Is the private sector more efficient? Big data analytics of construction waste management sectoral efficiency

Jinying Xu[a], Weisheng Lu[b*], Meng Ye[c], Fan Xue[d], Xiaoling Zhang[e], and Billy Fook Pui Lee[f]

This is the peer-reviewed post-print version of the paper:

Xu, J., Lu, W., Ye, M., Xue, F., Zhang, X. & Lee, B. F. P. (2020). Is the private sector more efficient? Big data analytics of construction waste management sectoral efficiency. *Resources, Conservation and Recycling*, 155, 104674. Doi: 10.1016/j.resconrec.2019.104674

The final version of this paper is available at: https://doi.org/10.1016/j.resconrec.2019.104674.

Highlights

- Big data can distinguish the public and private disparity with better certainty.
- Overall, public and private sectors have no significant CWM efficiency difference.
- The private sector outperformed their public counterpart in demolition projects.
- The public sector performed superior in foundation and new building projects.

[a] 7/f, Department of Real Estate and Construction, The University of Hong Kong, Pokfulam, Hong Kong, China. Email: jinyingxu@connect.hku.hk
[b] 7/f, Department of Real Estate and Construction, The University of Hong Kong, Pokfulam, Hong Kong, China. Email: wilsonlu@hku.hk
[c] 7/f, Department of Real Estate and Construction, The University of Hong Kong, Pokfulam, Hong Kong, China. Email: megan828@connect.hku.hk
[d] 5/f, Department of Real Estate and Construction, The University of Hong Kong, Pokfulam, Hong Kong, China. Email: xuef@hku.hk
[e] Yeung-B7309, Department of Public Policy, The City University of Hong Kong, Kowloon Tong, Hong Kong, China. Email: xiaoling.zhang@cityu.edu.hk
[f] Room 1202, Carnival Base Company Limited, Tsuen Wan, Hong Kong, China. Email: fplee@carnivalbase.com.hk
[*] Corresponding author.

Abstract

Efficiency disparity between the public and private sectors is a non-trivial issue that concerns fundamental choices of socio-political-economic systems. Waste management academia and industry also wrestle with issues relating to the choice between public and private sectors. To examine the disparity exclusively caused by "sector", in statistics language, one needs data that is sufficiently big to control many other confounders, e.g., sites, project types, and construction technologies. This paper attempts to ascertain the construction waste management (CWM) efficiency disparity between the public and private sectors by using big data in Hong Kong. The waste disposal records of 132 projects, including 70 public and 62 private projects, were extracted and analysed. By comparing the waste generation flows (WGFs) and accumulative WGFs, it is found that, by and large, there is no significant efficiency disparity in CWM between the two sectors. However, a closer investigation discovered that the private sector outperforms their public counterpart in demolition projects, while the latter performs better in foundation and new building projects. Although there are private projects with higher CWM performance, their divergence between the best and average projects are larger than public ones. Such findings thus reject casual remarks that the private sector is more efficient in CWM. The underlying reasons maybe the waste management index practice promoted in public projects while the private sector is often incentivized to perform better CWM to save waste disposal levies. Future research is recommended to delve into the causes of the efficiency disparity and introduce CWM interventions accordingly.

Keywords: Public-private disparity; economic efficiency; construction waste management; big data; Hong Kong

Introduction

Whether the public sector is more efficient than its private counterpart, or vice versa, is a non-trivial concern in many fundamental choices related to our political, social, and economic systems (Sappington and Stiglitz, 1987; Meier and O'Toole, 2011; Mihaiu et al., 2010). Majority of such research usually conducts comparative analyses, either qualitatively or quantitatively, of the effects obtained in resources used. The comparisons even have an implication to the choice of capitalism and socialism, privatization and nationalization in the institutional economics. However, the debate on comparisons of private and public efficiency has not been concluded. The comparison between the dynamism of private sector and the inefficiency of public sector has been the principal political dogma of the past decades (Busch and Gustafsson, 2002). The fanatic of private sector superiority acclaims that the compared to public sector, private sector is more efficient and dynamic, while the public sector is slower and more wasteful; that a higher proportion of private sector participation will make things better (Simms and Reid, 2013). The neoliberalism also puts superiority in the private sector, arguing it being efficient, dynamic, and modernize. While capitalism adherents are convinced by the public sector with evidences that towering debts have been run up under privatization and tremendous services are being brought back into public ownership. They think privatization *per se* does not guarantee improved efficiency. There are also more and more standpoints disputing that privatized services perform worse according to largest studies. The reasons driving the efficiency disparity between the public and private sectors can be multiplex, ranging from institutional, managerial, technical, and organizational, to information accessibility aspects (Ring and Perry, 1985; Sappington and Stiglitz, 1987; Bretschneider, 1990; Boyne, 2002; Bysted and Hansen, 2015).

Concerning the efficiency disparity between the public and private sectors, there are a rich vein of works on different aspects. Some economists, from a theoretical perspective, have advanced a strong argument that private firms are more efficient than public firms (Alchian, 1965; De Alessi, 1974; Sheshinski and Lopez-Calva, 2003). They emphasized the importance of non-transferability of ownership and weakening of property rights in public sectors in support of the efficiency disparity between public and private sectors. However, the priori theorized view is weak in empirical confirmation with inconclusive results. Das (2012) confirms that in the mining industry, the participation of the private sector can boost the overall productivity by comparing the extraction efficiency of public and private mining firms. Bhattacharyya et al (1994), on contrary, by analyzing public water utilities practice projects, offer evidence of higher efficiency in public sector although they are more widely scattered between best and worst. More empirical studies reveal that there is no convincing evidence of one form of ownership systematically surpassing over another. For example, Byrnes et al (1986) failed to find any evidence to support the superiority of privately owned utilities over publicly owned ones by measuring efficiency directly in terms of a production function in the water utility industry. The same result goes to Estache and Rossi (2002), who also choose samples of water companies. Karas et al (2010) provide the results that the Russian public banks are not more inefficient than private ones.

When shifting to the area of waste management, the empirical studies on the public-private argument are limited (Xu et al., 2018). Ichinose et al (2013) find that prefectures where private sector participated in household solid waste collection with a higher proportion are more efficient from the solid waste logistics practices in Japan. By conducting case studies of waste management in Lebanon, Massoud et al (2003) suggest a mixture of private and public sectors without distinguishing the efficiency disparity between the two. Simões et al. (2012) evaluated the productivity and efficiency of the waste sector based on 228 waste collection and treatment utilities and that private sector participation does improve the efficiency in waste collection but benefits ephemerally in waste treatments. Massoud et al. (2003) suggested that, from the cost perspective, private sector provided services were between than public sector provided ones based on the comparison of municipal solid waste collection in two largest cities. Jacobsen et al. (2013) also reached a similar conclusion by the analysis of multiple household waste collection service cases. Lu et al. (2016) applied the Coase Invariant Theorem as a guiding theory to examine potential waste management performance disparity among the public and private construction clients. Therefore, the debate on the efficiency disparity between public and private sectors is far from concluding. Especially, when narrowing down to construction waste management, confident answer is due with the support of empirical research.

According to previous research, the answer to the debate of efficiency disparity between the public and private sector in waste management with empirical supports is still missing. This paper aims to fill this research gap by answering the question whether the private sector is more efficient by using big empirical data reflecting waste management performance in Hong Kong's construction industry. Empirical big data analytics from real cases of housing development will be adopted as the research method. There are two rationales behind this research method. First, it is to make the classic inquiry more manageable by narrowing the scope down to construction waste management (CWM), which is one of the most oft-examined areas concerning efficiency disparity between sectors. In contrast to previous studies, the research reported here seeks to understand the specific question of efficiency disparity of CWM between the public and private sectors. Second, it is to make good use of a set of big data of CWM in Hong Kong, and other useful information, such as the project location and features, that will guide better business predictions and decision-making (Lu et al., 2015). It is anticipated that big data can help uncover hidden patterns and unknown correlations, control the numerous factoring confounding the efficiency of an economic system to allow the exclusive contribution of "sector" to surface. To this end, this paper aims to contribute to the general question of efficiency disparity between sectors by introducing big data analytics, hoping that big data can open a new avenue, through which the classic question can be brought to a conclusion.

To be specific, the authors plan to select representative housing construction projects from both the public and private sector, extract their waste treatment data from the open data sets, and conduct comparative analyses of the public and private sector. The detailed research methods will be explained in the Data and methods section. The rest of the paper is organized as follows. After the introductory section is a brief literature review focusing on how big data can be used in applied statistics to examine the classic question of efficiency disparities between sectors. Section 3 presents the big data and the data processing methods, which include standardization of the project data for visualization and statistical analyses. Section 4 is to report the data analyses, results, and findings, followed by an in-depth discussion in Section 5. Conclusions are drawn in Section 6.

