

Article

An Exploration of the Impacts of Compulsory Source-Separated Policy in Improving Household Solid Waste-Sorting in Pilot Megacities, China: A Case Study of Nanjing

Fu Chen ^{1,2}, Xiaoxiao Li ^{3,*}, Jing Ma ^{1,4} , Yongjun Yang ³ and Gang-Jun Liu ²

¹ Low Carbon Energy Institute, China University of Mining and Technology, Xuzhou 221008, China; chenfu@cumt.edu.cn (F.C.); jingma2013@cumt.edu.cn (J.M.)

² Geospatial Sciences, College of Science, Engineering, and Health, RMIT University, Melbourne 3000, Australia; gang-jun.liu@rmit.edu.au

³ School of Environmental Science and Spatial Informatics, China University of Mining and Technology, Xuzhou 221008, China; yangyongjuncumt@163.com

⁴ Amap, Inra, Cnrs, Ird, Cirad, University of Montpellier, 34090 Montpellier, France

* Correspondence: lixiaoxiao@cumt.edu.cn; Tel.: +86-5168-388-3501

Received: 5 April 2018; Accepted: 20 April 2018; Published: 25 April 2018



Abstract: Source-separated policy is very important for household solid waste (HSW) management in global megacities. The low proportion of source-separated collection has led to a low comprehensive utilization rate of municipal solid waste (MSW) in China. In March 2017, the Chinese government required major cities to fully implement compulsory source-separated systems by 2020. To determine policy impacts and efficiency in improving HSW sorting, the government launched a mandatory MSW source-separated program in Nanjing in November 2016. A household survey was implemented in three types of 11 communities over a period of 10 weeks. The results showed that approximately 52% of the respondents supported the mandatory policy and that household size was the most important sociodemographic factor influencing the support of the source separation policy. Income, gender, age, and knowledge play significant roles in different groups of respondents. This mandatory policy effectively improved the source-separated rate of HSW by 49.7%. Source-separated facilities investment, publicity investment, and special supervision coverage in these communities had significant positive effects on source-separated HSW. Every 1 million CNY investment in source-separated facilities and publicity will increase the source-separated rate of HSW by 1.1%. A 1.0% increase of special supervision coverage in communities can increase the source-separated rate by 3.6%. The findings from this study may help improve source-separated management of HSW for other cities in the future.

Keywords: source-separated policy; household solid waste; garbage sorting; HTBR model; urban management

1. Introduction

Global municipal solid waste (MSW) output continues to rise though quasi-carbon-neutral processes that are the current goal of development [1]. It is predicted that in 2025, global MSW output will exceed 2.2 thousand million tonnes [2]. Inappropriate MSW management not only endangers the environment and human health [3–6] but also wastes recyclable materials and increases CO₂ emissions [7–11]. Mandatory source-separated sorting is an important means for household solid waste (HSW) management in developed countries to enhance recycling and to reduce the

output of wastes [12–14]. In certain countries, HSW source-separated sorting has become an accepted practice by urban citizens and MSW collection boxes are categorized into waste, recyclable materials, and hazardous waste [15]. For instance, in some Japanese cities, MSW is classified into 25 categories [16,17]. This not only improves the recovery of recyclable materials but also reduces the volume and cost of MSW disposal [18–20].

The source-separated policy for HSW management in China was piloted in June 2000 in Shanghai and seven other major cities [21–23]. The initiative is expected to reduce HSW generation and enhance the recycling of valuable materials. Economic and administrative instruments, such as garbage disposal fee marketizing and exempting renewable resource enterprises from income taxes, have been adopted for enhancing HSW management [24–28]. An integrated HSW reduction program was proposed in Shanghai in December 2010 to reduce HSW per capita by 5% annually until 2020 [29]. The foundation for the implementation of these policies was entirely dependent on the individual's self-consciousness rather than mandatory. As a result, the implementation of HSW source-separated systems in pilot cities were unavoidably ineffective [30,31]. For example, only 29.0% of respondents in urban areas of Suzhou could accurately classify HSW at home [32]. Previous studies have shown that the failure of policy was attributed to the negative neighbor effect, lack of public environmental protection awareness, lack of HSW recycling facilities for clear classification, mixed transportation, and other factors [21–23,29,31,33].

Source-separated collection at home is vital to the recycling of materials as well as reducing the output of HSW. Therefore, the Chinese government has not let it go. Approximately 21,000 million CNY were invested in MSW recycling facilities, publicity, and management training from 2010 to 2015 [28,32,34]. In March 2017, the National Development and Reform Commission and Ministry of Housing and Urban–Rural Development of China promulgated the “Implementation Plan of HSW Source-Separated System” to pilot the mandatory HSW sorting in the major cities of China [35]. However, enforcement policies are not guaranteed to be effective [12]. The implementation of source-separated collection is also affected by sociodemographic characteristics, pro-environmental attitude, opportunity cost, knowledge of recycling, and social norms [36–39]. Generally, females, those with high-income, highly educated people, and elders pay more attention to waste recycling, in contrast with those with low-income, less educated, and young people [40,41]. Opportunity cost and social norms determine the recycling behaviors of citizens [42]. Knowledge of recycling has an effect on the source-separated accuracy [43,44]. The pro-environmental attitude has either a positive or negative impact on recovery behavior [45,46]. Although source-separated collection depends on the citizens' attitude towards recycling, the effect of administrative stimulus on the HSW recycling rate and the reduction of disposal costs should not be ignored [47–49]. Previous studies focused on the attitudes of respondents, ignoring the policy and its environment. Moreover, it should be noticed that source-separated collection does not depend on the behavior of the respondent but rather depends on the attitude of the person mainly engaged in the HSW disposal of a household.

To improve HSW sorting, MSW separation facilities, HSW output, and HSW disposal were investigated in some representative communities of Nanjing, China. The objectives of this study are as follows: (1) inquire about the attitudes of the pilot communities to the compulsory source-separated policy; (2) assess the effectiveness of the policy on HSW recycling; and (3) identify environmental factors that affect the source-separated collection of HSW and provide suggestions for policy improvement.

