastes, which accounts for a higher proportion compared to 1.1% from another research on UK university students (Wilson et al., 2017), indicating the need of improving general awareness on electronic waste pollution in domestic universities.

According to Fig. 5, among all the reasons of keeping electronics, the option of “the lower recycling/selling price” was lower than others, indicating that the economic factor was the last consideration when they make a decision of handling unused electronics. With regard to the other four options, lacking convenient recycling facilities is basically an objective cause. Although it needs to clarify that when keeping on asking, more than half of respondents acknowledged that they did not really know whether there is recycling service nearby. Considering it with another option also with the largest share, i.e., “storing is more convenient”, a widely known and convenient recycling channel may obviously downsize the hibernating stocks. Besides, as digital equipment, the electronics usually store personal information of owners, and consumers are often unaware of how to transfer or clear all the information, or they may be afraid of the disclosure of sensitive information even when they have deleted personal information stored on the device. These concerns for information privacy become the second category of cause that hampered the recycling of old electronics. To this end, making more students know how to thoroughly remove personal information stored in these electronics can help to reduce dormant stocks of personal electronics.

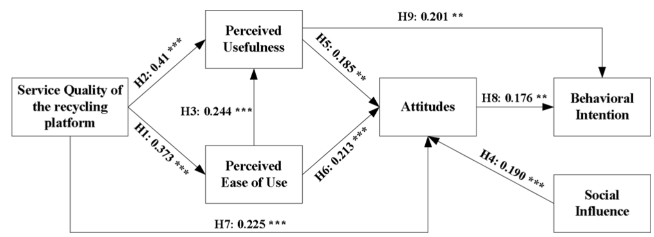


**Fig. 6.** Path coefficient results of model.
Note: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns: not significant

### 3.4. University students’ behavior intention towards using online recycling platform

On a five-level Likert Scale with 1 meaning “completely disagree” and 5 meaning “completely agree”, average scores for the statement to test ATT and BI were both above neutral 3. This suggests that on the whole university students are inclined to adopt the online recycling platform as an option of disposing of hibernating personal electronics.

After measuring the reliability and validity of the collected data (with the details of measurement are presented in Table S3 of the SI), and all hypotheses are supported. The path diagrams obtained by the fit of our model are shown in Fig. 6.

As is shown in Fig. 6, we obtain the general conclusion of TAM that PU and PEOU have a significantly positive impact on ATT and ATT is positively related to BI. By and large, PU was the most important determinant for students’ BI to use online recycling platforms since it also has a direct influence on BI. SQ of the recycling platform could explain a considerable part of the variance of PU and PEOU. When the online recycling platform provides high-quality services with faster response, safer transaction process and stronger functions, users are more likely to perceive the performance improvement of the online recycling service compared to the original recycling channel. Also, when users are provided with high-quality service, they will feel that the online service are easy to use and hold that the anticipated result is more likely to be achieved.

In addition, we can find that SI has an indirect positive effect on BI through ATT. This may be interpreted that sometimes students make decisions based on behaviors of their organizations or influential individuals around them when they are hesitant to use the platform. Besides, students’ attitudes toward recycling are usually affected by environmental beliefs (e.g. everyone needs to do something to protect the earth, or, recycling of unused electronics helps to reduce pollution and resource conservation, etc.), which further will influence their BI to adopt online recycling service.

## 4. Discussions

### 4.1. Valuable resources contained in hibernating electronics

As has been mentioned, personal electronics contain a large number of metals despite their relatively small size, and the concentration of metals (by weight) is usually much higher than that in natural mines (Takahashi et al., 2009). Based on the ownership level of hibernating personal electronics by university students in Jiangsu, the electronics stockpiled by students in higher education in China would include 21.79 million MP, 1.58 million TPC, 3.68 million LPC, 4.88 million DPC, and 1.84 million DC, respectively (although it is understood that this can only be described as an estimate due to sample representativeness). In view of the current recycling scale of 20 million MP in the whole of China annually (Meng, 2017), the hibernating amount is far from negligible. By weight, it means about 58.3 kt of small e-waste is in stockpile (product weight can be found in SI).

**Table 6**
Estimated resources contained in hibernating electronics among university students at national scale.

| Personal electronics | Common metals (kt) | | | Precious metals (t) | | | | |
|---|---|---|---|---|---|---|---|---|
| | Cu | Al | Fe | Au | Ag | Pd | In | Co |
| MP | 2.18 | 0.65 | 1.09 | 0.65 | 43.58 | 37.04 | 24.01 | 348.64 |
| TPC | 0.32 | 0.13 | 1.76 | 0.79 | 3.23 | 0.20 | 0.00 | 0.00 |
| LPC | 0.39 | 0.10 | 1.37 | 0.22 | 1.30 | 0.13 | 0.96 | 73.07 |
| DPC | 1.75 | 0.88 | 4.39 | 1.46 | 7.31 | 0.61 | 0.97 | 0.00 |
| DC | 0.02 | 0.01 | 0.14 | 0.05 | 0.20 | 0.01 | 0.00 | 0.00 |
| Total | 4.67 | 1.77 | 8.74 | 3.17 | 55.61 | 38.00 | 25.94 | 421.71 |

Further, the quantity of valuable resources in these hibernating electronics are shown in Table 6, with metal content of each kind of electronics obtained from relevant literature (Oguchi et al., 2011; Parajuly et al., 2017; Zeng et al., 2015) and details can be found in SI. For basic materials of Cu, Al and Fe, their amount stocked in personal electronics seems insignificant compared to huge domestic output (e.g. the proportion is lower than 0.01% for Cu). As for precious metals, the dormant amount may play a great role. Take Pd for example, its size stocked in hibernating MP can offset total import from other regions of the world (which is 15.5 t in 2015 according to the UN Comtrade, http://comtrade.un.org/), provided that all of them are exploited. In short, the hibernating electronics have relatively high potential as secondary resources of various metals.