Big data and better certainty

A consensus on the definitions of "big data" is yet to be reached. Researchers are converged to adopt Gartner's three definitional characteristics of big data: volume, variety, and velocity (McAfee et al., 2012). Volume indicates the large quantity of the data; velocity indicates that the data is incoming in a high speed, which requires prompt processing to harness its value; and variety indicates big data must be rich in semantics in the forms of structured, unstructured, semi-structured, or a combination thereof (Russom, 2011; Zaslavsky et al., 2013). In view of the fact that big data does not mean quality data, researchers are increasingly emphasizing 'veracity' - how accurate or truthful a data set may be - as the fourth 'V" of big data. Big data analytics have been developed to analyze big data in order to discover hidden patterns, non-linear relationships and casual effects that will guide better informed decision-making (Lu et al., 2015). Likewise, according to Agrawal (2016) and WEF (2012), big data can lead to some potential knowledge or guidance information that can be utilized for further decision-makings. Hence, value is advocated as the fifth 'V' of big data.

Lu et al. (2018) critiqued that too often big data analytics is mistakenly associated with 'pattern detection algorithms', 'unsupervised machine learning', 'deep learning', 'artificial intelligence', NoSQL database, Hadoop, and other fascinating data mining methods. Instead, they echoed with Leek (2014) that applied statistics should not be left out when harnessing the value of big data. In the history of probability theory, there is a "law of large numbers", which is a theorem that describes the average value of the results retrieved from a large number of trials should be close to the expected value and will become closer when more trials are conducted (Sen and Singer, 2017). If treating an economic sector as a complex system, it would be legitimate to expect that big data can approach the entirety of the sector as it operates (i.e., tries naturally), and allow the inquiry of their efficiency disparity, if there is any, to be ascertained.

The potential of big data to ascertain something in a complex system is further hyped in stories of the psephological analysis of big data about voter behavior, such as Donald Trump's election campaign in 2016 and Brexit in the same year. These scenarios present a lot of uncertainties, e.g., to vote or not, or to leave or to remain. It has been reported that Cambridge Analytica, a data analytics company, can understand the scenarios with greater certainties with its enormously voluminous and various big data. Actually, they were reported to manipulate the public towards a more certain direction which was wanted by their clients. Inspired by the stories, big data analytics may open a new avenue to examine the classic inquiry on efficiency disparity between the public and private sectors. In statistical language, the data, if big enough, can control the numerous confounders to examine the efficiency disparity that is solely contributed by "sector". This potential, however, has not been well explored in the literature. It is under the potential that this paper tends to examine the CWM efficiency difference between the public and private construction objects.

Data and methods

Data

The Hong Kong Environmental Protection Department (HKEPD) launched a Construction Waste Disposal Charging Scheme (CWDCS) in 2006. It requires that all construction waste, unless being reused or recycled, must be disposed of at designated government waste disposal facilities such as landfills, public fills, or off-site sorting facilities. Prior to using the facilities, a main contractor who is awarded a contract with more than HK$ 1 million is mandated to open a billing account in the HKEPD for the contract solely, with basic information of the project including the contract name, client (e.g., public or private), contract sum, site address, type of construction work, etc. When the construction waste is disposed of at the facilities, HKEPD records information on every load of construction and demolition waste, including vehicle number, time, and weight when the vehicle enters and exits, and the billing account number the vehicle uses. Unintentionally, the practice in Hong Kong generates a large data set which makes probing into many aspects of CWM, such as the performance of public and private projects. Figure 1 illustrates the structure of the data sets, which contains the following five types of databases:

- *Project* database, contains basic information (including site addresses, clients, project types, and other details) of all projects with an account to access the above government facilities for waste disposal. There are a total of 27,536 construction projects being recorded in this database.
- *Facility* database, contains basic information (address, capacity) of all government CWM facilities.
- *Vehicle* database, contains 9,863 waste hauling vehicles for construction waste transport.
- *Waste Disposal* database, records detailed information of every truckload of construction waste disposed at the government waste management facilities. There are a total of 7,866,085 disposal records being generated by all the construction projects executed during the eight-year period from 2011 to 2018.
- Moreover, the Hong Kong Buildings Department (HKBD) keeps the *Building* data of all existing and new building projects, including the address of the site, number of blocks and storeys, building type, domestic and non-domestic gross floor area (GFA). The data can also be integrated with the waste disposal data above.

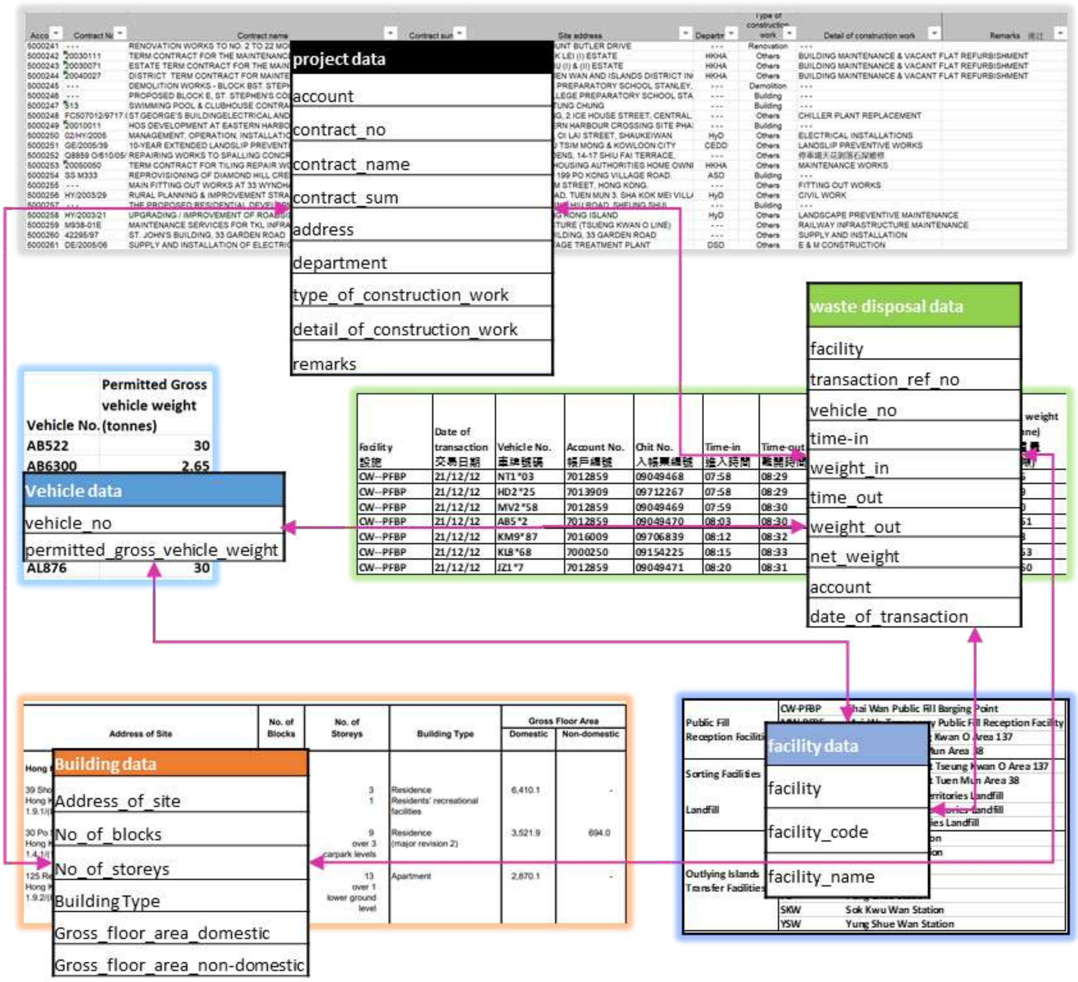

Figure 1. The big data set

It is argued as big data, according to the five 'Vs' criteria as described above, despite the volume is not as big as terra- or zetta-bytes. It is also argued that big data should not be mechanically equated to big volume, but it covers a fuller picture of the subject matter that is not possible provided by small data.

Data processing methods

The data processing methods, as illustrated in Figure 2, comprises of eight connected steps ranging from project selection, data extraction, processing, visualization, to detailed comparisons.

