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Disentangling the chicken or egg causality dilemma of household waste sorting and segregated waste collection

A randomized controlled trial in India

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Disentangling the chicken or egg causality dilemma of household waste sorting and segregated waste collection: A randomized controlled trial in India*

Shivani Wadehra[a], Zihan Nie[b], and Francisco Alpizar[c]

Abstract

The provision of public goods often requires coordination among different actors. This is the case with waste management. If waste collectors collect waste separately, households would find it more worthwhile to segregate waste at home. If the households could segregate better at source, it would be cheaper for the waste collectors to collect waste separately and reduce processing costs and environmental impacts. However, neither collectors nor households have an incentive to engage in the required behavior if they do not expect the other party to change. In this paper, we aim to disentangle this chicken or egg causality problem with a large-scale intervention that provides a guaranteed segregated collection service and promotes waste segregation at source. Our study takes place in India, where waste management is an important concern. We find that a guaranteed service increases segregated waste only slightly, whereas encouraging households to segregate, given a guaranteed segregated service, increases the waste disposal rate by over 200% and the positive effect is in place even six months after the initial treatment. Our experimental design allows us to show that a reliable segregated waste collection service is key to successful household-side interventions. Breaking the vicious circle of waste segregation may require simultaneous actions from both parties.

Keywords: waste segregation, collection service, information campaign

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Abstract

The provision of public goods often requires coordination among different actors. This is the case with waste management. If waste collectors collect waste separately, households would find it more worthwhile to segregate waste at home. If the households could segregate better at source, it would be cheaper for the waste collectors to collect waste separately and reduce processing costs and environmental impacts. However, neither collectors nor households have an incentive to engage in the required behavior if they do not expect the other party to change. In this paper, we aim to disentangle this chicken or egg causality problem with a large-scale intervention that provides a guaranteed segregated collection service and promotes waste segregation at source. Our study takes place in India, where waste management is an important concern. We find that a guaranteed service increases segregated waste only slightly, whereas encouraging households to segregate, given a guaranteed segregated service, increases the waste disposal rate by over 200% and the positive effect is in place even six months after the initial treatment. Our experimental design allows us to show that a reliable segregated waste collection service is key to successful household-side interventions. Breaking the vicious circle of waste segregation may require simultaneous actions from both parties.

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1. Introduction

The provision of public goods often requires coordination among different actors. This is the case with waste management. Households would find it worth their while to segregate waste at home if waste was collected in a segregated manner by waste collectors. Collecting waste separately would be cheaper for the waste collectors because it would reduce processing costs if households separate waste at source. However, neither collectors nor households have an incentive to engage in the required behavior if they do not expect changes from the other party. Worldwide, municipal solid waste consists on average of 44% organic and 38% recyclable materials (Kaza et al., 2018) and municipal solid waste in developing countries tends to contain more organic content, with a share of 50% or higher (Aleluia & Ferrão, 2016). In India, solid waste consists of around 50% organics, 20% recyclable items and 10% inert waste (Annepu, 2012). This makes the segregation of organics from recyclables a priority , for efficient management of waste in India. In the absence of segregation at source, cross contamination of valuable non-organic materials renders them either unrecyclable or of much lower value due to the more complex processing processes required for their reuse. Similarly, clean organic waste can be used at the households or off-site for compost or as animal feed, thereby avoiding subsequent methane emissions from landfilling of mixed waste.

India's Solid Waste Management Rules (SWMR 2016) mandate that households segregate waste before it is collected (Ministry of Environment, Forest and Climate Change, 2016). Municipalities and NGOs also regularly promote waste segregation at home. However, despite efforts over the years, only a small fraction of households segregates their waste at home (e.g., 12% in the city of Palwal, our study site). The crux of the problem is a mismatch between efforts of actors. On the one hand, governments and municipalities (service providers) complain that lack of household-level waste segregation discourages them from investing in separated waste collection services.[1] On the other hand, households frequently identify the lack of reliable and credible segregated collection services is the reason they give up segregation practices (Nepal et al., 2023; Wadehra & Mishra, 2018). The two together create a vicious cycle that can trap the waste management system in an undesirable equilibrium. One-sided efforts focusing solely on influencing households or ensuring suitable collection services may not be able to move the system out of the equilibrium. In other words, decision-makers face a challenging chicken or egg causality problem in efforts to ensure that waste is properly managed. The situation in India is similar to that in other developing countries, where segregation at source remains a weak link (Biswas, Parida et al. 2021; Kumar & Agrawal, 2020; Srivastava et al., 2015).

In this paper, we aim to disentangle this chicken or-egg causality problem with a large-scale intervention that provides a guaranteed segregated collection service and then evaluates different approaches to

[1] https://www.unicef.org/rosa/stories/investing-waste-management
https://www.hindustantimes.com/cities/campaign-on-solid-waste-management-from-aug-15/story-oNaEVJTRHzGwIqhCrTlGyO.html

promote waste segregation at source. We do this using a carefully designed field experiment that actively monitors the waste sorting behavior of 1,242 households. Our experiment took place in Palwal, India. We worked with local ragpickers to provide a credible door-to-door collection service to collect segregated and potentially recyclable inorganic materials, alongside the regular mixed waste collection service that was available to all households in our sample. We then evaluated to what extent household-level interventions can promote waste segregation at source. Specifically, we examined the effect of a one-shot campaign providing information and in-house sorting devices. For a subgroup of the campaign treatment, we also provided periodical reminders to the households. We monitored households' waste segregation for 7 weeks, roughly one week before the initial treatment and six weeks after the treatment. This continuous monitoring allowed us to explore how effects of the one-shot campaign evolved over time. We also conducted a follow-up survey 6 months after the conclusion of the experiment to explore the extent to which the changes induced by the intervention were sustained without the collection service.

The provision of guaranteed segregated waste collection increased waste sorting at home by about six percentage points, to 18%. This increase was gradual, as households slowly learned about the ragpicker's collection service. The one-shot campaign increased the share of segregating households by 46 percentage points, compared to control households that were not exposed to the campaign but were provided with the segregated waste collection service. Contrary to our expectations and results from previous studies, the initial effect did not fade away over time. Instead, the share of households that segregated their waste steadily increased after the one-shot campaign. The reminders further improved the segregation rate. At the last rounds of waste monitoring, over 90% of households in the reminder group sorted their waste. Even more striking is that 6 months after we stopped the collection service, the share of households who reported to be segregating in the treatment groups was still about 20 percentages points higher than the control group. This persistent effect implies potential habitual changes induced by our experiment.

Our study contributes to an understanding of household waste segregation in several ways. First, a distinctive feature of our interventions is that we introduce a reliable segregated waste collection service. This service was available to all households in our sample and served two purposes. On the one hand, it allowed us to accurately establish if a household is segregating and how much waste is produced. Note that one of the main complications of working with household waste is that it is not regularly measured or easily observable (unlike energy or water consumption). On the other hand, by comparing the baseline waste segregation behavior of households with subsequent measurements, we could establish if a guaranteed segregated waste collection results in increased segregation for households in our sample, using a before-after comparison. Studies that have looked at the role of providing a segregated waste collection service on waste segregation behavior are mostly in developed countries, where collection services targeting a specific type of waste are introduced on top of the

existing segregated collection system. Ek & Miliute-Plepiene (2018) find that a segregated collection service for food waste introduced in Sweden increased collection of segregated packaging waste at municipality level. A similar organic waste collection service in Australia is found to have a slight negative effect on segregated dry recyclables (De Silva & Taylor, 2024). Similar studies in developing countries are far scarcer, probably because segregated collection services have rarely been implemented in these countries. An important aspect of our study is that it is set in a context of minimal institutional trust, as opposed to earlier studies set in the context of higher institutional trust (Mallick et al., 2023; Swaminathan & Palshikar, 2021).