2. Methodology and Data Collection

2.1. Study Area

Nanjing City, a major city of China, is located in the western zone of the Yangtze River Delta. In 2016, the built-up urban area was 923.8 km², the urban population was 6.7 million, and the GDP per capita was \$19,000 USD. In 2016, the HSW output of Nanjing was 3.14 million tonnes, which overburdened five landfills and an incinerator. Yaohuamen, Laoshan, and other places have

dozens of “garbage mountains” that have formed in in the past few decades that amount to more than 20 million tonnes.

Nanjing is also one of the eight pilot HSW source-separated cities of China since June 2000. Due to lack of administrative encouragement or financial support, municipal governors were unwilling to implement the source-separated system [50]. According to HSW source-separated collection, all communities in Nanjing can be divided into three types: the 5 “HSW source-separated demonstration communities” (rewarded by the Ministry of Housing and Urban–Rural Development of China in December 2012), 16 “Nanjing HSW source-separated pilot communities” and some high-grade communities, and other communities (Table 1). Furthermore, in this study, the survey percentage of communities (households) in Nanjing is 20% (2.3%), 18.8% (2.5%), and 0.5% (0.1%), respectively.

Table 1. Statistics of the municipal solid waste (MSW) source-separation conditions of communities and households in Nanjing.

Description	Community Type		
	I	II	III
General description	MSW source-separated demonstration communities	MSW source-separated pilot communities and some high-grade communities	Other communities
Number of communities in Nanjing	5	16	1394
Community facilities and services	Three types of trash cans, classified transportation vehicles, door-to-door service for hazardous article collection, and other services	Two types of trash cans	No classification facilities
Community publicity and supervision	Informing check-in households, publicity with community electronic screens and APPs, periodic sampling–supervision, and organization of volunteer work	Publicity with bulletin boards and occasional propaganda	Public service advertising on newspaper or television
Number of communities (households) in this study	1 (56)	3 (150)	7 (281)
Survey percentage of communities (households) in Nanjing	20.0% (2.3%)	18.8% (2.5%)	0.5% (0.1%)

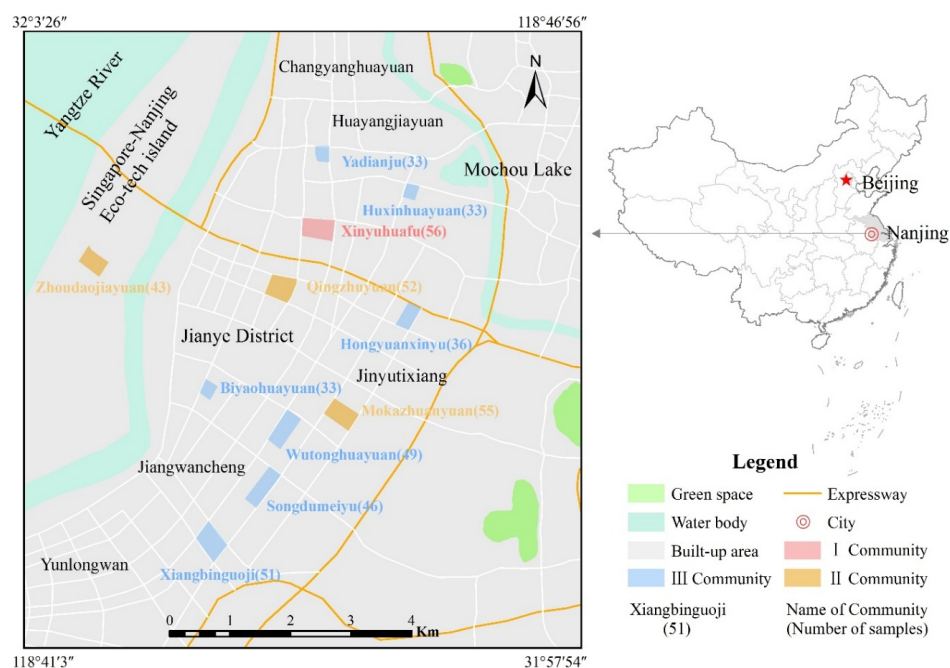
2.2. Design of Household Survey

A mandatory HSW source-separated pilot program has been conducted in the Jianye District since November 2016. Only four communities belonged to Type I or II, while also belonging to the pilot program (Table 1). Therefore, only a “snowball” sampling method—which is a nonprobability sampling technique that helps to derive reliable and representative data—was used in this study [51,52]. A forced-choice questionnaire, which contained the sociodemographic statistical characteristics of respondents and support degree for the policy (Table 2), was designed for this study. A household survey was taken in 2016, and all ethical norms were strictly followed.

Before the survey, it was ensured that the households had been informed of the purpose of the survey and all relevant privacies were strictly kept by the investigators. Then, from 18 October to 26 December, 13 investigators conducted the survey (Figure 1) in 487 households of 11 communities who were willing to be interviewed in the Jianye District of Nanjing. A 10-week form (recording the daily number of waste packages, number of classified packages, and the number of bulky items such as televisions and refrigerators) was filled out by each household. It is worth emphasizing that, in this study, the “packages” was defined as the plastic garbage which was packed using bags or bundled with a string such as books, newspapers, and so on. The Chinese families had few experiences in the traditional practice of making these waste packages. Therefore, most of the household wastes were mixed and packed in only one bag. However, when the garbage was mixed, the number of packages would become less. If various wastes were classified, the number of packages would increase. It was a good reference to force the waste classification, and the changes were evaluated and used in this study.

Table 2. Statistical characteristics of the respondents in Nanjing.