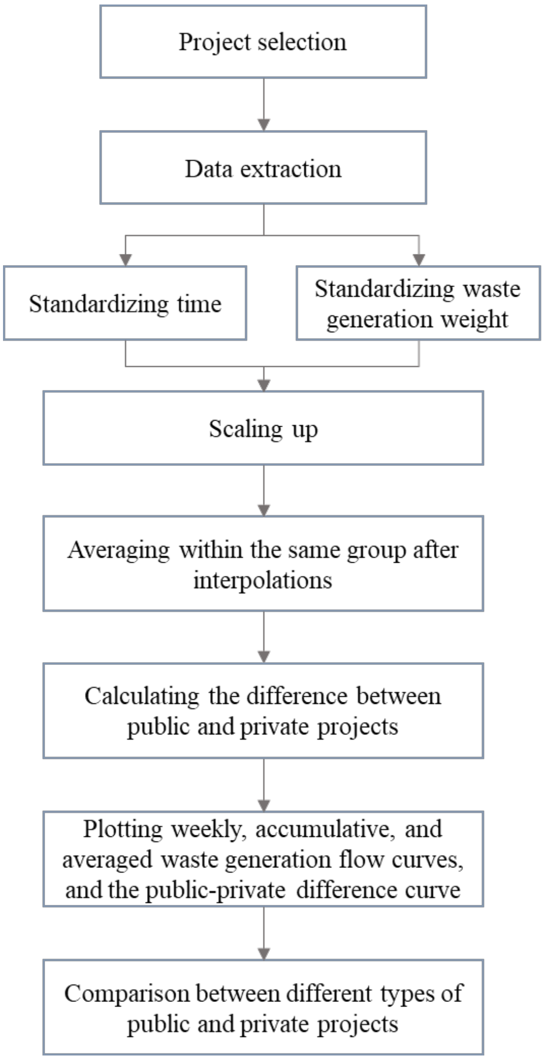

Figure 2. The procedures of data extraction and analysis

Project selection

The first step is to select projects for the analysis. A set of 'qualified" projects is selected from the big data set by meeting the following criteria:

(1) The project must be started after 2011 and finished before 2019 to be reflected completely in the big data set;

(2) Project type is restricted to demolition, foundation, and new building, as these types of projects are the major source of construction waste; and

(3) The project must be relatively sizeable, as these projects allow more regular patterns than their smaller counterparts, which are often impacted by random factors.

By applying the three criteria, 132 projects, including 19 demolition, 59 foundation, and 54 new building projects were sourced. They can be further divided into two groups: 70 public and 62 private projects. Basic information of the selected projects is shown in Table 1.

Table 1 Basic information of the selected projects

Project type	No. of projects	No. of raw records	Contract Sum (HK$)	Project duration (weeks)	Average project duration (weeks)
Public demolition	8	2,734	[1016392, 19008080]	[7, 30]	16.9
Private demolition	11	10,289	[15756600, 55166000]	[28, 155]	55.9
Public foundation	31	238,039	[4404854, 923000000]	[40, 173]	78.8
Private foundation	28	200,075	[94022505, 644652285]	[41, 161]	77.0
Public new building	31	232,393	[339388300, 4711780000]	[109, 441]	220.0
Private new building	23	49,684	[36890955, 3780000000]	[52, 398]	171.1
Total	132	733,214	[1016392, 3780000000]	[7, 441]	122.0

Data extraction

With the account number of the selected projects as the reference, the waste disposal records of the project can be queried and extracted from our database. The query is done by SQL server. Afterward, all the extracted data are sorted on the project basis.

Standardizing time and waste generation weight

Since projects are different from each other in terms of project duration, the first step to process the data is to standardize the time to make the projects comparable. The time of a project is counted from its first record of waste disposal. For example, if the first record of Project A is the 27th week of 2015, then we count from week 27 of 2015 and calculate the following time based on this baseline. Suppose Project A ends at 10th week of 2017, then the duration of Project A is 87 weeks taken that one year is 52 weeks. Different projects may start from a different time, which means their baselines are different. The time is then standardized by percentage, see formula (2):

$$T_i\% = {t_i}/{T} * 100\% \qquad (2)$$

Where t_i is the time point of a project; T is the total time of the project

Take Project A as an example, T = 87 weeks, the standardized time of the second week is $T_2\%$ = 2/87*100% = 2.3%. The above standardization method is on a weekly basis. Actually, the data available allows to do it on a daily basis, but it turned out to be “over-engineered” by having so many days. It is also too sparse to examine waste generation on a monthly basis, therefore, the weekly scale is used.

Meanwhile, waste generation weight is also standardized, as the weight could range radically from one project to another depending on their size. The approach is to treat the total weight of waste generation of a project as 100%, and the weekly generation as a certain percentage of the total waste generation of that specific project. Adding together the construction waste weight of every vehicle using the same account number at one day, the total waste disposed of by the corresponding project at that day can be calculated. The construction waste of every project is further calculated on a weekly basis for easier analysis. The weight of weekly construction waste was further accumulated to calculate the waste generated until a time point.

The ratio of the disposed waste at the corresponding week in the total waste generation of the project is calculated using formula (3):

$$r_i\% = {w_i}/{W} * 100\% \qquad (3)$$

where r_i is the percentage of total waste generation at week i, w_i is the waste generated at week i, while W is the total waste generation.

By using the $T_i\%$ as the x-axis and the $r_i\%$ as the y-axis, the waste generation flow (WGF), which portrays the changing of construction waste generation ratio with the changing of time, can be plotted. The WGF curves can provide a clear and general visualization of the waste generation performance of projects at different stages.

The accumulative percentage of disposed waste till week j is calculated using formula (4):

$$AP_i\% = \sum_1^j r_i * 100\% \qquad (4)$$

where AP_i is the accumulative percentage of waste generated till week i, p_i is the percentage of total waste generation at week i.

Similar to WGF, applying the $T_i\%$ as the x-axis and the $AP_i\%$ as the y-axis, the accumulative waste generation flow (accumulative WGF) can be drawn. Different from WGF, an accumulative WGF curve brings a straightforward illustration of how waste is accumulated during the project developing process, serving as another important indicator of construction waste management efficiency.

Plotting weekly and accumulative WGF curves

With the standardized time ($T_i\%$) as the x-axis, percentage of total waste generation ($r_i\%$) as the y-axis, the weekly WGF curves can be drawn. Replacing the percentage of total waste generation ($r_i\%$) with accumulative percentage of total waste generation ($AP_i\%$), the accumulative WGF curves can be portrayed.

Scaling up

The same approaches of data extraction, time and waste generation weight standardization and WGF curve plotting are applied to all other projects. The data processing, analysis and scaling up take place in Microsoft Excel 2016. Projects of the same type (there are a total of six types of projects, e.g., public demolition, private demolition, public foundation, private foundation, pubic new building, private new building) are arranged together for the representative WGF curves for comparisons and analyses.

Averaging waste generation proportion with interpolation

To compare between the public and private clients, a representative curve for one type of projects is desired. Since different projects have different time scale, all the project should be averaged on a unified time scale. A 0.1% of scale is used to standardize the timeline to keep the resolution of the data better. For the waste generation percentage at every time point, the percentage covered a period is averaged under the assumption that the waste is evenly generated for that period and then be disposed of once. For example, project B disposes of 15% of waste at 25% of time after its last disposal at 15% of time, then, for every 0.1% of time between 15% and 25% of the completion time, the averaged waste generation proportion is 15%/(25%-15%)*0.1% = 0.1%. By this averaging calculation, every project has its averaged waste generation percentage at a 0.1% time point. Averaging the averaged waste generation percentage of same type projects at every time points, an average waste generation percentage value as their representative can be generated. For the accumulative WGF, linear interpolation is used to fill the vacant value for the 0.1% of time scale representation. After acquiring all the points on a 0.1% of time basis, the representative WGF and accumulative WGF curves can be plotted.

Calculating the difference between the public and private sectors

After the interpolation, every type of project has a representative set of WGF and accumulative WGF data set on the 0.1% time scale. Therefore, their difference can be calculated directly by doing minus between the two sectors. Since this paper aims at investigating if private sector outlaws, metrics of the private sector is used to minus that of the public sector and keep their difference as the indicator of their waste management efficiency disparity.

Comparison

After processing the data, the results of public projects and private projects are compared separately. Firstly, the overall waste generation rate (WGR) of all projects will be calculated and displayed to investigate whether their WGRs have a significant difference. Afterward, the WGFs and AWGFs of the public and private sector of demolition projects, foundation projects, and new building projects will be compared one by one to examine their waste management performance disparity.

Microsoft Excel 2016 is used to process and analyze all the data and further draw the figures. It is capable of dealing with big data when the data is structured and can be converted in different worksheets even for a 1-million-row dataset. Our 12,828-row data is structured and can be converted between different worksheets and calculated easily using simple formulas. By drawing the WGFs and accumulative S-curves, how the waste is generated during the whole process of the project can be delineated.

Analyses, results, and findings

Demolition projects

Figure 3 displays the contrast between the WGFs in the 8 public and 11 private demolition projects. The x-axis is the standardized time, and y-axis the standardized waste generation percentages. Both types of projects have their own patterns as shown in Figures 3 (a) and (b): private projects have evenly distributed proportions except three outliers; public projects have more randomly distributed ratios with the change of time. By contrast, the weekly waste generation percentages in public demolition projects are generally larger than private ones and fluctuate more obviously. It is largely due to the longer duration and larger waste disposal times of most private projects than the public projects. Figure 3 (c) is the comparison of the average percentage of total waste generation between public and private demolition projects on a 0.1%-time basis. On this meticulous time scale, the averaged WGFs of both types of projects fluctuate dramatically. At the first 15% of the time, public demolition projects generate a much larger proportion of waste than the private. Afterward, they change alternatively until around 80% of the time, when private projects produce wastes at a far higher speed. These findings indicate the better control of waste generation in private projects at early and middle stages.