Secondly, we contribute to the literature on using household-level interventions to promote waste segregation at source in developing countries. Our one-shot campaign combines infrastructure (dustbin and collection services) and information provision to induce behavioral changes, but it does so in a best-case scenario of guaranteed segregated waste collection. In this way, we are able to isolate the effect of our campaign from a potentially dysfunctional collection service. Many studies have examined the effectiveness of different policy instruments, including information provision (Dai et al., 2016; Lim-Wavde et al., 2017), moral suasion (Hage et al., 2009; Xu et al., 2016), appealing to social norms (Czajkowski et al., 2019; Wan et al., 2017), monetary rewards (Boonrod et al., 2015; Wadehra & Mishra, 2018; Xu et al., 2018) and enforcement of punitive law (Dur & Vollaard, 2019; Vollaard & van Soest, 2024). However, almost all of these studies assess the impact of household-side intervention within an existing waste collection system. Few studies abstract from the existing system of waste collection. One notable exception that is similar to our study is Nepal et al. (2023), who conduct a field experiment that provides both the waste collection infrastructure at the street and an information campaign in Nepal. They do not find improvements in households' self-reported waste segregation behavior, and speculate that this is because in their interventions the waste was not collected separately. With our experimental design we are able to show that a reliable segregated waste collection service is key to the success of household-level interventions, although the existence of the service itself is not enough. Breaking the vicious cycle in waste segregation requires simultaneous actions from both sides.

We also followed up with the households after 6 months to explore whether households continued segregating in the absence of our collection service. A few studies examine the long-term impact of various interventions on different types of pro-environmental behavior (for example, Allcott & Rogers (2014) on electricity use). However, similar studies on waste segregation are rare, particularly those looking at effects after removal of the intervention. Vollaard and van Soest (2024) show that a short enforcement campaign can lead to a persistent improvement in the quality of segregation in a Dutch city, which they attribute to habit formation. In a setting where the baseline segregation rate was much lower, we show that changes in waste segregation can survive even after the collection service is stopped. This finding provides further evidence for the idea that new habits can be formed in a relatively short time frame.

Our study also evaluated the prospects of incorporating ragpickers into the waste collection system. Incorporating the informal sector into the formal waste collection system is encouraged in the SWM Rules 2016. Our results show that the resale value from the collected non-organic waste was enough to make if financially beneficial for ragpickers to do full-time door-step waste collection. In the follow-up survey, we find that households were willing to pay a non-negligible amount for the service, suggesting the collection service improved household welfare and there is room to charge households for such a service.

The paper proceeds as follows. Section 2 provides backgrounds information on waste segregation policies and practices in India and waste collection and segregation realities in our study site. Section 3 describes the experiment. Section 4 provides the main results. Section 5 discusses further exploratory results, potential mechanisms, and the financial implications of the intervention as a policy instrument. Section 6 concludes the paper.

2. Background and Study Site

2.1 Waste Segregation Policy in India

In India, Solid Waste Management Rules 2016 (MoEFCC, 2016) mandate households to segregate waste before it is collected. As per the rules, waste should be separated into three categories: dry waste, wet waste, and hazardous waste. Dry waste consists of items such as plastics, cardboard boxes, wrappers, and bottles. Wet waste consists of most organic items such as kitchen waste. Hazardous waste consists of waste materials that potentially pose health and environmental risks and need to be treated separately, such as electronic and electrical waste. Although these are the rules notified by the central government, municipalities still follow two-category segregation, into dry and wet waste. It is this definition of segregation that we use for our intervention.

2.2. Study Site

We conducted the study in the city of Palwal, in the state of Haryana, India. It covers an area of 1,359 km^2 with a population of 1 million (Census of India, 2011). The city is divided into 31 wards. The municipal council provides street sweeping and garbage collection from secondary points in all 31 wards. Residents can dump their waste to the collection points themselves. Many residents also pay garbage collectors to collect their waste at their doorstep. In five wards, about 8,300 households also have the option of door-to-door collection by auto tippers, which is provided by the municipality through a private contractor.[2] We choose these five wards to run our experiment because the availability

[2] The auto tipper provides door to door collection for lanes it can enter and for independent houses. Residents of multi-storied houses are expected to bring their waste down. Residents who live in lanes that are too narrow for the tipper, are expected to bring their waste to the tipper. According to the contractor's supervisors, at the time of the study, there were 8 auto tippers. The auto tippers collect waste daily from 7:30-12:00 and then 14:30-16:00 or

of reliable waste collection service is the basis for any meaningful effort to push for waste segregation at source.[3] Despite the requirement of waste segregation by the national decree, waste segregation at source is not a common practice in Palwal. Official data on household-level waste segregation is not available. In our sample, at the baseline, only 12.6% of households segregated their waste.

Most waste segregation occurs in the form of post-collection segregation, where ragpickers sort sellable recyclable waste such as plastic bottles, metals, and cardboard out of the mixed waste at the dumpsites.[4] Ragpickers play a pivotal role in ensuring a certain degree of recycling by recovering these discarded items and introducing them into the informal waste recycling chain. Such segregation is carried out under poor hygiene conditions, though. The ragpickers are exposed to infections and injuries, while earning a meager income from their segregation efforts.

3. Experimental Design

The experiment has two major components: an independent segregated waste collection service for inorganics in addition to the existing waste collection system; and a household-level intervention to promote waste segregation at home.

3.1 Guaranteed Segregated Waste Collection Service

The literature finds that households in developing countries often cite mixing of waste by the garbage collector as a reason for not segregatign their waste at source or discontinue segregation (Nepal et al., 2023; Wadehra & Mishra, 2018). To overcome this challenge, we introduce a guaranteed collection service for inorganic waste in addition to the one provided by the municipality. Households found the municipal waste collection service unreliable and also to have a poor history of collecting segregated waste. To strengthen perceptions of the reliability and credibility of the service, we organized local ragpickers who normally collect recyclable waste from dumpsites as our waste collectors. The ragpickers only collected segregated inorganics (including dry recyclables and inert waste) from the households and left the unsegregated waste and organic waste to the usual waste collectors. The collection service was provided to all households in our study. This service serves as the basis to disentangle the chicken or egg causality problem we set out to examine.

17:00.

[3] While all households in the 5 wards have the option of door-to-door collection by auto tippers, not all households use the service, either because they already have a garbage collector who provides door to door collection or because of time mismatches. According to official communication from the municipal council, about 60% of the residents in the 5 wards use this service. The municipality presently does not charge the households for the service.

[4] No detailed data on waste generation in Palwal was available, at the time of study. A rough estimation by the Executive Officer of Palwal Municipality is that the average amount of waste generated was about 400g per person per day. With this number and the estimated waste composition, the total waste generated by the city was estimated to be about 400 tons per day, comprising 30% dry recyclables, 55% wet (organic) waste, and 15% inert waste.

Enumerators in our study served the dual purpose of ensuring that the additional collection service was reliable, and measuring households' waste segregation behavior. If the waste was segregated, the inorganics bin was handed over to the ragpickers, after being weighed. Where the waste was not segregated, the enumerator weighed the waste and returns it to the household, leaving it to be collected by their usual waste collector. In this way, the additional collection service ensured that the waste from households who segregate their waste is not mixed by the collector. The ragpicker's inorganics[5] collection service did not provide households with information on how to segregate properly. This was particularly important for the control households, who were exposed to the collection service but not to the information treatment. This setting of the control group also imitates the setting in which the municipal authorities generally provide services. The service itself carries no risk of contamination between treatment and control.

Collecting segregated recyclables at the household doorstep provides a cleaner work environment for ragpickers, and thus reduces their susceptibility to diseases. In addition, such a collection system has the potential to keep recyclables uncontaminated and thereby reducing the cost of recycling. Further, such a collection service aligns with the Indian governments' emphasis on involving the informal sector in waste management (MoEFCC, 2016). We explore the cost-effectiveness of this collection service and its potential as part of the municipal waste management system.