Variables		Abbreviation → Input Value	Summary Statistics	
Categories	Description		N	%
Independent Variables				
Gender	The gender of the person in a household mainly dealing with HSW	G1 → female	325	66.7
		G2 → male	162	33.3
Age (years)	The age of the person in a household mainly dealing with HSW	A1 → <35	104	21.4
		A2 → 36–60	158	32.4
		A3 → >60	225	46.2
Household size	Household size	H1 → not more than 2	97	19.9
		H2 → 3–4	221	45.4
		H3 → not less than 5	169	34.7
Number of education years	The number of education years of the highest educated person with an income in a household	E1 → <9	19	3.9
		E2 → 9–12	58	11.9
		E3 → 12–16	339	69.6
		E4 → >16	71	14.6
Monthly income (CNY)	Household monthly income per capita	I1 → <3000	57	11.7
		I2 → 3000–5000	153	31.4
		I3 → 5000–9000	214	43.9
		I4 → 9000–15000	42	8.6
		I5 → > 15000	21	4.3
Knowledge	Person in the household mainly dealing with HSW’s knowledge about how to separate HSW	K1 → does not know the classification of MSW	51	10.5
		K2 → partly knows the classification of MSW	197	40.5
		K3 → substantially knows the classification of MSW	166	34.1
		K4 → completely knows the classification of MSW	73	15.0
Target Variables				
Degree of support for the new policy	–	S1 → totally unsupportive	64	13.1
		S2 → unsupportive	68	14.0
		S3 → neutral	101	20.7
		S4 → supportive	173	35.5
		S5 → advocating (fully supportive)	81	16.6

**Figure 1.** Location of the study area and sampling sites.

In addition, the investigators also interviewed 13 officials of Nanjing HSW management institutions and community management institutions to understand the investment in the HSW source-separated facilities, special supervision coverage, attitudes, and suggestions for policy implementation. All analyses were performed by using SPSS19.0 software (IBM SPSS Statistics, USA) at the significance level of 1%.

2.3. Data Analysis with a Hierarchical Tree-Based Regression Method

The dependent variables (i.e., nominal variables, degree of support for the policy, and ways of dealing with the waste) obtained in this survey were stochastic and could be linked with independent variables in many respects. In general, it was impossible to explain a piecemeal constant approximation to the underlying regression function through parametric linear regression. However, the approximation could be estimated accurately with hierarchical tree-based regression (HTBR), which, therefore, was used in this study to analyze the survey data [53]. The HTBR model was essentially a nonparametric tool that had neither a given function form nor a statistical assumption [54]. It used the segmentation method to determine the optimal splitting rules and proved to be an efficient and explicit interpretable approach to explore the relationship between dependent and independent variables. According to the characteristics of dependent and independent variables, the hierarchical tree structure design rules were concluded as follows in this study:

- (a) The maximum tree depth was not more than five levels.
- (b) The minimum number of survey samples of parent nodes was not less than 50, and the minimum number of survey samples of child nodes was not less than 20.
- (c) The significance levels of splitting nodes and merging categories were set to 0.05.

In addition, the chi-squared automatic interaction detection algorithm was used to determine the optimal tree size because it allowed for the multipath segmentation of a parent node, distinct from the classification and regression tree algorithm and the quick-unbiased-efficient and statistical tree algorithm.

2.4. Evaluating the Effectiveness of the Compulsory Source-Separated Policy Implementation

2.4.1. Variable Selection

The household waste source separation state was reflected by the dependent variable (total number of classified packages and bulky items divided by total number of packages and bulky items) in the questionnaire. The following variables functioned as explanatory. (1) Income per capita. Those with high-income usually pay more attention to environmental protection, but the opportunity cost may be adversely affected to the recycling efficiency. (2) Household size. The larger the household is, the better the HSW source-separated efficiency. (3) The number of years of education. More highly educated people pay more attention to waste recycling. (4) Gender. Females tend to pay more attention to recycling than males. (5) Source-separated knowledge. Households with source-separated knowledge have higher sorting effects. (6) Age. Elders usually pay more attention to recycling than younger people. (7) Community source-separated facilities and publicity investment. The higher the investment is, the better the separated effect. (8) The coverage of special supervision. Usually, more frequent and greater coverage of special supervision will result in a better separated effect. The definitions and expectations of these variables are shown in Table 3.

Table 3. Descriptions and potential impact of all variables considered.

Variable	Description	Expected Symbols
I	Monthly income per capita of the household (CNY)	+ / −
H	Population size	+
E	The number of education years of the highest educated person with an income in a household	+
A	Age of the person in a household mainly dealing with HSW	+
G	Gender of the person in a household mainly dealing with HSW	+
K	Know-how to separate collected HSW	+
C	Community source-separated facilities and publicity investment (million CNY)	+
S	Coverage of special supervision in communities (%)	+
P	Policy dummy variable	+
R	Percentage of classified HSW at the source (dependent variable)	

2.4.2. Empirical Model

In this study, it was assumed that the dependent variables were a set of [0, 1] values, which were continuous variables that depended on certain factors and followed a particular distribution. They agreed with the two assumptions of the Tobit model: the explained variable must have a positive probability of 0, and the remaining non-zero samples show continuous states [55]. As far as panel data analysis was concerned, the Tobit model with fixed effects cannot provide consistent estimated values, while the Tobit model with random effects can yield consistent estimated values [56]. Therefore, the Tobit model was adopted with random effects for empirical analysis [57,58].

The full-sample panel regression model is presented as follows:

$$R_{it} = a_{it} + \beta_1 P_{it} + \beta_2 I_{it} + \beta_3 H_{it} + \beta_4 E_{it} + \beta_5 A_{it} + \beta_6 G_{it} + \beta_7 K_{it} + u_i + e_{it} \quad (1)$$

After implementation of the mandatory source separation policy, the sample panel regression model was as follows:

$$R_{it} = a_{it} + \beta_1 I_{it} + \beta_2 H_{it} + \beta_3 E_{it} + \beta_4 A_{it} + \beta_5 G_{it} + \beta_6 K_{it} + \delta_1 C_{it} + \delta_2 S_{it} + \beta_7 W_2 + \beta_8 W_3 + \beta_9 W_4 + u_i + e_{it} \quad (2)$$

where i and t were the sample and time, respectively; a was the intercept item; P was the dummy variable that referred to the respects of compulsory source-separated policy; β and δ were parameter vectors; u_i was an individual variable that varies with individuals but does not change over time and was not related to explanatory variables; e_{it} were random variables independent of time and sample; and W_2 , W_3 , and W_4 were the time variables in the second, third, and fourth week of the policy implementation, respectively. The definitions of other variables are shown in Table 3.

The logic of this study was as follows. First, determine the effectiveness of the mandatory policy by analyzing the difference between dependent variables before and after the implementation of the policy. Second, if the policy is effective, estimate the marginal effects of the explanatory variables on the dependent variables through the sample regression after the implementation.