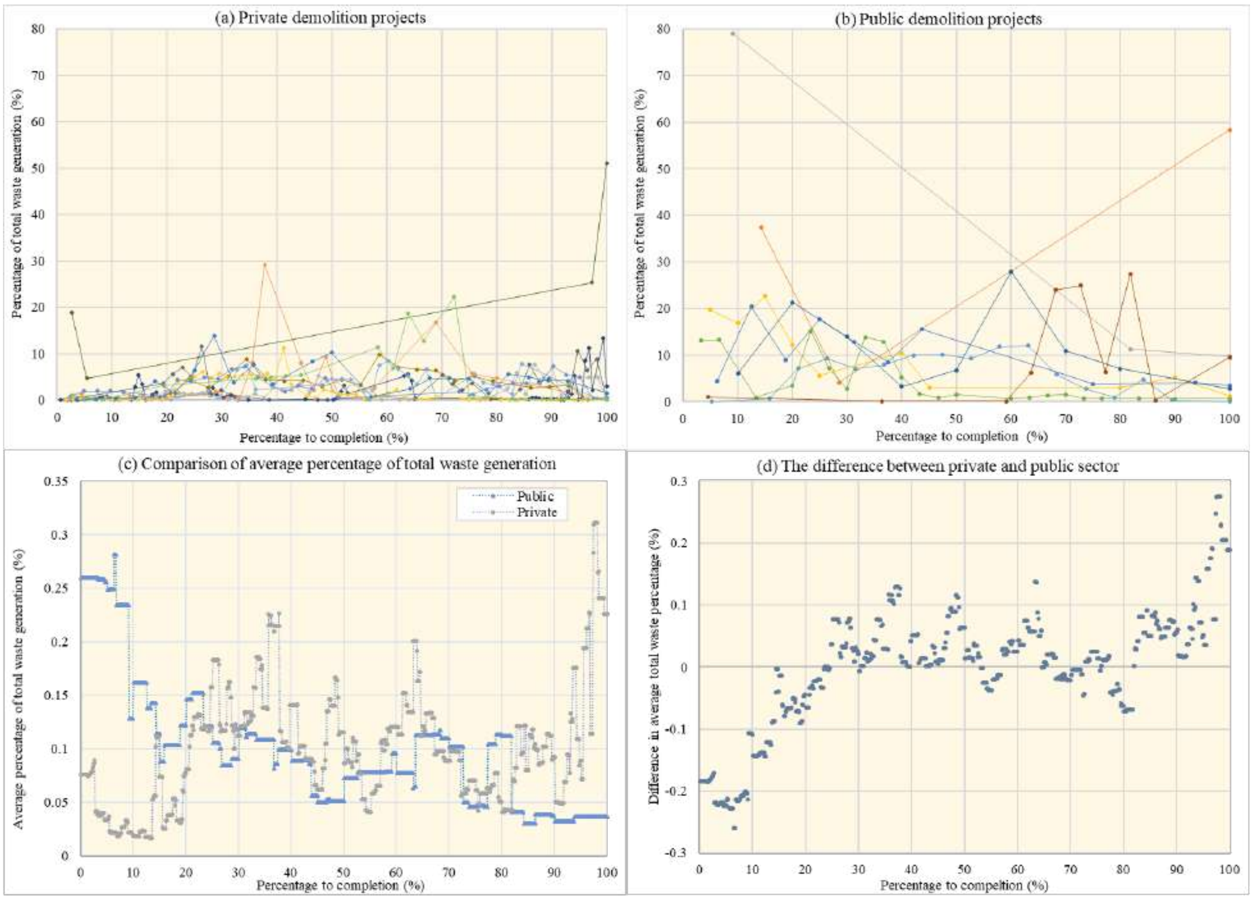

Figure 3. Waste generation flow of public and private demolition projects

Figure 3 (d) further compare the private and public projects by showing their difference with the changing of time. The y-axis is the difference between private and public average waste generation percentage. The difference also waves greatly. Generally, it increases rapidly at 25% of progress, then fluctuates gently to 80% of the time, and increases at high speed again in the final period. Such results indicate that private projects generate wastes in a slower way at the beginning but faster at the late stage than the public projects. However, the difference is actually small within the range of 0.3% of total waste. A t-test (two samples assuming equal variances) on the average percentage of total waste generation proves that the two sectors perform equally (mean average percentage of total waste generation for public projects is 0.001 and private projects 0.000999) with no significant difference (P=0.971). From this aspect, the performance of the public and private sector in demolition waste management projects have no substantial dissimilarity.

The accumulative waste generation curves of public and private demolition projects are shown in Figure 4. Different from Figure 3, the y-axis of Figure 4 is the accumulative waste generation percentage. It is easy to recognize their difference from Figures 4 (a) and (b): the shapes of private curves are more concentrated while public projects vary greatly from each other. To compare their differences, the average accumulative percentage on a 0.1% of time basis of all public demolition projects and all private demolition projects are calculated separately and then plotted in the same figure, see Figure 4 (c). The dots are the actual averaged accumulative waste generation ratios of public and private projects at different time points. Combining the four sections in Figure 3, it can be interpreted that for private projects, the accumulative waste generation is less than 10% in the first 20% of the time for most projects. Afterward, the difference in waste generation speed among projects varies. For public projects, the situation diverges more fiercely. The two curves in Figure 4 (c) is sketched by the averaged accumulative percentage of waste generated after linear interpolation on a 0.1%-time basis. It represents the difference between the public and private projects: the averaged accumulative waste generation of public projects is higher than that of private ones. This difference is rooted in the early stages of the first 20% time and keeps until 80% of the time when the difference is narrowed. Figure 4 (d) illustrates the difference in a more straight-forward way. Public projects cumulate an average of nearly 30% more waste than private projects in the first 20% of the time. Afterward, their difference narrowed in ups and downs. These features also echo the findings of WGF comparisons.

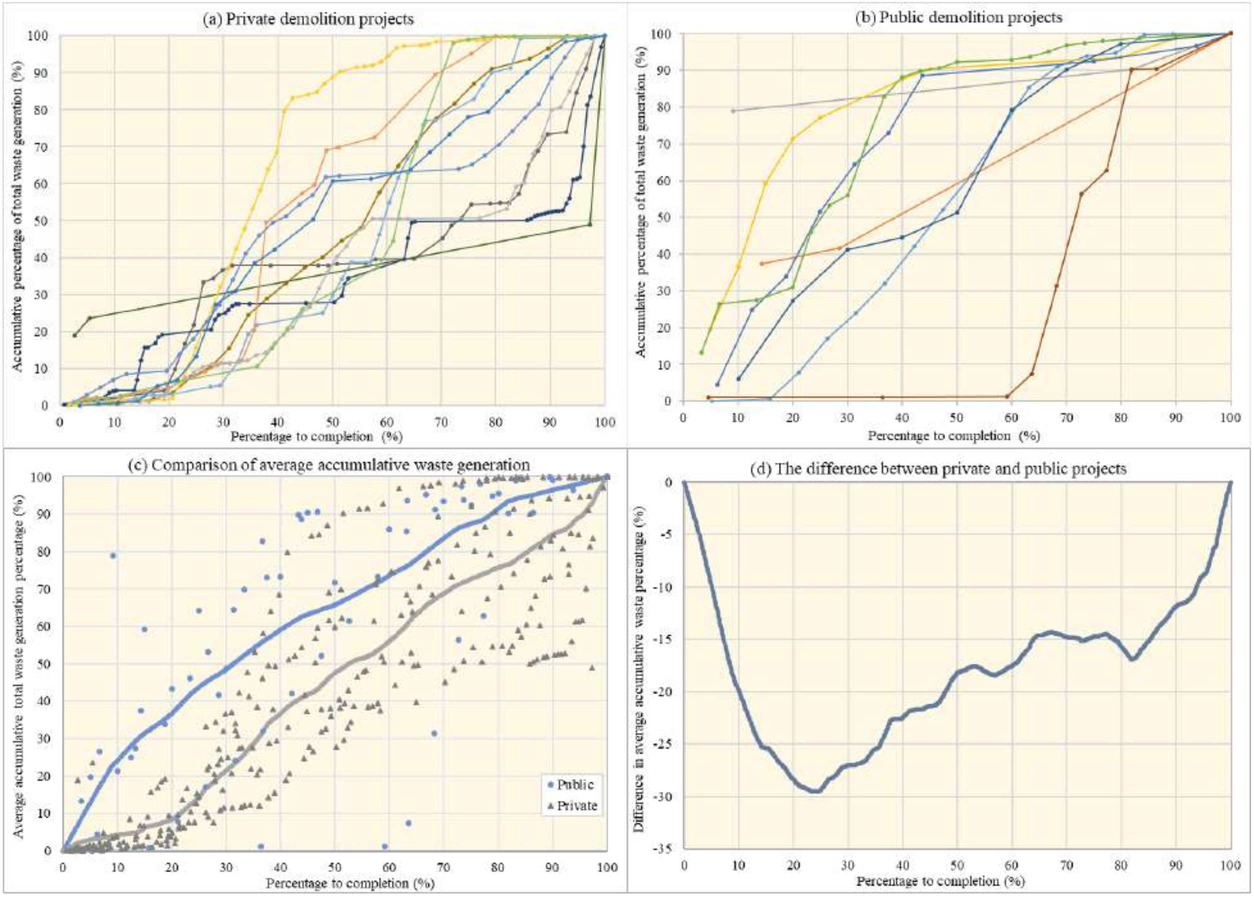

Figure 4. Comparison of accumulative waste generation flow of public and private demolition projects