3.2 Interventions

Our interventions at the household level was a household campaign that aimed to promote waste segregation at source. The campaign had two components: information provision through supplying households with an information brochure, and the provision of a dustbin for segregation to each household. The information brochure offered households information on how to segregate their waste according to the SWM Rules 2016.[6] It aims to increase the households' understanding of the benefits of waste separation and their intrinsic motivation to do so. The bin was provided to the households for free and households were told that they could use the bin to store inorganic waste such as plastics. We provided the bins to reduce the behavioral costs of waste segregation. The bins could provide the physical infrastructure to store the waste and might serve as a reminder to segregate.[7] There would be no consequences regardless households' decisions to use or not to use the bins. In the household campaign the brochure and bins were delivered only once to the household in a face-to-face interaction.

For half of the treatment group, selected randomly, we enhanced the initial one-shot campaign with reminders after the initial campaign delivery. The reminders were delivered in form of a leaflet with

[5] In our endline survey, all households reported they were aware of the collection service we provided.
[6] Details of the brochure are in the Appendix.
[7] Studies such as Bernstad et al. (2013) and Miafodzyeva & Brandt (2013) point out the households' storage constraints regarding waste segregation should be considered when designing waste segregation systems and policies. Providing additional bins for the segregated collection service is also a common policy approach (Alacevich et al., 2021; De Silva & Taylor, 2024).

information about the benefits of waste segregation. These were meant to increase waste segregation by refocusing households' attention on segregation, as inattention could lead to decay of daily behavioral changes. The reminders were delivered on a weekly basis to the households by the enumerators. After two rounds of the reminders, households could decide whether they wanted to continue receiving the next two rounds of reminders, through a multiple price list approach.[8] For the brevity and clarity, we will refer to the group that received only the campaign as the Campaign group (T1) and refer to the group that also received the reminders as the Campaign with Reminders group (T2).

Household in the control group, received only the collection service from the ragpickers. This group served as a benchmark for evaluating the effect of the household-level campaign. We also use the before-after comparison of waste segregation as a simple benchmark for what was happening before our intervention and what happened when the guaranteed waste collection service was introduced.

Ideally, to fully disentangle the chicken or egg causality dilemma in waste segregation at source, the study should have an additional experimental group that receive only the household-level campaign, with no segregated collection service, as well as a control group with no interventions. While having an untouched control group is methodologically sound for identifying the causal effect of the collection service itself, in practice it is very hard to observe waste segregation without some sort of intervention on the control group. Therefore, we rely on the before-after comparison of waste segregation in our sample to shed some light on the effect of the guaranteed service provision and compare the treatment groups with the control group to identify the effect of household-side intervention on waste segregation behavior given the guaranteed collection service.

3.3 Measuring waste segregation: waste monitoring

We measure waste segregation behavior at the household level by having a team of two persons, an enumerator and a ragpicker, actually inspect and weigh the household waste. The enumerators weigh the waste and observe if the households handed over different types of waste separately or not. Normally, this type of waste monitoring would be rather intrusive or strange to the households, which may induce strong demand effect. However, the additional segregated waste collection service provide us with a reasonable cover to do so. Given that the premise of the collection service is to only collect segregated inorganic waste, it is natural to inspect the waste. Moreover, households only see the enumerator weighing their waste but the fact that information on segregation is also being collected. Figure 1 shows how we define our outcome variables based on the waste monitoring.

[8] Similar to Allcott and Kessler (2019), we intended to use this approach to elicit households' subjective valuation of the reminder service.

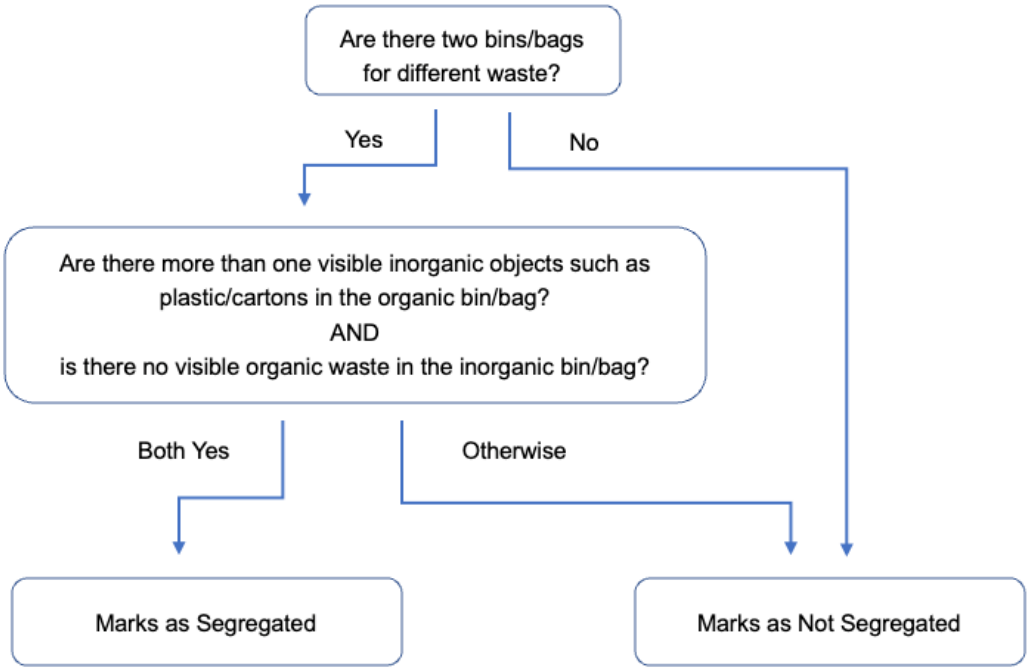

Figure 1. Definition of waste segregation in our study based on waste monitoring.

Enumerators are given strict instructions to mark the waste as unsegregated if they find more than one plastic/packaging item in the organic bin and if the inorganic waste is visibly contaminated by organic waste. The waste monitoring in the above manner is repeated every four days. In total, there are thirteen rounds of waste monitoring, once at the baseline and twelve rounds post-intervention.

At the baseline, garbage was weighed one day after the household survey. Households were informed that their garbage would be weighed the next day, because a few households might have the habit of disposing their garbage as soon as it was generated. Households were unaware of the purpose of weighing their waste and the interviewer's expectations. We collect baseline data only once to reduce Hawthorne effect. We therefore believe that our baseline waste monitoring captures the natural state of households' segregation behavior.

Importantly, the monitoring of waste had to be finished before it was picked up by the usual collector, so enumerators only had 2-3 hours in the morning for this task. Given such time limitations, and the need to monitor and collect segregated waste at the same time, we were unable to monitor each household randomly. While household monitoring did follow a pattern, the particular days on which households were monitored were not fixed, so we do not expect our results to be affected by day-of-week effects. Adding to this, the fact that households were unaware that their segregation habits were being monitored, we do not expect our results to be affected by experimenter demand effects.

All households in the treated and control groups were subjected to the same waste monitoring system, in all rounds of monitoring, including the baseline.

3.4 Follow-up Survey: Six months after completion of the Experiment

We also conducted a follow-up survey six months after the initial experiment was completed. Households were not informed of this survey in advance. No segregated collection service was provided to households in these six months or during the follow up survey. The objective of this survey was to understand if households continued segregating as a result of our interventions. Another objective was to understand whether households are willing to pay for an additional collection service. We rely on self-reported waste segregation behavior to evaluate the persistent effect.

3.5 Data Collection

We conducted the main body of the experiment during December 2021 – March 2022. Households in the five wards serviced by auto-tippers with regular doorstep waste collection service formed the sampling frame for the experiment. From the selected wards, we sampled households, proportionate to the population of the wards, following a stepwise systematic randomization. In the next step, lanes were chosen and every third household was sampled. In case a household refused to be a part of the study, it was replaced by the next house. In the five wards, we randomly invited 1,328 households to participate in our study and 1,242 households consented to join. All of the 1,242 households stayed in the sample throughout the experiment. In the baseline waste monitoring, the waste segregation behavior of all households was collected. Due to reasons such as households were not at home or households had disposed of their waste prior to our enumerators collecting data, there were times that the enumerators could not observe households' waste segregation behavior at the scheduled monitoring day in a certain round. In such cases, the enumerators would revisit those households the next day. Despite our effort to revisit households, there are still some missing values in later rounds. However, the missing values in each round never exceeded 2.2% (27/1,242). Overall, 98.3% of the households were monitored at least 11 times. Therefore, we believe that the missing values will not pose an issue to our evaluation.