2.5. Data Processing

Direct use of the survey data to estimate the effectiveness of the policy is questionable because the distribution of samples between the intervention and control groups is not random. To avoid multicollinearity between the variables in the model, STATA14 software was used for the regression and the results were tested with the expansion coefficients [59,60]. The mean of the expansion coefficients between the variables was 1.44, which is much less than 10 [61]. Therefore, there was no multicollinearity between the variables.

3. Results and Discussion

3.1. Mapping of Household Support Degree for the Mandatory Source-Separated Policy Using the HTBR Model

The hierarchical tree-based regression model to estimate the degree of support for the mandatory HSW source-separated policy by the respondents in Jianye District, Nanjing, is shown in Figure 2.

The first bifurcation of the tree corresponds to household size, showing that household size played the most significant role in supporting the policy. Based on household size, all respondents were divided into three subgroups. In the H1 subgroup, 33.0% of respondents were totally unsupportive and accounted for 50.0% of all unsupportive respondents in this study. In the H3 subgroup, 26.0% of respondents were fully supportive and accounted for 54.3% of all fully supportive respondents in this study.

The second bifurcation of the tree corresponds to three explanatory variables: monthly income, gender, and age. The support degree for the policy in the H1 group was further divided into the I1, I2, and I4 groups due to the difference in monthly income. In total, unsupportive households accounted for 51.4% of the I1 group but accounted for 59.4% of all respondents in the H1 subgroup. In the I4 group, supportive households accounted for 28.0% but accounted for 77.8% of all respondents in the H1 subgroup. These data demonstrate that monthly income was the most important factor affecting the support degree of small households. The degree of support in the H2 group was further divided into the G1 and G2 subgroups due to gender difference. Males were much less supportive than females. The support degree in the H3 group was further divided into the A1, A2, and A3 subgroups because of age. In a large household, the older the person disposing of the HSW, the higher the support degree.

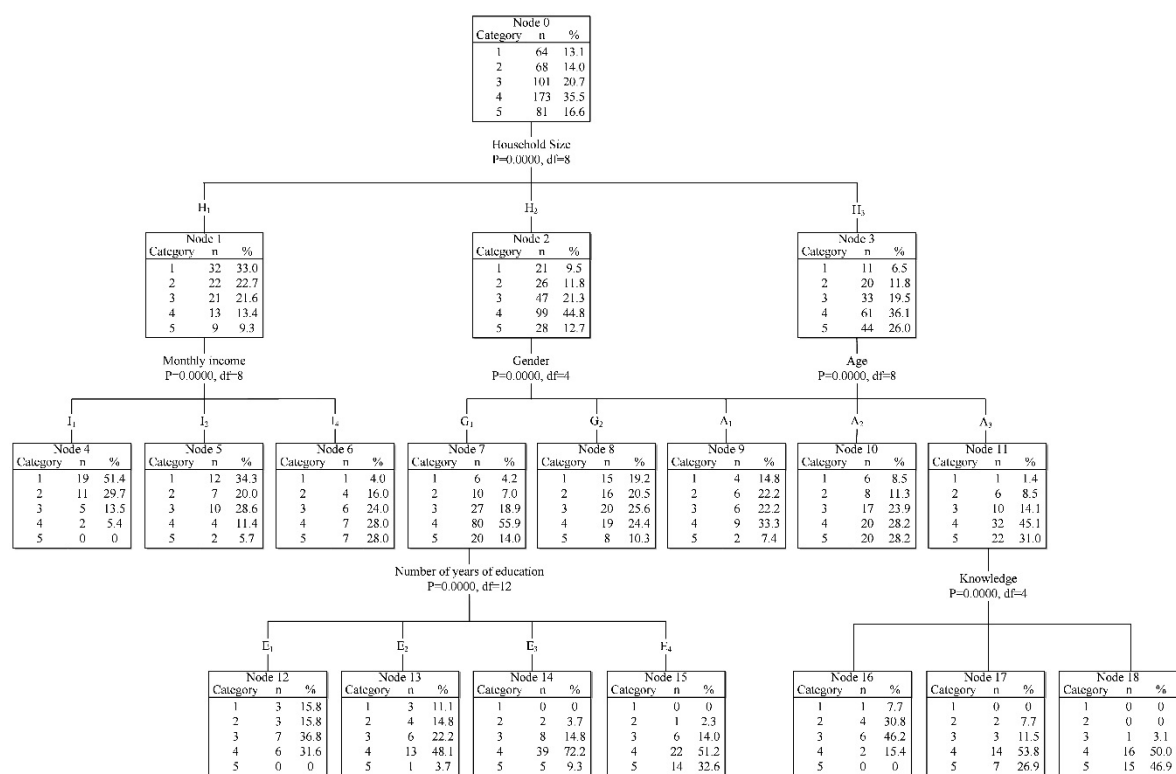


Figure 2. Degree of support for the mandatory household solid waste (HSW) source-separated policy classified with the hierarchical tree-based regression (HTBR) model.

The third bifurcation corresponded to two explanatory variables: years of education and knowledge. The support degree in the G1 group was divided into the E1, E2, E3, and E4 subgroups according to years of education. The E1 and E2 groups were completely unsupportive, and the

E1 group did not advocate (i.e., did not definitely support) the new policy. Those who supported (i.e., were not fully unsupportive) and advocated the policy in the E3 and E4 groups accounted for 95.0%, indicating that education was the most important factor affecting the support level of females from a household of medium size. In the A3 group, the support degree was further divided into K1, K2, and K3 according to the knowledge about the separation procedure. Those who advocated the policy in the K3 group accounted for 68.2%, and everyone supported (i.e., was not fully unsupportive) the new policy. In the K1 group, no one advocated the new policy. These results showed that the sorting knowledge of the elderly was the most important factor affecting the HSW source-separated collection of a large household.

The hierarchical tree-based regression results exhibited some characteristics that differed from the results of previous studies; household size was the most significant factor affecting the support degree for the mandatory source-separated policy [12,21–23]. This may have been related to the complex household structure in China. The regression analysis results of the second and third levels of the tree were similar to those of previous studies, indicating that monthly income, years of education, and knowledge about sorting were still the most important factors that affected HSW source-separated collection [16,17,24,28,29].