Interpreting the finding from the comparisons of WGF and accumulative WGF between demolition projects, the answer to the question "is the private sector more effective" is that the private and public sector has no significant difference in waste management performance of demolition projects. Yet, the investigations into details indicate that private sector control of WGF during the demolishing process is more effective than the public. The waste management performance here is considered by the control of waste generation. Moderate waste generation is better for the capacity planning of waste disposal facility and the transportation arrangement of contractors. Speedy waste generation in a compact society like Hong Kong will cause pressure to public transportation, environment, as well as the waste disposal facilities. Besides, the variance among private projects is much smaller than public projects. It implies the consistency in waste management performance, which is critical for waste management prediction and planning.

Foundation projects

The changes in the weekly percentage of total waste generation over time in foundation projects are displayed in Figure 5. Figures 5 (a) and (b) show that there are some similarities and differences in the WGFs of private and public projects. For most of the recorded points, the percentage of total waste generation is less than 5%. More private projects have a high waste generation proportion at the middle stage than public projects. Also, the peaks of the public projects come later, one at 26% of the time and the others around 60-80% to completion. Figure 5 (c) further depicts their difference, which changes moderately with some big waves. A more clear-cut result of the contrast is presented in Figure 5 (d). By and large, public/private projects exceed the other alternatively within the range of 0.1%. Private projects outpace public ones on the waste generation speed for a larger proportion of time at early, middle, and later stages. Even though, a t-test on the average percentage of total waste generation by assuming a null hypothesis that the two means are equal shows that the two sectors perform the same in foundation projects on the aspect of waste management with the p-value being 0.97. The mean percentage of total waste generation is 0.099 for public projects and 0.099 for private projects.

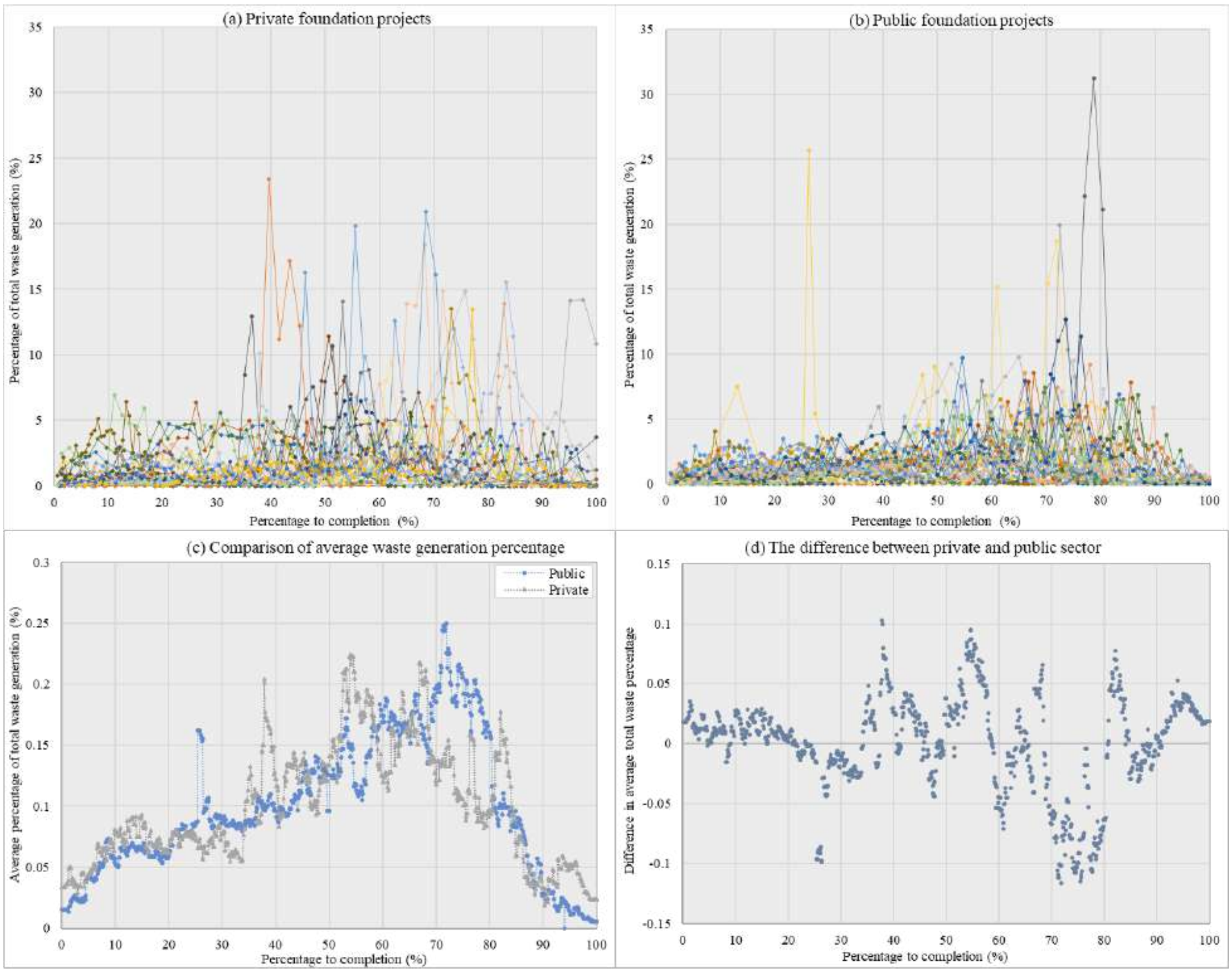

Figure 5. Waste generation flow of public and private foundation projects

Figure 6 illustrates the accumulative WGFs of public and private foundation projects. Obviously, the distribution of the S-shape curves of public projects are more focused while the private ones are sparser, as shown in Figures 6 (a) and (b). This major difference implies that public projects are more standardized in waste management while the performance of waste management in private projects staggers with each other. Figure 6 (c) further compare the two sectors by contrasting their averaged accumulative percentage of total waste generation. The distribution of dots demonstrates that private projects have more scarce distribution in accumulative WGF, which is also evidenced in Figures 6 (a) and (b). The interpolated average S-shape curves in Figure 6 (c) advance the comparison in a more pruned way. In general, the gap between the public and private sector in foundation projects is slight when compared with demolition projects. The accumulative percentage of total waste in private projects is larger than that of public projects for most of the time. Figure 6 (d) shows the difference in average accumulative waste generation percentage in a simple and direct way. At the peak of the curve, private projects cumulate an average of 6% more waste at the middle stage. Public projects reverse the trend at 75% of the time and reach the biggest difference of 3% accumulative waste at 80% of the time.