We employed 10 ragpickers to provide the separated collection service. We paid them a fixed daily wage of 400 INR and they could sell the recyclables collected from the households. The daily wage was to guarantee that the ragpickers would show up every day.

The follow-up survey was carried out in September 2022. The enumerators visited the households at the recorded address in the baseline survey. If the households were not present, the enumerators would revisit on the next day. Among the 1,242 households in the original sample, our enumerators were able to trace back 1,194 households.

4. Results

4.1 Summary Statistics and balance check

We first give a brief description of our sample and check if the randomized treatment allocation actually generated a balanced sample across groups. **Table 1** describes the demographic and economic characteristics of the households in our sample, as well as for the subsamples of the treatment and control groups. The information is obtained from our baseline household survey.

Most of respondents of the survey are middle-age females, who are likely to be responsible for daily waste management. The education levels of the respondents are diverse. Over a quarter have received higher education but there are almost 16% that are illiterate. The average household size is 5.3 members. Over 93% households have at least one refrigerator and 10% with a microwave. The self-reported household monthly income concentrates in the range between INR. 0 – 60,000.

The demographic and economic characteristics of the treatment and control groups are largely balanced. In most of the cases, the sample means of the variables are close. In some cases, we do see slight difference between two groups. For example, one key variable that shows signs of unbalance is the proportion of households not having a refrigerator. Having a refrigerator or not is an important factor for household waste generation. While the proportions are similar with T1 and T2, it is higher in the control group. Proportion tests show that the difference between Control and T2 is marginally significant at 10% level. Despite signs of some differences between certain groups for particular variables, a joint evaluation approach shows no individual and household characteristic could predict the allocation to the treatment or control groups (Details in Table A1 and A2 in Appendix). Hence, we believe the overall the randomization process has produced a balanced sample across groups with regard to demographic and economic characteristics.

Table 1. Summary statistics by treatment conditions

	Total	Control	Campaign (T1)	Campaign with Reminders (T2)
No. of obs.	1242	422	389	431
Respondent's characteristics				
Age	44.2	44.1	42.7	45.6
Female	72.8%	76.1%	70.2%	71.9%
Education levels				
Illiterate	15.5%	16.6%	13.9%	15.8%
Up to class 5	9.8%	9.5%	11.3%	8.8%
Up to class 8	11.3%	10.7%	11.8%	11.4%
Up to class 10	15.0%	15.9%	11.8%	16.9%
Up to class 12	15.4%	14.5%	16.7%	15.1%

Diploma and certificate	6.9%	5.9%	7.5%	7.4%
Graduate	17.3%	17.5%	19.3%	15.3%
Post graduate and above	8.9%	9.5%	7.71%	9.3%
Household characteristics				
Household size	5.3	5.3	5.3	5.3
Area of housing*	115	110	120	116
No refrigerator	6.2%	8.1%	5.4%	5.1%
Have microwave	10.2%	9.5%	10.3%	10.9%
House ownership	87.8%	84.5%	89.7%	89.1%
Household income**				
Below Rs. 30000	50.0%	51.0%	48.8%	50.1%
Rs. 30000-59999	37.5%	37.1%	38.9%	36.6%
Rs. 60000-99999	9.0%	9.2%	8.5%	9.3%
Above Rs. 1 lakh	3.5%	2.7%	3.8%	4.0%

Note: Calculated by the authors from the data.

* There are missing values for the area of housing. Only 1171 households with valid information in total, with 394 in Control, 366 in T1 and 411 in T2.

** There are households refused to provide income information. There are 1088 households that provided income information with 369 in Control, 342 in T1 and 377 in T2.

We further look at the waste related behavior before the intervention, particularly the waste segregation behavior. Note that at this stage there is still no differential treatment in our sample. Table 2 shows the waste segregation and waste generation observed at the baseline monitoring. At the baseline monitoring, the households in our sample on average generated 1.71 kg waste for collection. Accounting for the time since previous waste collection, an average household in our sample generated 1.11 kg waste per day, which puts waste generation per capita per day at 0.22 kg. This number is in range of the estimated waste generation in India, which is 0.2 - 0.6 kg per capita per day (Kaushal et al., 2012). We find no significant difference in the amount of waste generated by households between groups.[9]

Overall, about 12.6% of the households (156/1242) segregated their waste at the baseline. The differences at the baseline between control and treatment groups in households' waste segregation behaviour is small in absolute terms and not statistically significant.[10] We further look at the amount of segregated waste generated by the waste-segregating households. The total amount of waste of these households is larger than the sample mean, and thus greater than those of the households that did not segregate. About 77% (1.76/(0.51+1.76)) of the total waste is organic, which is consistent with typical waste composition in typical Indian cities (Kumar & Agrawal, 2020). Again, between groups, there are no statistically signifcant differences. The fact that households across groups behaved very similarly in

[9] In pairwise t-tests for weight of waste collected at baseline monitoring, Control vs. T1, p=0.891; Control vs. T2, p=0.407; T1 vs. T2, p=0.539; for waste per day, Control vs. T1, p=0.423; Control vs. T2, p=0.616; T1 vs. T2, p=0.779.

[10] In pairwise tests of proportions, Control vs. T1, p=0.825; Control vs. T2, p=0.689; T1 vs. T2, p=0.865.

waste generation and segregation at baseline offers us confidence in the quality of our randomization process and thus the casual inference of the treatment effects.

Table 2. Baseline waste management behaviour by groups

	Total	Control	Campaign (T1)	Campaign with Reminders (T2)
Weight of household waste at collection (kg)	1.71	1.74	1.73	1.66
	(1.55)	(1.48)	(1.71)	(1.47)
Waste per day (kg)	1.11	1.13	1.09	1.10
	(0.74)	(0.71)	(0.73)	(0.78)
Segregated	156	51	49	56
Not Segregated	1086	371	340	375
% of segregation	12.6%	12.1%	12.6%	13.0%
For households that segregated waste				
Weight of inorganics at collection (kg)	0.51	0.46	0.55	0.52
	(0.42)	(0.39)	(0.40)	(0.47)
Weight of inorganics per day (kg)	0.33	0.32	0.34	0.34
	(0.29)	(0.22)	(0.23)	(0.38)
Weight of organics at collection (kg)	1.76	1.70	1.99	1.63
	(1.66)	(1.36)	(2.09)	(1.49)
Weight of organics per day (kg)	1.10	1.19	1.06	1.05
	(0.68)	(0.60)	(0.70)	(0.70)

Note: Calculated by the authors from the baseline waste monitoring data. Standard deviation in parentheses. For households that segregated their waste, the total weight of waste is the sum of the weight of recyclables and the non-recyclables; for households that did not segregate, the total weight of waste is the weight of the mixed waste.
Pairwise t-test between the three groups for segregated organic waste: $p>0.27$; for segregated inorganic waste, $p>0.25$. There are no significant differences.

Households segregated their waste mostly because they could use the organic waste as animal feed or for compost at home. In the baseline survey, only 13% (165/1,242) were aware of the Municipal Solid Waste Handling Rules 2016. When asked about if they knew how the household waste could be processed, only 14% (177/1,242) could offer an answer, and these 165 households gave diverse answers when pressed further for details. Fewer than 3% had any idea what waste treatment facilities Palwal had. In sum, households in the baseline clearly do not have enough knowledge about proper waste management practices, and there seems to be an untapped potential to improve waste segregation in Palwal.