3.2. Estimating Effectiveness of the Mandatory Source-Separated Policy

Table 4 shows the regression results of the full-sample panel data from the STATA14 software. All samples were involved in the fitting. The chi-square value of the model likelihood ratio test was 753.58 (significant at the 1% confidence level), indicating that the model fitting was accurate and reliable. As shown in Table 4, the estimation results of these explanatory variables matched the expected symbols (Table 3), showing that these explanatory variables had positive effects on the efficiency of the mandatory source-separated policy in addition to monthly income. Unfortunately, the age estimation results failed to pass the 10% significance test. The policy dummy variable coefficient was 0.4974, indicating that in the presence of the mandatory policy, the efficiency of HSW source-separated collection could be improved by 49.7%. This shows that the effect of the mandatory source-separated policy was remarkable. This estimate was significant at the level of 1.0%, proving the validity of the regression estimation. Previous studies have also yielded to similar results in other cities, China [24,28].

Table 4. Regression results of panel data of the effectiveness of the mandatory source-separated policy.

Explanatory Variable	Coefficient	Z Value	p Value
P	0.49741 ***		
I	0.00019 **	2.07	0.05
H	0.23116 **	2.37	0.02
E	0.01178 *	1.65	0.09
A	0.00013	0.63	0.51
G	0.09456 *	1.81	0.06
K	0.01065 *	1.72	0.07
R ²	0.8347		
Wald chi ²	753.58 ***		
N	487 × 6		

Note: ***, **, and * denote 1%, 5%, and 10% significance levels.

Changes in the number of HSW packages and the percentage of classified HSW of the respondents in 10 weeks, both of which increased significantly, are shown in Figure 3. This also evidenced the estimation results of the regression model. After the implementation of the new policy, the number of HSW packages in community II increased to the largest extent by 62.4%. The percentage of classified HSW in community III increased to the largest extent by 118.5%. However, the average number of HSW packages/average percentage of classified HSW of households in communities II and III were much lower than those in community I by 30.2%/39.3% and 20.6%/42.9%, respectively.

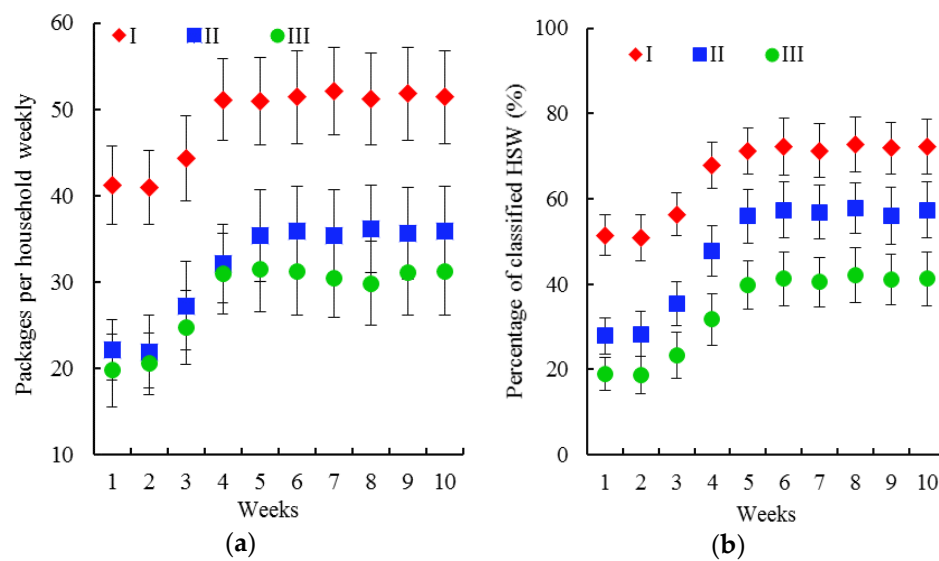


Figure 3. Survey data of packages per household weekly (a) and percentage of classified HSW (b) in different communities of Nanjing.

3.3. Identification of Environmental Factors Affecting HSW Source-Separated Collection

Although the results of dummy policy variables explain the policy validity, the regression estimation results do not identify the contribution of each factor to the MSW source-separated rate. This required another panel regression for the samples after the implementation of the mandatory source-separated policy. To eliminate the endogeneity resulting from missing variables, as many control variables as possible must be added [61]. Therefore, the dummy policy variables in this study were substituted for community source separation facilities, publicity investment (C), and special supervision coverage in a community scale (S). The heteroscedasticity, autocorrelation, and cross-section correlations of the short panel data were tested. The panel data do not have cross-section correlations but do have heteroscedasticity and autocorrelation. A random-effects clustering-robustness generalized least squares method was employed because it can resolve heteroscedasticity and autocorrelation problems simultaneously [62].

The sample panel regression estimation results after the implementation of the mandatory source-separated policy are shown in Table 5. The coefficients of each explanatory variable are positive, which shows that these variables play positive roles in HSW source-separated collection. Household size (H) was significant at the 1% level, showing that it was the most important sociodemographic factor in the HSW sorting of urban citizens in China. This result also supported the regression estimation results with the HTBR model. After the policy variables were substituted, the regression estimation results showed that the coefficients of investment in community source-separated facilities and publicity (C) as well as coverage of special supervision (S) were positive, and both variables were significant at the 5% and 1% levels, respectively. This suggests that the variables C and S have significantly positive effects on HSW source-separated collection. In other words, every 1 million CNY investment in community source-separated facilities and publicity (C) can increase the community HSW source-separated rate by 1.1%. Every 1% increase in the coverage of special supervision (S) can increase the community HSW source-separated rate by 3.6%. The coverage of special supervision (S) was particularly important during the early stages of implementation of the policy because special supervision can rapidly promote HSW source-separated collection. The investments in community source-separated facilities and publicity (S) are an important insurance for the long-term HSW source-separated rate. Furthermore, one study in Suzhou found that the current HSW source separation pilot program was valid, as HSW source separation facilities and residents' separation behavior both became better and better along with the program implementation [32].

Table 5. Regression estimation results after the implementation of the mandatory source-separated policy.