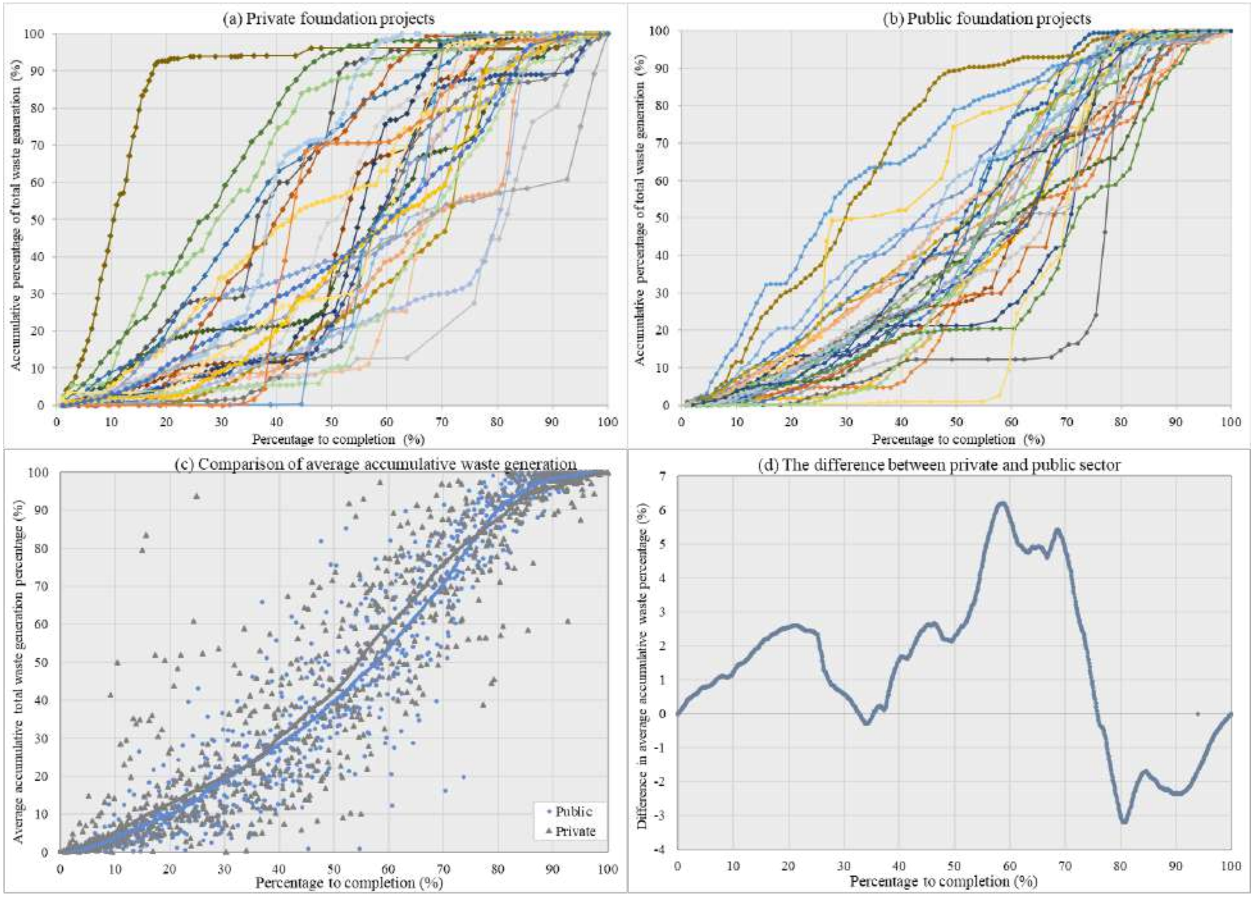

Figure 6. Accumulative waste generation flow of public and private foundation projects

Closer probes into the comparison between the projects of the public and private sectors do disclose some differences. The averaged WGFs and their difference curve illustrate the divergences in waste generation efficiency between the two sectors: the public sector has a smaller extent of variation than the private sector. The accumulative WGFs corroborate this inference. Though averagely, the accumulative WGFs has a minor difference, the variance among private projects is greater. On this aspect, the public sector has more consistent waste management performance to a small degree.

New building projects

The WGFs of public and private new building projects are illustrated in Figure 7. Figures 7 (a) and (b) demonstrate that the waste generated in one week is less than 5% of the corresponding total waste amount for most projects, be they public or private. Four private projects produce more than 15% of total waste in one week, but their peaks happen at different time. No public projects generate more than 10% of waste in one week, and their peaks also occur at different time ranges. The difference is that all peaks happen before 72% of public projects progress while randomly in private ones. The reason behind can be the standardization of public projects which will result with controlled waste generation at early and middle stages while the divergent standards among private projects themselves lead to the waste management efficiency disparity. To better detect the difference between public and private projects, the averaged WGFs are plotted on a 0.1% basis, as shown in Figure 7 (c). At the very early and late stages, the difference is obvious: private projects generate waste quicker than their public counterparts. But at middle stages, public projects generate more waste than private ones. Therefore, Figure 7 (d) gives a clear and direct way to expand the comparison. Although for most of the time, their difference fluctuates alternatively, it keeps within 0.1% for most of the time, which is very slight. It is hard to compare the overall performance of the two-sector; thus, a t-test on the average percentage of total waste generation is conducted. It indicates that the two sectors have no significant difference in the average waste generation speed with a two-tailed p-value of 0.892. Their means of average waste generation percentages are 0. 998 and 0.996, for public and private sector respectively.

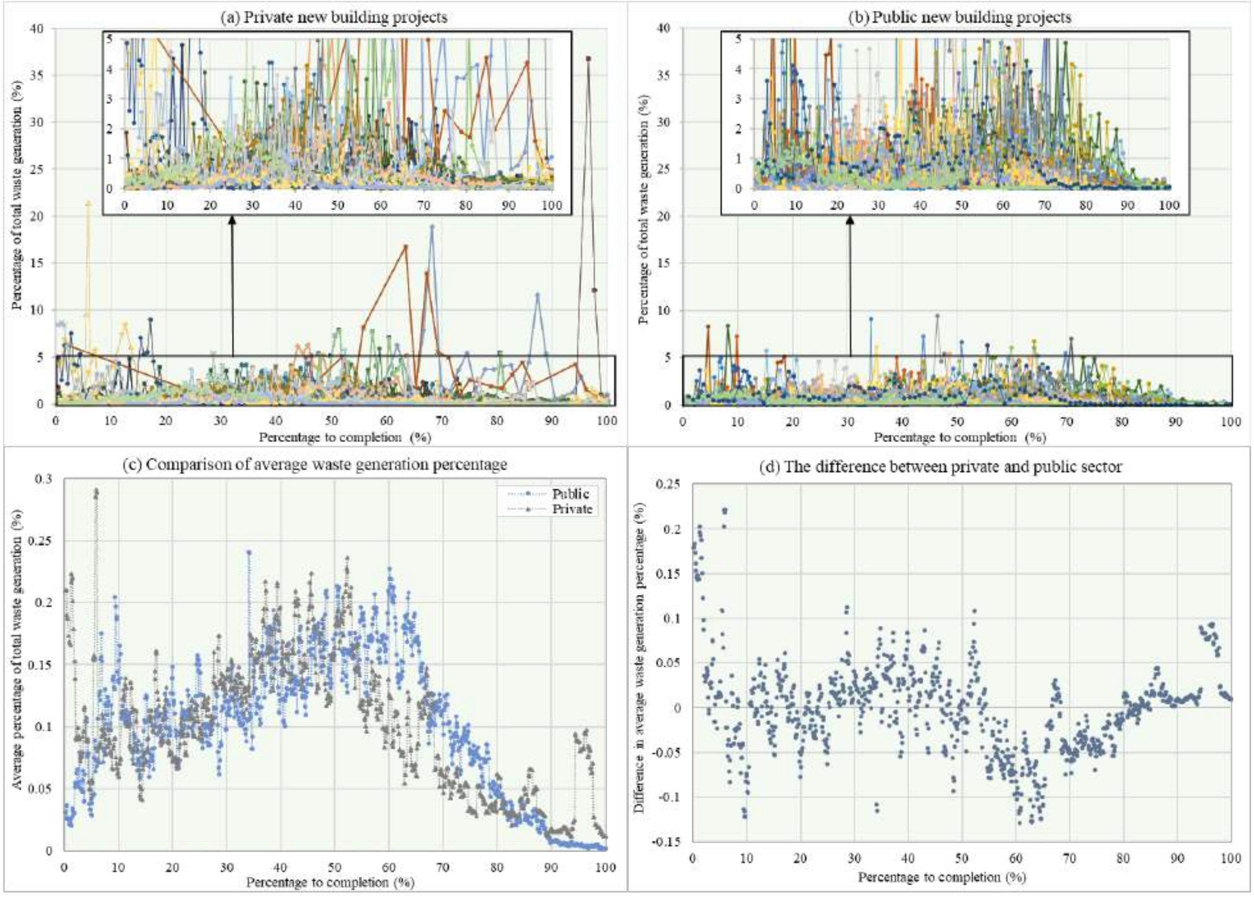

Figure 7. Waste generation flow of public and private new building projects

The accumulative waste generation curves of public and private new building projects are demonstrated in Figure 8. Similar to foundation projects, the distribution of the S-shape curves of public projects are more concentrated while the private ones are more diverse, as shown in Figures 8 (a) and (b). There are eight outliers in the private projects, among which five generates waste very quickly at early stages (more than 65% of waste at 40% of the time) and the other three very slowly at early stages (more than 65% of the time to produce 40% waste). Figure 8 (c) presents a more direct comparison between the public and private sectors. It is observable that private projects have more outlier points while public ones are more compact. This difference might be rooted in the promotion of waste management index (WMI) practice in public new building projects. The curves show that for the first half of the time, the accumulative waste proportion of private projects is slightly larger than public projects at the same progress. The difference between the two sectors keeps at an average of around 5%, as shown in Figure 8 (d), which is moderate.