4.2 Treatment effect on household waste segregation

Figure 2 plots the evolution of the share of households that segregated their waste over entire study period by treatment condition. The horizontal axis represents the waste monitoring rounds. Round 0 represents the baseline round. The intervention took place right after the baseline was collected, and is

indicated by red dotted line. Round 1-12 are the post-intervention monitoring rounds. For the households that received reminders after the initial campaign, the first two reminders were delivered every two rounds of waste monitoring (indicated with the green dotted line). At Round 7, we gave households an option to opt out of the reminder service. For the households who kept the reminders, we deliver another two reminders (the timing is shown by the blue dotted line). For the households who opted out, they did not receive these reminders.[11]

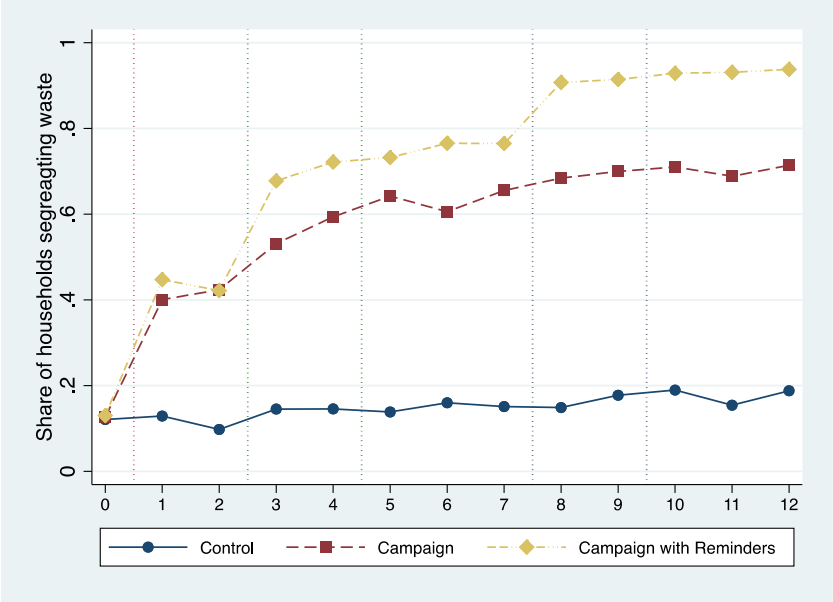

Figure 2. Household waste segregation rate over the study period by treatment conditions

We first look at the control group. The waste segregation rate in the control groups stays relatively stable over 13 rounds of waste monitoring. It increases gradually from 12.1% at the baseline to 18.8% at the end of the experiment. Even though the relative increase is large (over 50% from the baseline level), the absolute size of the increase is small and the segregation rate remains low in comparison to the treatment groups. Comparing the segregation rate at the baseline (12.1%), which we regard as the pre-intervention "natural" state, and the average segregation rate for the control group in post-intervention rounds (15.2%), we find that the guaranteed collection service only increases segregation rate by merely 3.1 percentage points. Even if we allow for a discovery period and use the segregation rate in the last round (18.8%), the increase in segregation is just 6.7 percentage points.

The validity of the before-after comparison is built on the assumption that there were no other concurrent events that would affect households' waste segregation behavior or there is no natural trend in waste segregation behavior. We are not aware of any other campaigns, interventions or policy changes in Palwal with regard to waste segregation during the experimental period. A natural increasing

[11] The vast majority of the households (382 out of 431) continued to receive the reminders.

trend due to increasing environmental awareness and concern might happen, but it is unlike to happen this fast.[12] One concern would be the experimenter demand effect, where repeated visits by the ragpickers and enumerators could have pushed more households into segregating over time. Another concern would be potential spillover effects. Because we ran a household level randomization, there were chances that a treated household talked to a household in the control and made the household more likely to segregate. However, in both cases, the true effect of having the segregated collection service would be even smaller than what we observed. This (lack of) change over time highlights the limited role of a segregated collection service alone could play in achieving higher waste segregation rates. The one-sided effort of the service provision was not enough to induce sufficient household waste segregation. In this sense, the collectors seem to be right in their complain that it is pointless to provide the segregation service. This result aligns well with the situation in Palwal, where municipal auto tippers have two separate compartments for segregated collection as mandated by the national legislation, but in practice they are not used in such way.

We now focus on the treatment groups. Given the guaranteed segregated waste collection, the household campaign results in a sharp immediate increase in waste segregation post-intervention. The segregation rate of informed households in T1 is 40.1% in the first round of post-treatment monitoring and 42.4% in the second round, compared to 12.6% in the control group. For T2, the corresponding segregation rates are 44.7% and 42.1%. These over three-fold increases, compared to the control, represent a very large immediate impact of the intervention.

What's more interesting is that for the one-shot campaign intervention (T1), the initial impact did not fade away as we expected based on previous findings in similar settings (Wadehra and Mishra, 2018). On the contrary, there is a steady increase in the segregation rate over time. In the last round of the waste monitoring, 71.4% of the households segregated. With a guaranteed collection service for the inorganics, we see sustained changes in households' waste segregation behavior.

Before receiving the reminders, households in the reminder group T2 received the same intervention materials as T1, and as expected, the effects are very similar. The divergence between T1 and T2 comes after the first reminder, where the segregation rate in T2 jumps to a higher level at Round 3. The increase after the second reminder is rather mild. Interestingly, despite a part of the households in T2 declined to receive reminders after Round 7, there's another jump in segregation rate at Round 8 to over 90%, and then remain slowly increasing afterwards. At the last round of waste monitoring, the segregation rate in T2 reaches a stunning 93.8%, with almost all households segregating their waste.

The comparison from **Figure 2** reveals significant positive effects of our one-shot intervention on household waste segregation, and the positive effects is further reinforced by the reminders. Now we

[12] If the rising trend reflects the natural trend of behavioral changes, the 6-percentage-points increase in two months would have meant a 36-percentage-points increase in one year. Given that the Nation Decree on waste segregation was introduced in 2016 and we only found a 12% segregation rate at the baseline, this is very unlikely.

formally estimate the size of the effects for different stages of the game using regression models. **Table 3** shows the results based on linear probability models.

In column (1), we estimated the average treatment effects for the entire study period. Specifically, we estimate the following regression model:

$$Y_{it} = \alpha + \beta_1 T1_i * Post_t + \beta_2 T2_i * Post_t + \boldsymbol{\theta T_i} + Post_t + DoW_{it} + \varepsilon_{it}. \qquad (1)$$

Y_{it} is a binary variable indicating whether a household i is segregating or not at monitoring round t. It equals 1 if the household i is segregating, otherwise 0. *T1* is a binary indicator for the Campaign group; *T2* is a binary indicator for the Campaign with Reminders group; and $\boldsymbol{T}$ is the treatment group status vector for T1 and T2; *Post* indicates post-intervention period and takes the value 1 for rounds 1 to 12 and 0 for round 0; DoW_{it} are the week of day dummies capturing the potential weekday/weekend patterns. Coefficients of the two interaction terms, β_1 and β_2 are the parameters of interest, representing the average treatment effect of the interventions. The coefficient of *Post* can also be interpreted as the effect of having a guaranteed segregated waste collection service.

Overall, receiving the one-shot campaign alone increases household's probability of waste segregation by 45.5 percentage points, which is an increase of 3.76 times from the baseline in the control. Strengthening the one-shot campaign with reminders proves to be even more effective, raising the treatment effect by another 15 percentage points to 60 percentage points[13], representing an almost five-fold increase from the baseline levels. These results mean that our intervention has been very successful in promoting household waste segregation despite being purely voluntary-based and involving no monetary incentives. As shown by the coefficient of *Post*, simply offering the separate collection service by the ragpickers barely affects the waste segregation behavior of households.

Because the experiment has several phases with different experimental elements, particularly for the group with reminders, we also look at the treatment effects of different phases separately. We classify all the post-intervention waste monitoring into three phases. Phase 1 includes Round 1 and 2, where both treatment groups received the same one-shot provision of information and waste bins. Round 3-7 are phase 2, when the Campaign with Reminders group received reminders. Phase 3 is Round 8-12, when households who received reminders before had the option to choose to keep the reminders or not. Accordingly, we replace the post-intervention indicator in equation (1) with the three phase indicators and estimate the following model:

$$Y_{it} = \alpha + \sum_{K=1}^{3} \beta_{1K} T1_i * PhaseK_t + \sum_{K=1}^{3} \beta_{2K} T2_i * PhaseK_t + \boldsymbol{\theta T_i} + \sum_{K=1}^{3} PhaseK_t + DoW_{it} + \varepsilon_{it}. \qquad (2)$$

The results are reported in the column (3) of **Table 3**. In Phase 1, as expected, the treatment effects of both T1 and T2 are the same. Right after receiving the intervention, the probability of household waste segregation increased by around 30 percentage points. The effect of the one-shot campaign in T1 does

[13] The difference in coefficients is statistically significant at 1% level.

not fade away as time goes by. On the contrary, its effect goes up to 45 percentage points in Phase 2 and to 52 percentages points in Phase 3. These increases in effect sizes are also statistically significant.[14] This implies that our one-shot campaign along with a collection service may have triggered sustained changes in waste segregation habits.