Explanatory Variable	Coefficient	Z Value	p Value	Explanatory Variable
I	0.00011 *	0.00171	1.63	0.09
H	0.29372 ***	0.16784	3.28	0.01
E	0.01465	0.02478	1.46	0.17
A	0.00097 *	0.00104	1.85	0.07
G	0.15323 *	0.29872	1.67	0.09
K	0.01096 *	0.02187	1.97	0.06
C	1.14708 **	2.29372	2.41	0.03
S	3.56234 ***	7.15783	3.51	0.01
W ₂	21.4653 ***	17.8435	7.24	0
W ₃	0.94572 *	0.51471	1.87	0.07
W ₄	0.19142	0.29778	1.17	0.213
Constant	18.9347 ***	11.3024	3.85	0
R ²	0.8031			
Wald chi ²	576.43 ***			
N	487 × 4			

Note: ***, **, and * denote 1%, 5%, and 10% significance levels, respectively.

The constant term of time effect was 18.9, which was significant at the 1% level. This means that the average HSW source-separated rate increased by 18.9% during the first week after the policy was implemented (18–24 October 2016). In the second week (25–31 October 2016), the average source-separated rate increased by 21.5% and was significant at the 1% level. In the third week (1–7 November 2016), the average source-separated rate increased by 0.9% and was significant at the 10% level. In the fourth week (8–14 November 2016), although the time-effect constant was still positive, it was not significant. This was consistent with the statistical analysis results shown in Figure 3. With the extension of time, the source-separated rate tended to be stable and gradually converged. The policy was normalized and balanced.

4. Concluding Remarks

Source-separated collection is the first step of the waste recycling process. Accurately sorting, especially the classification of waste batteries, CRT TVs, and other hazardous materials from other waste, not only reduces environmental pollution and human health risks but also saves a large amount of recyclable material to reduce greenhouse gas emissions. During the past two decades, the output of HSW in China has been rising, but the recycling rate has been low. To achieve the HSW recycling rate of 35% before 2020, rethinking the effectiveness of the mandatory HSW source-separated policy and the factors that influence the policy is significant for enhancing HSW management in the future.

The results of the HSW source-separated pilot program in Jianye District, Nanjing City, in November 2016 showed that the mandatory policy could effectively promote the classification of HSW and improve the HSW recycling rate. In general, the support rate of respondents for the compulsory policy was approximately 52%. The policy effectively improved the source-separated rate of HSW by approximately 49.7%. Some special phenomena were also disclosed in China. For example, in large households, if the older household members are in charge of HSW disposal, the source-separated rate will be high. This helps us to improve HSW source-separated collection. The investment in source-separated facilities and publicity as well as special supervision coverage have significant positive effects on HSW source-separated collection. Each 1 million CNY of investment in source-separated facilities and publicity can increase the source-separated rate by 1.1%, and each 1% increase in special supervision coverage can elevate the source-separated rate by 3.6%.

Based on the above conclusions, the following suggestions can be given:

- (1) Because the mandatory HSW source-separated process is gradual, attention must be paid to education/publicity on HSW source-separated collection, enhancement of public awareness of the classification, exploration of new source-separated mechanisms of HSW management, and the introduction of demonstration community management methods of HSW sorting and disposal.

- (2) Relevant laws and regulations should be rationalized, the management system of communities should be improved, and the implementation, supervision, punishment, and incentive mechanisms of the system (such as “HSW source-separated management in a community scale”, “HSW source-separated incentive rules”, and “hazards and emergency response of waste disposal”) should be explored.
- (3) The indices on “HSW source-separated rate” and “HSW recycling rate” should be incorporated into the evaluation system of local governments and community management corporations. “HSW source-separated vouchers” and community alliances of scavengers and municipal cleaners should be introduced to encourage community residents to fulfill source-separated action and HSW recycling tasks satisfactorily. Additionally, investment in source-separated facilities should be enhanced. For example, visual HSW identification markers and intelligent classification techniques can help to optimize the source-separated process.
- (4) In the future, China should change the current industry chain of HSW, which only emphasizes the output of recyclable material and underestimated waste collection, as well as improve HSW sorting at home through source-separated policy.

Author Contributions: F.C. and X.L. performed all the survey and drafted the manuscript. All authors participated in the design of the study and analysis of results. F.C. conceived and coordinated the study.

Acknowledgments: The authors would like to thank the Nanjing Environmental Protection Bureau and Bureau of Land and Resources of Nanjing City for their support during the research. In addition, the authors would like to thank SAGE Language Services for providing linguistic assistance during the preparation of this manuscript. The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by the Fundamental Research Funds for the Central Universities (2017XKQY070).

Conflicts of Interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

References

1. Ali, M. Urban waste management as if people matter. *Habitat Int.* **2006**, *4*, 729–730. [[CrossRef](#)]
2. Hoornweg, D.; Bhada-Tata, P.; Kennedy, C. Environment: Waste production must peak this century. *Nat. News* **2013**, *502*, 615–617. [[CrossRef](#)]
3. Chan, J.K.H. The ethics of working with wicked urban waste problems: The case of singapore’s semakau landfill. *Landsc. Urban Plan.* **2016**, *154*, 123–131. [[CrossRef](#)]
4. Chen, F.; Yang, B.; Ma, J.; Qu, J.; Liu, G. Decontamination of electronic waste-polluted soil by ultrasound-assisted soil washing. *Environ. Sci. Pollut. Res.* **2016**, *23*, 20331–20340. [[CrossRef](#)] [[PubMed](#)]
5. Hird, M.J. Waste, landfills, and an environmental ethic of vulnerability. *Ethics Environ.* **2013**, *18*, 105–124. [[CrossRef](#)]
6. Zaman, A.U.; Lehmann, S. Urban growth and waste management optimization towards ‘zero waste city’. *City Cult. Soc.* **2011**, *2*, 177–187. [[CrossRef](#)]
7. Chen, F.; Yang, B.; Zhang, W.; Ma, J.; Lv, J.; Yang, Y. Enhanced recycling network for spent e-bicycle batteries: A case study in Xuzhou, China. *Waste Manag.* **2017**, *60*, 660–665. [[CrossRef](#)] [[PubMed](#)]
8. Johari, A.; Ahmed, S.I.; Hashim, H.; Alkali, H.; Ramli, M. Economic and environmental benefits of landfill gas from municipal solid waste in malaysia. *Renew. Sustain. Energy Rev.* **2012**, *16*, 2907–2912. [[CrossRef](#)]
9. Lu, C.; Zhang, L.; Zhong, Y.; Ren, W.; Tobias, M.; Mu, Z.; Ma, Z.; Geng, Y.; Xue, B. An overview of e-waste management in China. *J. Mater. Cycles Waste Manag.* **2015**, *17*, 1–12. [[CrossRef](#)]
10. Rada, E. Effects of msw selective collection on waste-to-energy strategies. *WIT Trans. Ecol. Environ.* **2013**, *176*, 215–223.
11. Zuberi, M.J.S.; Ali, S.F. Greenhouse effect reduction by recovering energy from waste landfills in pakistan. *Renew. Sustain. Energy Rev.* **2015**, *44*, 117–131. [[CrossRef](#)]