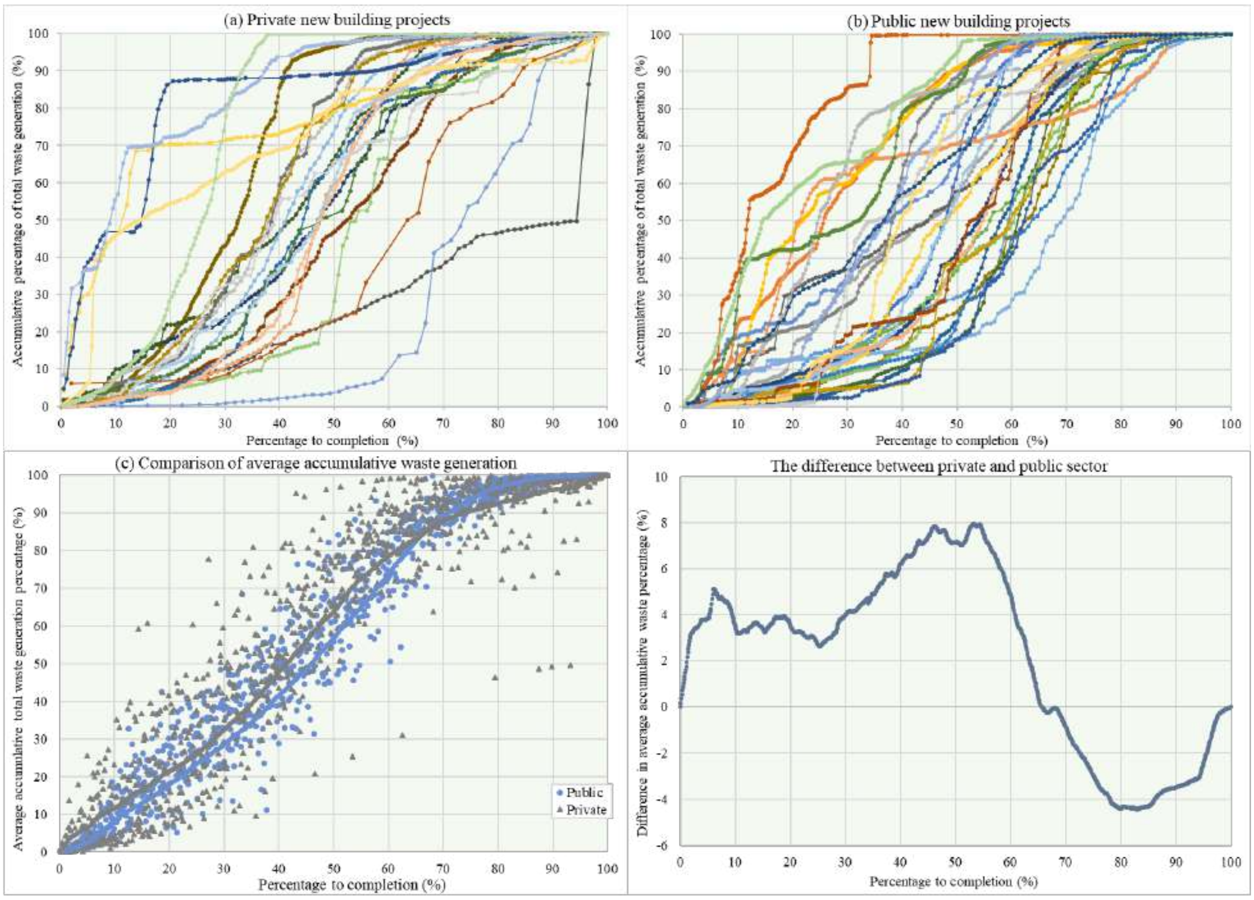

Figure 8. Accumulative waste generation flow of public and private new building projects

Interpreted from Figures 7 and 8, it is safe to draw a conclusion that the overall efficiency difference between public and private sector is not significant although there are indeed some slight differences during the process. For private projects, the performance between individual projects varies more largely than public ones. However, the findings from WGFs and accumulative WGFs is different from the results of the WGR comparison. This can be interpreted that although public projects generate waste more consistently between different projects, their overall waste management efficiency is still lagging compared to their private counterparts. In other word, private projects generate less waste on the same contract sum. Although the performance between one project and another may have a bigger difference, there are some private new building projects that are highly efficient in construction waste management. Therefore, it is necessary to enhance the regulation of private projects from the waste management perspective to enhance the overall efficiency. The successful waste management practices of public projects and some outstanding private projects should be promoted.

Discussions

Both the private and public sectors sponsor construction project development. In Hong Kong, a city evaluated as the world's freest economy for 25 consecutive years in a row (Sum, 2019), building construction clients use the same pool of contractors and sub-contractors, which are all private companies freely competing in the market. Under the same set of environmental regulations and construction codes, they should perform the same without an apparent disparity between their CWM efficiency measured by WGRs. However, the big data analytics in this study discovered that CWM efficiency varies with sectors and different types of construction projects they undertake. According to the comparisons of CWM efficiency of three categories of projects, the public and private sectors have no statistically significant difference in demolition and foundation projects. Surprisingly, in the sampled new building projects, the average WGR of the public sector is significantly larger than the private sector. In summary, the private sector is not consistently more efficient than public, or vice versa, in managing construction waste. Such results reject the significant efficiency disparity between the public and private sectors concerning construction waste management.

Although under the same set of environmental regulations and construction codes, it is widely considered that the public sector clients are subject to more stringent social scrutiny, therefore tend to care more about CWM efficiency. The public sector clients are promoting waste management index (WMI) practice in Hong Kong, which might be the reason that public foundation and new building projects have much similar WGF and accumulative WGF between each other while the divergence is large in private ones. On the private side, there are often casual remarks in Hong Kong that the private sector outlaws in managing their construction projects. However, the private sector cares more about the savings of material consumption and disposal fees; therefore, better managing construction waste. All these joints forces may explain the finding that no sector is consistently better than another. Nevertheless, CWM performance during the whole process differs observably from one project to another. Although the companies are under the same market conditions, CWM efficiency is determined not only by the client-contractor dyadic relationship, but also by the companies' environmental awareness, corporate social responsibility, and management discretion.

The big data sourced in this study did provide a fuller picture to examine CWM performance, and their detailed WGFs. The big data analytics helped to gain more statistical confidence, although the analyses did not tell which sector is more efficient than another. Big data opens a window to address the moot question of whether the private sector is more efficient than the public sector, but such data can never be too big to examine a complex system such as CWM. In this study, the data of 132 selected projects, including 70 public projects and 62 private projects, of three categories, i.e., demolition, foundation, and new building are sourced from a big data set. It is bigger than any other data sets one can ever see in the literature. Yet, it appears thin in ascertaining the efficiency disparity between the public and private sectors. Researchers are encouraged to exploit passive, unintentionally left-over big data to examine the classic inquiry of efficiency disparity between the public and private sectors. Even in further future, meta-analyses based on the big-data enabled analyses can bring the inquiry into a conclusion.

The methods and findings of this research will also supplement the body of knowledge by adding a new method and perspective to the examination of public and private sectoral efficiency disparity, as well as an answer to the investigation. It is hard to decide which one is better, the better way is to analyze which sector is doing greater in which specific aspect and improve the other sector using the experience and knowledge learnt from the empirical practice comparison. For the field of practice, the answers obtained from empirical case analyses indicate that the private sector needs more improvement than its public counterpart in the aspect of CWM. Private companies should pay more attention to their social environmental responsibilities and learn from the public counterparts. Although the public sector is doing better at a general scale, some private companies are actually doing better, whose experiences are worthy learning by the public sector and other private companies.

Conclusion

Efficiency disparity between the public and private sectors is a fundamental scientific inquiry that is closely related to grand challenges such as capitalism vs. socialism, privatization vs. nationalization, or public-private partnership. Over the past decades, it has attracted numerous studies, but the line of inquiry is largely inconclusive. This research aimed to ascertain the difference of construction waste management efficiency between the public and private projects, with a view to understanding the inquiry in a smaller setting and considering big data analytics as a promising solution to a moot question. In this study, the data of 132 selected projects, including 70 public projects and 62 private projects distributed in three categories of projects, including demolition, foundation, and new buildings are extracted and processed for the statistical and visual comparisons. The investigations looking at the waste generation flow (WGF) and accumulative WGF found that there is no statistical significance found in all three types of projects, i.e., demolition, foundation, and new building projects. A comfortable conclusion is that no sector is consistently more efficient than another in managing construction waste, although closer inspections detect the better performance in private demolition projects, public foundation and new building projects. Additionally, CWM performance ranges radically from one project to another, especially in private projects, which suggests the standardization of waste management practice in private projects as a feasible short-term strategy for CWM improvement. Further, improving CWM performance perhaps can be pursued through contractors' individual practices rather than through the project ownership only.