For households in T2 that received reminders in phase 2, the reminders reinforce the already strong effect, improves the probability of segregation by 57.4 percentage points, 12 percentage points higher that the effect of T1 in the same phase.[15] Strikingly in Phase 3, despite some households stopped receiving the reminders, the effect is stronger and its relative effectiveness to T1 also gets larger, rising from a difference of 12 percentage points in Phase 2 to 22 percentage points.

As we tentatively interpret the coefficients of the post-intervention dummies as the effect of the service provision, we see that the effect only gets larger and statistically significant in later stage of the experiment. If we add post-intervention time trend to equation (1), we could find a slow rising trend of 0.56 percentage points per round. Households' responses to the guaranteed collection service per se are far from impressive.

To alleviate any concern for the slight imbalance in certain variables such as owning a refrigerator or not, we also estimate the equation (1) and (2) with additional individual and household characteristics listed in Table 1. The results are shown in column (2) and (4) respectively in Table 3. While a few variables such as some education levels, having a refrigerator and some income levels are associated with waste segregation, including these control variables has almost no impact on the size of the treatment effects. Therefore, to utilize the most of the sample size, we focus on the results without these controls in most parts of the analysis.

Table 3. Average treatment effect on waste segregation

	(1)	(2)		(3)	(4)
	Overall effect	Overall effect		Effect by phases of the experiment	Effect by phases of the experiment
T1*Post	0.455***	0.451***	T1*Post Phase 1	0.294***	0.296***
	(0.028)	(0.030)		(0.032)	(0.035)
T2*Post	0.598***	0.599***	T2*Post Phase 1	0.312***	0.304***
	(0.026)	(0.028)		(0.030)	(0.032)
			T1*Post Phase 2	0.452***	0.453***
				(0.030)	(0.033)
			T2*Post Phase 2	0.574***	0.571***
				(0.029)	(0.031)
			T1*Post Phase 3	0.522***	0.512***
				(0.030)	(0.033)

[14] The pairwise tests between the three coefficients of the three phases of T1 are all significant at 1% level.
[15] The difference is statistically significant at 1 % level.

			T2*Post Phase 3	0.742***	0.746***
				(0.027)	(0.029)
Campaign (T1)	0.006	0.010	Campaign (T1)	0.0051	0.010
	(0.023)	(0.025)		(0.023)	(0.025)
Campaign with Reminders (T2)	0.0115	0.010	Campaign with Reminders (T2)	0.009	0.011
	(0.022)	(0.024)		(0.023)	(0.024)
Post intervention	0.024	0.043**	Post Phase 1	-0.000	0.014
	(0.018)	(0.020)		(0.018)	(0.020)
			Post Phase 2	0.032	0.044**
				(0.020)	(0.021)
			Post Phase 3	0.056***	0.064***
				(0.020)	(0.022)
Day of week dummies	Yes	Yes	Day of week dummies	Yes	Yes
Individual and household characteristics	No	Yes	Individual and household characteristics	No	Yes
Constant	0.134***	0.043	Constant	0.124***	0.117**
	(0.017)	(0.055)		(0.017)	(0.047)
No. of Obs.	15,928	13,291	No. of Obs.	15,928	13,291
R^2	0.299	0.310	R^2	0.346	0.360

Note: Linear probability models are used to estimate the regression models. Standard errors clustered at household level in parentheses. Individual and household characteristics include respondents' age, gender and education, household size, housing size, if the household has a fridge, if the households has a microwave, if the households own the house they live in, and household income level.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

4.3 Treatment effect on Weight of Waste

Because of the prevailing low waste segregation rates among Indian households, we designed our experiment to evaluate how to effectively improve segregation rates. However, segregating is only one aspect that affects the success of a segregated waste management system and the environmental consequences of waste segregation. Upon segregation, the quantity of waste collected is also an important aspect. In our particular setting where we mobilized ragpickers to collect inorganic waste, the quantity of recyclables directly links to the economic incentives for the rag-pickers and the potential to incorporate the informal sector into a formal waste management system.

We estimate the treatment effects on the quantity of segregated inorganic waste. For the segregating households, we measured the weight of the segregated inorganics during waste monitoring. For non-segregating households, we set the weight to be zero, even though their mixed waste still contains inorganics that could be sorted out later at dumpsites.

Table 4 shows the average treatment effects on the weight of collected inorganics and the treatment effects by different phases of the experiment for the whole sample, where we replicate the regressions in **Table 3**, but use the weight of segregated inorganics as the dependent variable. Overall, our one-shot campaign increases the segregated inorganics by 0.062 kg per household per day and the campaign

reinforced by reminders increases segregated recyclables by 0.081 kg per day per household. The latter is marginally larger than the former (statistically significant at 10% level). The size of the effects may look small because this is the average effect across all households including those who did not segregate. The relative size of the effects is still very large. The weight of recyclables segregated and collected at the baseline monitoring round is only 0.042 kg per day per household. An increase of 0.062 kg per households per day in T1 means an increase from the baseline by 148% and the 0.081 kg per household per day increase in T2 represents a 193% increase from the baseline. The campaign more than doubled the amount of recyclables collected from the households. To further put the effect size into perspective, during the experimental period, our interventions have increased the proportion of sorted-out recyclables from 3.8% at the baseline to 9.4% (T1) and 11.1% (T2). If we follow the baseline number from the segregating households in Table 2 that in Palwal 22% household waste are inorganic, then our intervention managed to sort out about 43-50% of total inorganic waste generated by the households in the sample. This may even be a underestimation because many households already sorted out recyclables with high residual value without our intervention.

Table 4. Average treatment effect on weight of collected clean inorganics

	Weight of collected clean inorganics
T1*Post	0.062***
	(0.010)
T2*Post	0.081***
	(0.011)
Campaign (T1)	0.004
	(0.009)
Campaign with Reminders (T2)	0.007
	(0.011)
Post intervention	-0.009
	(0.007)
Constant	0.038***
	(0.006)
No. of Obs.	15928
R^2	0.102

Note: Standard errors clustered at household level in parentheses. The dependent variable is the weight of collected recyclables per day calculated from dividing the weight at the collection by the days since last collection.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

An important confounding factor of the above findings is the potential rebound or unintended spillover effects. Households might start to generate more inorganic waste and/or organics as a result of waste segregation through behavioral mechanisms such as moral licensing. Studies have found evidence that a strong rebound effect could occur when environmentally friendly alternatives are provided for free

(e.g. Alpizar et al., 2024). If this is the case, the environmental benefits of more segregation will be at least partly neutralized. The spillover effect could also be in favor of waste reduction as people could seek consistence in pro-environmental behavior. For example, Alacevich et al. (2021) found that separated collection of organic waste had a substantial positive spillover effect on waste reduction in a Swedish municipality.

We first address this concern by examining if the treatments have any unintended effect on the total amount of waste generated. We run the same regression as before, but using the weight of household waste per day as the dependent variable. For segregating households, the weight is the sum of the weight of both organic and inorganic waste; for non-segregating households, it is the weight of the mixed waste. The results are shown in **Table 5**. We do not see significant increase in household waste generation. This result helps alleviate the concern for rebound effects.