From an economic perspective, the valuable resources encased in hibernating electronics worth 1.6 billion US$ in total, according to the price information obtained from Zeng et al. (2015). Of all the materials, precious metals, especially Pd and In, comprise 84% of the total economic potential, which are primarily found in hibernating MP. For common metals, Cu values highest, which mostly comes from MP and DPC. From this perspective, MP may deserve the most attention for recycling because of its large dormant amount and higher content in valuable materials.

### *4.2. Suggestions for recycling of hibernating stocks*

The scale of personal electronics hibernated by university students is considerable as discussed, and will continue to increase, considering the current size of in-use stocks and their shortening lifetime span. These stocks thereby call for a timely attention. Actually, the Chinese government issued a new Catalog of WEEE Recycling (2014 edition) in 2015, which additionally involved typical personal electronics of personal computer (including TPC, LPC and DPC) and MP (Ministry of Industry and Information Technology of the People's Republic China (MIIT), 2015). However, an effective collection and recycling system for personal electronics still has not established.

In the last few years, the concept of distinct urban mines (DUM) has been proposed by scholars (Ongondo et al., 2015). Based on our results, university should be treated as a kind of DUM. Instead of collecting waste electronics based on product type, which is often the case, universities can be utilized as recovery center for the scrap and hibernating stocks of personal electronics. Further effort is needed to investigate the practical feasibility of establishing takeback program, such as organizations or companies in charge, preferred drop-off locations, the exact role that universities should play in this regard, etc. And, as a large number of students will do not know the takeback service, the awareness of such service should be informed through the various media, including TV, internet, and poster/billboard in the universities, etc. Finally, university students could be encouraged and educated to use their electronics longer, as half of the replacement was not driven by physical damage of personal electronics.

In addition to establishing takeback program in universities, encouraging students to use online recycling platforms to handle their unused electronics would be a good alternative. According to results in Section 3.4, in order to prompt the online recycling service as a new disposal way, more efforts should be made by the online platform operators to improve user experience (especially to improve students' perception of the convenience of using the platform for recycling), enhance enterprise image through ads and word-of-mouth marketing outside the university campus. Although university students are accustomed to various online applications and more liable to embrace the new mode of recycling, they still expect high-quality services from new recycling channels. In view of the positive effect of SI on students' BI, the platform can launch campaigns to broadcast the importance of recycling obsolete electronics to the public, especially to university students. Online platforms can also recruit participators of online recycling among university students as references to promote more practice.

## 5. Conclusions

Personal electronics have a short lifespan and comprise substantial contents of valuable materials. And unused personal electronics constitute an important category of urban mines as they are inclined to become idle or discard carelessly. This paper explores the urban mining potential of universities through characterizing in-use and hibernating stocks of typical personal electronic devices among students. Different from previous research, the stocks are characterized from a bottom-up perspective. The behaviors of replacement, hibernation and recycling of personal electronics are also explored.

Our results first suggest that university students have more personal electronics than common Chinese residents on average, and most of these products owned by students are bought after their matriculation. The lifetime spans of all the 5 categories of personal electronics possessed by university students are shorter than that among the general population in China, implying university students' different consumption/disposal habits of personal electronics.

Secondly, the results show that university students stockpile a large size of personal electronics. Among all the 5 categories in this research, MP has the highest hibernating level, while it is still lower compared to results of the UK. All types of personal electronics have been retained for less than 3 years, and most participants have no idea of when to dispose of these electronics. It seems that these hibernating stocks will be discarded after their graduation, unless new incentives drive these stocks flowing into recovery system.

The decision of replacing old electronics with new ones is primarily led by functional damage, and the secondary cause of replacement is functional inefficiency of former electronics. After replacement, over a half of the participants choose to keep old electronics, which causes a huge amount of hibernating stocks. The option of keeping personal electronics is predominately driven by lacking convenient recycling facilities and concerns of information confidentiality.

The findings in this study bring insights into the urban mining potential of universities in China, and provide a theoretical basis for developing effective recycling programs and policies targeting at university students. Firstly, to improve the yields of UM, university can be treated as a DUM. As university students place more weight to convenience than profitability of recycling, establishing a recovery center within or near university for unused personal electronics would be a practical way. Additionally, university students are found to have a positive attitude to the new-emerging recycling channel of online platform, which provides another potential solution for unused electronic products. To promote both of recycling ways, efforts should be made to inform students of the easy access of recycling service, improve the convenience of the recycling process, and arouse their perceptions. Another important move is to widely advocate environmental beliefs and the importance of electronics recycling, especially to educate university students, as recycling is fundamentally a normative behavior (Barr, 2007).

However, there remains several aspects that worth further study. First, university students' disposal behaviors towards different types of personal electronics are discussed as a whole, but there should be some differences between different products which needs to be differentiated in future research. Second, this study explores university students' behavior intention towards using online recycling platforms. However, the behavior intention is just a proxy for predicting the behavior, and it does not necessarily guarantee students will participate in the recycling practice (Barr, 2007). Further study should also explore the degree to which these intentions might influence behavior, and how to motivate students' behavior intention into actual recycling actions.

## Declarations of interest

None.

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## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.resconrec.2019.01.007.

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