Big data demonstrated its power to paint a fuller picture of CWM in different projects. It allows us to obtain more statistical confidence, and to probe into detailed WGFs in individual projects. However, the data is still not big enough to allow the examination of many relevant aspects, e.g., contractors' internal CWM policies and onsite practices. By having the data with sufficient variety, it might be possible to ultimately answer the question of efficiency disparity between the public and private sectors. This big, but still not various enough data forms the major limitation of this research.

Acknowledgment

This research is supported by the Public Policy Research (PPR) (Project No.: 2018.A8.078.18D) and Strategic PPR (Project Number: S2018.A8.010) Funding Schemes, both from the Policy Innovation and Co-ordination Office of the Government of the Hong Kong Special Administrative Region.

References

Agrawal, A., Cockburn, I., & McHale, J. (2006). Gone but not forgotten: knowledge flows, labor mobility, and enduring social relationships. *Journal of Economic Geography*, *6*(5), 571-591.

Alchian, A. A. (1965). Some Economics of Property Rights. *II Politico 30* (4):816-29

Bhattacharyya, A., Parker, E., & Raffiee, K. (1994). An examination of the effect of ownership on the relative efficiency of public and private water utilities. *Land Economics*, 197-209.

Busch, T., & Gustafsson, O. (2002). Slack in the Public Sector: A comparative analysis of a private and a public enterprise for refuse collection. *Public Management Review*, *4*(2), 167-186.

Allison, G. T. (1980). *Public and private management: are they fundamentally alike in all unimportant respects?* (pp. 283-298). Cambridge, MA: John F. Kennedy School of Government, Harvard University.

Boyne, G. A. (2002). Public and private management: what's the difference?. *Journal of Management Studies*, *39*(1), 97-122.

Bretschneider, S. (1990). Management information systems in public and private organizations: An empirical test. *Public Administration Review*, 536-545.

Byrnes, P., Grosskopf, S., & Hayes, K. (1986). Efficiency and ownership: further evidence. *The Review of Economics and Statistics*, 337-341.

Bysted, R., & Hansen, J. R. (2015). Comparing Public and Private Sector Employees' Innovative Behaviour: Understanding the role of job and organizational characteristics, job types, and subsectors. *Public Management Review*, *17*(5), 698-717.Das, A. (2012). Who extracts minerals more efficiently—Public or private firms? A study of Indian mining industry. *Journal of Policy Modeling, 34*(5), 755-766.

Daw, J. (2015). Explaining the persistence of health disparities: social stratification and the efficiency-equity trade-off in the kidney transplantation system. *American Journal of Sociology*, *120*(6), 1595-1640.

De Alessi, L. (1974). An Economic Analysis of Government Ownership and Regulation: Theory and the Evidence from the Electric Power Industry. *Public Choice* 19 (Fall): 1-42.

Estache, A., & Rossi, M. A. (2002). How different is the efficiency of public and private water companies in Asia?. *The World Bank Economic Review, 16*(1), 139-148.

Galinienė, B., & Dzemydaitė, G. (2012). Spatial data envelopment analysis method for the evaluation of regional infrastructure disparities. *Social Technologies*, *2*(2), 390-403.

Hampson, K., Kraatz, J. A., & Sanchez, A. X. (2014). The global construction industry and R&D. In *R&D Investment and Impact in the Global Construction Industry* (pp. 42-61). Routledge.

HKHA (Hong Kong Housing Authority) (2008). Stepping forward in sustainable housing: Sustainability Report 2007-2008. Accessed on 26 August 2019 at: https://bit.ly/2lVe0zy.

Ichinose, D., Yamamoto, M., & Yoshida, Y. (2013). Productive efficiency of public and private solid waste logistics and its implications for waste management policy. *IATSS Research, 36*(2), 98-105.

Jacobsen, R., Buysse, J., & Gellynck, X. (2013). Cost comparison between private and public collection of residual household waste: multiple case studies in the Flemish region of Belgium. *Waste Management*, *33*(1), 3-11.

Karas, A., Schoors, K., & Weill, L. (2010). Are private banks more efficient than public banks? Evidence from Russia. *Economics of Transition, 18*(1), 209-244.

Leek, J. T. (2014). Svaseq: removing batch effects and other unwanted noise from sequencing data. *Nucleic Acids Research*, *42*(21), e161-e161.

Lu, W., Chen, X., Ho, D. C., & Wang, H. (2016). Analysis of the construction waste management performance in Hong Kong: the public and private sectors compared using big data. *Journal of Cleaner Production*, *112*, 521-531.

Lu, W., Chen, X., Peng, Y., & Shen, L. (2015). Benchmarking construction waste management performance using big data. *Resources, Conservation and Recycling*, *105*, 49-58.

Lu, W., Webster, C., Peng, Y., Chen, X., & Chen, K. (2018). Big Data in Construction Waste Management: Prospects and Challenges. *Detritus*, *4*, 129-139.

Lu, W., Yuan, H., Li, J., Hao, J. J., Mi, X., & Ding, Z. (2011). An empirical investigation of construction and demolition waste generation rates in Shenzhen city, South China. *Waste Management*, *31*(4), 680-687.

Lu, W. M., & Lo, S. F. (2007). A closer look at the economic-environmental disparities for regional development in China. *European Journal of Operational Research*, *183*(2), 882-894.

Massoud, M. A., El-Fadel, M., & Malak, A. A. (2003). Assessment of public vs private MSW management: a case study. *Journal of Environmental Management*, *69*(1), 15-24.

McAfee, A., Brynjolfsson, E., Davenport, T. H., Patil, D. J., & Barton, D. (2012). Big data: the management revolution. *Harvard business review*, *90*(10), 60-68.

Meier, K. J., & O'Toole Jr, L. J. (2011). Comparing public and private management: Theoretical expectations. *Journal of Public Administration Research and Theory*, *21*, i283-i299.

Mihaiu, D. M., Opreana, A., & Cristescu, M. P. (2010). Efficiency, effectiveness and performance of the public sector. *Romanian Journal of Economic Forecasting*, *4*(1), 132-147.

Petersen, O. H., Hjelmar, U., Vrangbæk, K., & la Cour, L. (2012). Effects of contracting out public sector tasks: A research-based review of Danish and international studies from 2000-2011.

PSIRU (Public Services Privatisation Research Unit). Public and private sector efficiency. Last accessed on 03 September 2019at: https://bit.ly/2kJjcqd.

Ring, P. S., & Perry, J. L. (1985). Strategic management in public and private organizations: Implications of distinctive contexts and constraints. *Academy of Management Review*, *10*(2), 276-286.

Russom, P. (2011). Big data analytics. *TDWI best practices report, fourth quarter*, *19*(4), 1-34.

Sappington, D. E., & Stiglitz, J. E. (1987). Privatization, information and incentives. *Journal of Policy Analysis and Management*, *6*(4), 567-585.

Sen, P. K., & Singer, J. M. (2017). *Large Sample Methods in Statistics (1994): An Introduction with Applications*. CRC Press, Boca Raton, USA.

Sheshinski, E., & Lopez-Calva, L. F. (2003). Privatization and its benefits: Theory, evidence and challenges. In K. Basu, B. N. Pulin, & R. Ranjan (Eds.), *Markets and Governments*. New Delhi: Oxford University Press.

Simms, A., & Reid, S. (2013). The private sector is superior'-time to move on from this old dogma. *The Guardian,(online) 25th April*.

Simões, P., Cruz, N. F., & Marques, R. C. (2012). The performance of private partners in the waste sector. *Journal of Cleaner Production*, *29*, 214-221.

Sum, L.K. (2019). Hong Kong ranked world's freest economy for 25th successive year, beating Singapore at 2nd place and mainland China in 100th. SCMP, 25 Jan 2019. Last accessed on 12 September 2019 at: https://bit.ly/2GeB84j.

WEF. (2012). Big Data, Big Impact: New Possibilities for International Development. *World Economic Forum*. Accessed at 1 July 2019 at: https://bit.ly/1d4OZCf.

Xie, H., Chen, Q., Lu, F., Wang, W., Yao, G., & Yu, J. (2019). Spatial-temporal disparities and influencing factors of total-factor green use efficiency of industrial land in China. *Journal of Cleaner Production*, *207*, 1047-1058.

Xu, J., Lu, W., Xue, F., Chen, K., Ye, M., Wang, J., & Chen, X. (2018). Cross-boundary collaboration in waste management research: A network analysis. *Environmental Impact Assessment Review*, *73*, 128-141.

Zaslavsky, A., Perera, C., & Georgakopoulos, D. (2013). Sensing as a service and big data. *arXiv preprint arXiv:1301.0159*.