Table 5. Treatment effect on waste generation

	Weight of household waste per day
T1*Post	0.046
	(0.045)
T2*Post	0.002
	(0.045)
Campaign (T1)	-0.041
	(0.051)
Campaign with Reminders (T2)	-0.024
	(0.051)
Post intervention	-0.101***
	(0.030)
Day of Week controls	Yes
Constant	1.129***
	(0.036)
Observations	15,913
R^2	0.003

Note: Standard errors clustered at household level in parentheses. The dependent variable is the weight of household per day calculated from dividing the weight at the collection by the days since last collection.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

As a final exploration, we look into the source of the observed changes in the weight of segregated inorganics. In principle the change might be the result of more households segregating (the extensive margin) or households that were already segregating simply generating more clean inorganic waste (the intensive margin). We follow the decomposition method used by Attanasio et al. (2011) and Carranza et al. (2020) to decompose the average treatment effect into effect at the extensive margin and effect at the intensive margin. Table 6 shows the decomposition of the overall treatment effects by treatment groups.

Table 6. Average treatment effect on weight of collected clean inorganics

	Campaign (T1)	Campaign with Reminders (T2)
Total effect	0.062***	0.088***
	(0.010)	(0.004)
Extensive margin effect	0.094***	0.127***
	(0.006)	(0.003)
Intensive margin effect	-0.032***	-0.039***
	(0.007)	(0.003)
Treatment effect conditional on segregation	-0.053***	-0.052***
	(0.011)	(0.003)

Note: Standard errors clustered at household level in parentheses. The dependent variable is the weight of collected recyclables per day calculated from dividing the weight at the collection by the days since last collection. We follow the decomposition method used by Attanasio et al. (2011) and Carranza et al. (2020).
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

We see that the positive average treatment effects of both treatment conditions on the weight of collected inorganics are driven entirely by the effects at the extensive margin, i.e., effects on the segregation rates. Moreover, the difference in the relative effectiveness of the two treatments also comes from the extensive margin, as T2 can better promote participation in waste segregation due to the reminders. Conditioning on segregation, the effects on the weight of segregated inorganics are actually negative, meaning our treatments reduces the weight of inorganics segregated by the households. The sizes of these negative conditional effects are almost the same for both treatments, suggesting the reminders works only at the extensive margin, rather than the intensive margin. The conditional effects are also sizable. Given that on average a household that segregated its waste can generate 0.33 kg inorganics per day, a decrease by 0.05 kg mounts to a 15% decline. The negative conditional effect further confirms that the rebound effect did not happen. Households do not increase their waste generation, but rather their consumption of inorganic waste has changed for the better.

5. Further Discussions

Our experiment finds that given a segregated waste collection service, a one-shot campaign that provided waste segregation information and a dustbin to the households produced a very large positive effect on their waste segregation behavior. Besides the overall size of the effect, we observe not only that the one-shot campaign generates a large initial impact, but also that the initial impact gradually increased over the roughly 7-week post-intervention monitoring period. For the households that were provided with reminders after the one-shot campaign, the treatment effect follows the same time pattern, but gets even stronger after the reminders. The time pattern of the effects is particularly interesting and to a large extent surprising. We expected to find a declining treatment effect over time for the one-shot campaign, which was to be enhanced by the reminders. This is also what is usually seen in the literature,

where the effect of one-shot campaigns and behavioral nudges tends to fade away fast (Brandon et al., 2017; Osbaldiston & Schott, 2012; Wadehra & Mishra, 2018).

There are several channels through which our intervention can affect households' waste segregation behavior. For example, the provision of information can update consumers information sets and reoptimize their behavior. In the baselines survey, we did find that households were not well-informed about the waste segregation. Only 13% of the respondents were aware of the national mandate. It might also serve as an exogenous cue, drawing people's attention to waste management issues. Moreover, the simple guidelines on how to segregate properly and the availability of dustbins can reduce the behavioral cost of segregation efforts. The dustbins themselves can serve as a further nudge to encourage waste segregation because their physical presence may serve as a cue or a reminder. We are not able to disentangle these channels in our study. A previous study with a similar intervention package carried out in a very similar context but without a guaranteed segregated waste collection service does not find that the information campaign can induce sustained increase in segregation (Wadehra & Mishra, 2018). Therefore, another potential explanation from the supply side is that the segregated collection service also acts as a constant cue or reminder for households, even though the small change in segregation rates in the control group clearly shows that the collection service itself is also not enough.

We believe that the gradually increasing effect of the one-shot campaign must be the combined result of the household-side campaign and the waste collection service. The campaign raised awareness on the subjective value of waste segregation, and reduced behavioral costs through the provision of knowhow and dustbins. The segregated collection service guaranteed that households' behavior would translate into social benefits and allayed any fears of households that their efforts would go waste. The increasing share of segregating households may reflect the value discovery process. Some households may initially have doubt about the credibility and reliability, but were later convinced and started to segregate. In the endline survey, we do see that the campaign reduced perceived inconvenience of waste segregation, suggesting lower behavioral costs. Households also hold generally positively views of the segregated collection service with regard to its value to the households, the municipality and the environment, but more so in the treatment groups. In this sense, our results reveal that households in developing countries do not act so differently from their counterparts in developed countries. Upon properly informed and serviced, many households show intrinsic demand for waste segregation as what is found in more developed regions (Cantillo et al., 2023; Czajkowski et al., 2014). Our results imply that to break the vicious circle of no segregation and no collection, interventions on either side alone are probably not enough. A combined approach should be adopted and the collection service shall be sustained even if the initial responses form the households are not ideal.

5.1 Consistency of behavioral changes

Our explanation above implies that if households change their behavior upon learning the value of waste segregation, these changes should be persistent, ceteris paribus. Once a household started to segregate as a result of the intervention, they should be keeping segregating afterwards.

The previous analysis focused on the overall effect instead of tracking individual households. Here, we explore how consistent households are with regard to waste segregation. **Figure 3** tracks the segregation rate of all the households that segregated at the baseline (12.6 % of households in the sample) by treatment groups. There are 51, 49 and 56 segregating households at the baseline, later assigned to the control group, T1 and T2 treatment groups respectively.

Two things stand out. First, in the control group, the segregation rate among the households that segregated at the baseline drops sharply in the next two monitoring rounds. At Round 2, only less than 20% were still seen segregating their waste and the share remains low in the later rounds. However, the overall segregation rate in the control group has no such decline. The stable segregation rate in the control group (see Figure 1) does not come from a small number of households that consistently segregated their waste. In the control group, while there were never more than 19% of households segregating their waste in any given round of monitoring, about 52% of them were observed to have segregated at least once and only less than 10% segregated more than five times in the total 13 rounds of waste monitoring. This means that segregation in the control was definitely not a consistent behavior.

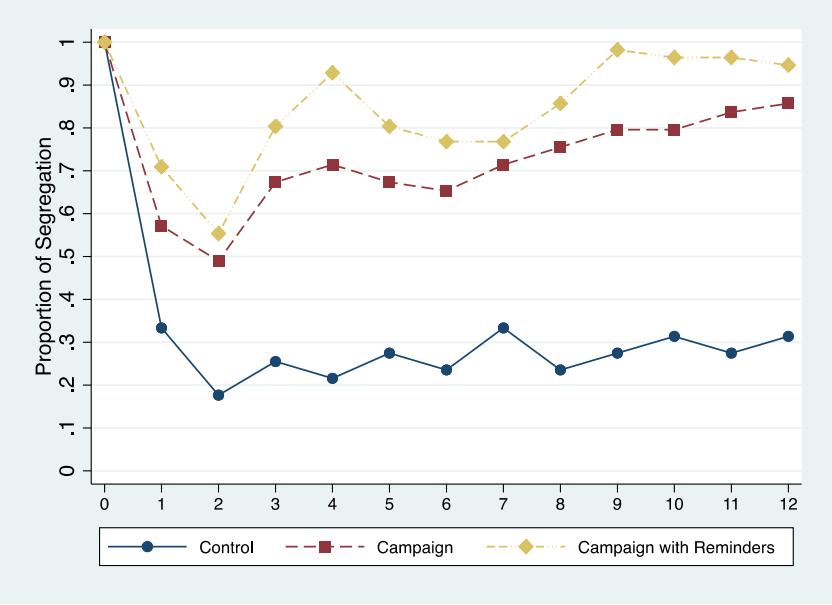

Figure 3. Segregation rate of households that segregated at the baseline

Second, in the treatment groups, the segregation rate among those who were recorded as segregating at the baseline experienced a much smaller decline and bounced back quickly. In the end, the vast majority

(86% in T1 and 95% in T2) of the households that segregated in the baseline continued to do so. The interventions greatly improved behavioral consistency.