12. Hotta, Y.; Aoki-Suzuki, C. Waste reduction and recycling initiatives in Japanese cities: Lessons from Yokohama and Kamakura. *Waste Manag. Res.* **2014**, *32*, 857–866. [[CrossRef](#)] [[PubMed](#)]
13. Kuusiola, T.; Wierink, M.; Heiskanen, K. Comparison of collection schemes of municipal solid waste metallic fraction: The impacts on global warming potential for the case of the Helsinki metropolitan area, Finland. *Sustainability* **2012**, *4*, 2586–2610. [[CrossRef](#)]
14. Wen, X.; Luo, Q.; Hu, H.; Wang, N.; Chen, Y.; Jin, J.; Hao, Y.; Xu, G.; Li, F.; Fang, W. Comparison research on waste classification between China and the EU, Japan, and the USA. *J. Mater. Cycles Waste Manag.* **2014**, *16*, 321–334. [[CrossRef](#)]
15. Abbott, A.; Nandeibam, S.; O'Shea, L. Explaining the variation in household recycling rates across the UK. *Ecol. Econ.* **2011**, *70*, 2214–2223. [[CrossRef](#)]
16. Matsumoto, S. Waste separation at home: Are Japanese municipal curbside recycling policies efficient? *Resour. Conserv. Recycl.* **2011**, *55*, 325–334. [[CrossRef](#)]
17. Özkan, K.; Ergin, S.; Işık, Ş.; Işikli, İ. A new classification scheme of plastic wastes based upon recycling labels. *Waste Manag.* **2015**, *35*, 29–35. [[CrossRef](#)] [[PubMed](#)]
18. Inglezakis, V.J.; Moustakas, K. Household hazardous waste management: A review. *J. Environ. Manag.* **2015**, *150*, 310–321. [[CrossRef](#)] [[PubMed](#)]
19. Martin, M.; Williams, I.D.; Clark, M. Social, cultural and structural influences on household waste recycling: A case study. *Resour. Conserv. Recycl.* **2006**, *48*, 357–395. [[CrossRef](#)]
20. Ramayah, T.; Lee, J.W.C.; Lim, S. Sustaining the environment through recycling: An empirical study. *J. Environ. Manag.* **2012**, *102*, 141–147. [[CrossRef](#)] [[PubMed](#)]
21. Deng, J.; Xu, W.; Zhou, C. Investigation of waste classification and collection actual effect and the study of long acting management in the community of Beijing. *Huan Jing Ke Xue* **2013**, *34*, 395–400. [[PubMed](#)]
22. Tai, J.; Zhang, W.; Che, Y.; Feng, D. Municipal solid waste source-separated collection in China: A comparative analysis. *Waste Manag.* **2011**, *31*, 1673–1682. [[CrossRef](#)] [[PubMed](#)]
23. Zhuang, Y.; Wu, S.; Wang, Y.; Wu, W.; Chen, Y. Source separation of household waste: A case study in China. *Waste Manag.* **2008**, *28*, 2022–2030. [[CrossRef](#)] [[PubMed](#)]
24. Han, H.; Zhang, Z. The impact of the policy of municipal solid waste source-separated collection on waste reduction: A case study of China. *J. Mater. Cycles Waste Manag.* **2017**, *19*, 382–393. [[CrossRef](#)]
25. Han, H.; Zhang, Z.; Xia, S. The crowding-out effects of garbage fees and voluntary source separation programs on waste reduction: Evidence from China. *Sustainability* **2016**, *8*, 678. [[CrossRef](#)]
26. Reichenbach, J. Status and prospects of pay-as-you-throw in Europe—A review of pilot research and implementation studies. *Waste Manag.* **2008**, *28*, 2809–2814. [[CrossRef](#)] [[PubMed](#)]
27. Skumatz, L.A. Pay as you throw in the US: Implementation, impacts, and experience. *Waste Manag.* **2008**, *28*, 2778–2785. [[CrossRef](#)] [[PubMed](#)]
28. Chen, H.; Yang, Y.; Jiang, W.; Song, M.; Wang, Y.; Xiang, T. Source separation of municipal solid waste: The effects of different separation methods and citizens' inclination—Case study of Changsha, China. *J. Air Waste Manag. Assoc.* **2017**, *67*, 182–195. [[CrossRef](#)] [[PubMed](#)]
29. Zhang, W.; Che, Y.; Yang, K.; Ren, X.; Tai, J. Public opinion about the source separation of municipal solid waste in Shanghai, China. *Waste Manag. Res.* **2012**, *30*, 1261–1271. [[CrossRef](#)] [[PubMed](#)]
30. Chu, Z.; Wang, W.; Wang, B.; Zhuang, J. Research on factors influencing municipal household solid waste separate collection: Bayesian belief networks. *Sustainability* **2016**, *8*, 152. [[CrossRef](#)]
31. Tong, X.; Tao, D. The rise and fall of a “waste city” in the construction of an “urban circular economic system”: The changing landscape of waste in Beijing. *Resour. Conserv. Recycl.* **2016**, *107*, 10–17. [[CrossRef](#)]
32. Zhang, H.; Wen, Z. Residents' household solid waste (hsw) source separation activity: A case study of Suzhou, China. *Sustainability* **2014**, *6*, 6446–6466. [[CrossRef](#)]
33. Fu, H.; Li, Z.; Wang, R. Estimating municipal solid waste generation by different activities and various resident groups in five provinces of China. *Waste Manag.* **2015**, *41*, 3–11. [[CrossRef](#)] [[PubMed](#)]
34. Gu, B.; Wang, H.; Chen, Z.; Jiang, S.; Zhu, W.; Liu, M.; Chen, Y.; Wu, Y.; He, S.; Cheng, R.; et al. Characterization, quantification and management of household solid waste: A case study in China. *Resour. Conserv. Recycl.* **2015**, *98*, 67–75. [[CrossRef](#)]

35. NDRC. The Implementation Plan of the Classification System of Household Solid Waste. Available online: http://www.ndrc.gov.cn/gzdt/201703/t20170331_843112.html (accessed on 18 December 2017).
36. Ando, A.W.; Gosselin, A.Y. Recycling in multifamily dwellings: Does convenience matter? *Econ. Inq.* **2005**, *43*, 426–438. [[CrossRef](#)]
37. Bruvoll, A.; Halvorsen, B.; Nyborg, K. Households' recycling efforts. *Resour. Conserv. Recycl.* **2002**, *36*, 337–354. [[CrossRef](#)]
38. Jakus, P.M.; Tiller, K.H.; Park, W.M. Generation of recyclables by rural households. *J. Agric. Resour. Econ.* **1996**, *21*, 96–108.
39. Matsumoto, S. The opportunity cost of pro-environmental activities: Spending time to promote the environment. *J. Fam. Econ. Issues* **2014**, *35*, 119–130. [[CrossRef](#)]
40. Lansana, F.M. A comparative analysis of curbside recycling behavior in urban and suburban communities. *Prof. Geogr.* **1993**, *45*, 169–179. [[CrossRef](#)]
41. Yang, L.; Li, Z.-S.; Fu, H.-Z. Model of municipal solid waste source separation activity: A case study of Beijing. *J. Air Waste Manag. Assoc.* **2011**, *61*, 157–163. [[CrossRef](#)] [[PubMed](#)]
42. Halvorsen, B. Effects of norms and opportunity cost of time on household recycling. *Land Econ.* **2008**, *84*, 501–516. [[CrossRef](#)]
43. Hornik, J.; Cherian, J.; Madansky, M.; Narayana, C. Determinants of recycling behavior: A synthesis of research results. *J. Socio-Econ.* **1995**, *24*, 105–127. [[CrossRef](#)]
44. Sidique, S.F.; Lupi, F.; Joshi, S.V. The effects of behavior and attitudes on drop-off recycling activities. *Resour. Conserv. Recycl.* **2010**, *54*, 163–170. [[CrossRef](#)]
45. Ekere, W.; Mugisha, J.; Drake, L. Factors influencing waste separation and utilization among households in The Lake Victoria Crescent, Uganda. *Waste Manag.* **2009**, *29*, 3047–3051. [[CrossRef](#)] [[PubMed](#)]
46. Zhang, S.; Zhang, M.; Yu, X.; Ren, H. What keeps Chinese from recycling: Accessibility of recycling facilities and the behavior. *Resour. Conserv. Recycl.* **2016**, *109*, 176–186. [[CrossRef](#)]
47. Guerrero, L.A.; Maas, G.; Hogland, W. Solid waste management challenges for cities in developing countries. *Waste Manag.* **2013**, *33*, 220–232. [[CrossRef](#)] [[PubMed](#)]
48. Seejeen, P.; Frances, S.B. Analyzing effective municipal solid waste recycling programs: The case of county-level MSW recycling performance in Florida, USA. *Waste Manag. Res.* **2013**, *31*, 896–901.
49. Lakhan, C. The relationship between municipal waste diversion incentivization and recycling system performance. *Resour. Conserv. Recycl.* **2016**, *106*, 68–77. [[CrossRef](#)]
50. Chen, F.; Luo, Z.; Yang, Y.; Liu, G.; Ma, J. Enhancing municipal solid waste recycling through reorganizing waste pickers: A case study in Nanjing, China. *Waste Manag. Res.* **2018**. [[CrossRef](#)] [[PubMed](#)]
51. Blanche, M.T.; Blanche, M.J.T.; Durrheim, K.; Painter, D. *Research in Practice: Applied Methods for the Social Sciences*, 3rd ed.; UCT Press: Cape Town, South Africa, 2007.
52. Viljoen, K.; Blaauw, P.; Schenck, R. "I would rather have a decent job": Potential barriers preventing street-waste pickers from improving their socio-economic conditions. *S. Afr. J. Econ. Manag. Sci.* **2016**, *19*, 175–191. [[CrossRef](#)]
53. Stewart, J. Applications of classification and regression tree methods in roadway safety studies. *Transp. Res. Rec. J. Transp. Res. Board* **1996**, *1542*, 1–5. [[CrossRef](#)]
54. Friedman, J.; Hastie, T.; Tibshirani, R. *The Elements of Statistical Learning*; Springer Series in Statistics; Springer: New York, NY, USA, 2001; Volume 1.
55. Staub, K.E. A causal interpretation of extensive and intensive margin effects in generalized tobit models. *Rev. Econ. Stat.* **2014**, *96*, 371–375. [[CrossRef](#)]
56. Uchida, E.; Xu, J.; Rozelle, S. Grain for green: Cost-effectiveness and sustainability of China's conservation set-aside program. *Land Econ.* **2005**, *81*, 247–264. [[CrossRef](#)]
57. Zhao, Y.; Xu, Q.; Huang, X.; Ling, C.; Zhong, T.; Li, J.; Zhang, X.; Du, G.; Zhang, B. Effects of land supervision on cultivated land requisition-compensation balance in China. *Trans. Chin. Soc. Agric. Eng.* **2012**, *28*, 1–7.
58. Xu, D.; Li, B. Research on regional ecological compensation performance appraisal based on propensity score analysis. *China Popul. Resour. Environ.* **2015**, *25*, 34–42.
59. Rosenbaum, P.R.; Rubin, D.B. The central role of the propensity score in observational studies for causal effects. *Biometrika* **1983**, *70*, 41–55. [[CrossRef](#)]

60. Abadie, A.; Imbens, G.W. Matching on the estimated propensity score. *Econometrica* **2016**, *84*, 781–807. [[CrossRef](#)]
61. StataCorp, L.P. *Stata Survival Analysis and Epidemiological Tables: Reference Manual Release 14*; Stata Corporation: College Station, TX, USA, 2015.
62. Greene, W. Fixed effects and bias due to the incidental parameters problem in the tobit model. *Econ. Rev.* **2004**, *23*, 125–147. [[CrossRef](#)]



© 2018 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).