We further examine the effect on behavioral consistency in **Table 7**. Panel A of Table 7 follows Figure 3, looking at the segregating households at the baseline. It shows the results from between-group comparisons of post-intervention waste segregation behavior. We look at the effect on the number of rounds households were observed to have segregated, the probability that households segregated in all rounds, the probability that households segregated in more than half of the time, and the probability that households never segregate again. We see that our interventions greatly improve waste segregation behavior and its consistency over time. In column (1), we see that, among the 12 rounds of post-intervention waste monitoring, the one-shot campaign (T1) increases the observed waste segregation by 5 rounds and the campaign with reminders (T2) increases it by almost 7 rounds. Given the average times of segregation observed in the control group is only 3.2 rounds, the interventions have pushed an average household to be segregating for the majority of the times. This is also confirmed by results in column (2) – (4). The likelihood of always segregating is more than tripled in T1 and quadrupled in T2 (from 7.8% to 24.5% and 32.1%). About 80% of households in T1 and 95% in T2 segregated more than half of the time, in contrast to the 24% in the control. Almost no one stopped segregating in the post-intervention period in the treatment groups, while almost 40% of the households that segregated at the baseline was not seen segregating again.

Table 7. Treatment effect on post-intervention behavioral consistency

	Panel A. Segregating Households at baseline			
	(1) Times of segregation	(2) Always segregated	(3) Segregated more than 6 rounds	(4) Never segregated again
Campaign (T1)	5.295***	0.166**	0.561***	-0.351***
	(0.646)	(0.081)	(0.073)	(0.061)
Campaign with Reminders (T2)	6.837***	0.249***	0.710***	-0.392***
	(0.628)	(0.079)	(0.070)	(0.059)
Constant	3.235***	0.078	0.235***	0.392***
	(0.452)	(0.057)	(0.051)	(0.043)
Obs.	155	155	155	155
R^2	0.458	0.063	0.422	0.254
	Panel B. Non-segregating Households at baseline			
	(1) Times of segregation	(2) Always segregated	(3) Segregated more than 6 rounds	(4) Never segregated
Campaign (T1)	5.599***	0.099***	0.536***	-0.507***
	(0.233)	(0.023)	(0.029)	(0.025)
Campaign with Reminders (T2)	7.435***	0.186***	0.762***	-0.524***
	(0.228)	(0.023)	(0.029)	(0.024)
Constant	1.638***	0.014	0.081***	0.543***
	(0.161)	(0.016)	(0.020)	(0.017)

Obs.	1,044	1,044	1,044	1,044
R^2	0.524	0.061	0.419	0.368

Note: Calculated by the authors. The dependent variables are post-intervention waste segregation behavior. *Times of segregation* stands for how many rounds that households were observed to have segregated waste in the 12 post-intervention waste monitoring rounds. Always segregated equals 1 if a household segregated in all post-intervention rounds, otherwise 0. *Segregated more than 6 rounds* equals 1 if a household segregated 7 or more times in all post-intervention rounds, otherwise 0. *Never segregated again / Never segregated* equals 1 if a household never segregated waste in any post-intervention round.
Results from regress the dependent variable on two treatment group dummies and a constant term are reported using OLS regressions. Therefore, the coefficients of the constant terms standard for the mean for the control group. The coefficients of the two treatment group dummies stand for the mean differences between the treatment groups and the control group.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The effect on the non-segregating households at the baseline shows very similar patterns (Panel B). As a result of the intervention, an average household in T1 would segregate in 7 rounds out of the 12 monitoring rounds, and in T2 it would be almost 9 rounds, whereas the corresponding figure in the control is merely 1.6. While the share of households that always segregated is still low, the majority of the households would segregate more than 6 rounds, showing behavioral consistency upon changes as a result of the interventions.

5.2 Persistence of behavioral changes

So far, we find that our intervention induces consistent behavioral change over the monitoring period. Given the rising trend in the segregation rates and consistent waste segregation behavior as a result of the intervention, we also wonder to what extent the treatment effects are able to be sustained after the experiment ended. In the context of a Dutch city, Vollaard and van Soest (2024) show that a short-term enforcement campaign can induce sustained waste segregation behavior. Our intervention shares similar features with theirs in the sense that the interventions were short-term and the households were aware of it. This is especially interesting in our context, as the regular waste collection service provided by the municipality with auto tippers could collect waste in a segregated manner but was not being used to do so. We wanted to explore if the habit formation as a result of our experiment translated to potential usage of auto tippers in the intended manner. Ideally, we would have liked to keep tracking the households in a similar manner, but we were not able to do so due to the budget constraint. Instead, we conducted a follow-up survey in mid-September 2022, six months after the end of the main experiment. We revisited all the households in our experimental sample and asked if they were still segregating their household waste.

We managed to obtain waste segregation information from 1,191 households out of the 1,242 households in the original sample. The self-reported segregation rate is 38% in the control group, 55.7% in T1 and 60.3% in T2. The differences between the two treated groups and the control groups are statistically significant, while the difference between the T1 and T2 is not.

Interestingly, compared with the control group, six months after the segregated collection service stopped, the treated households were still much more likely to continue segregating. The 17-21 percentage points increases in the two treatment groups, about 50% increase from 38 percent segregation rate of the control group, represent large persistent effects. This finding implies that our intervention might have induced persistent behavioral changes for some households. Some of the treated households might have formed a habit of waste segregation as a result of our intervention. This is consistent with the habit formation finding in Vollaard and van Soest (2024). Furthermore, the fact that waste segregation rate in Campaign with Reminders group (T2) is no longer higher than the Campaign group (T1) in the follow-up survey implies that the effect the reminders is transitory. Those who were nudged into segregating by the reminders fell back to old habit once the reminders stopped. However, given the self-reported nature of the follow-up waste segregation measure, we do not want to overstate the persistent effects. Households might overstate their waste segregation behavior to please the researchers, and this is particularly so for the households that received the intervention. Further study is needed to properly assess the persistent effects of the interventions of similar nature.

5.3 Cost effectiveness of the ragpicker service and its policy implications

The large effects found in our study should be interpreted as results under a reliable and credible segregated collection service. We organized local ragpickers to provide the households with a reliable and credible segregated collection service for free. Collecting clean and properly handled recyclables is time consuming and labor intensive. Ragpickers will only provide such a service if they earn an income at least at par with their current mode of collection, i.e., collecting recyclables from secondary dumpsites and landfills. Many efforts have failed due to the high costs of the intervention (Wilson, 2007). Here, we discuss the financial sustainability and cost effectiveness of the collection service we use in the experiment and their policy implications.

In our experiment, we employed ten ragpickers to provide the collection service. They were allowed to sell the recyclables they collected and keep the revenue. We also paid ragpickers a daily wage of 400 INR to ensure they would not skip any day. We decided on 400 INR because our discussions with ragpickers revealed that they earned 500-1000 INR per day from their present mode of collection. This serves as their reserve wage and the benchmark for our analysis of financial sustainability of the collection service.

Because we want to know if such a collection service has the potential to sustain itself, we collected information on the weight of sellable recyclables collected and the amount of money earned from selling them over the experimental period. The total weight of recyclables sold by all ten ragpickers ranged from 13 kg to 29 kg per day, with a total value of 217-390 INR. Even with the wage we paid, the income barely reaches the lower bound of their daily earnings.

However, to extrapolate the earnings from our experiment to a full-scale collection service, one should note that during the experimental period, the ragpickers worked only 2-3 hours a day and collected from on average 30 households. The random sampling of households made ragpickers spend more time traveling between households, and being paired with our enumerators for the waste monitoring also greatly slowed the collection process down. Furthermore, the ragpickers served households in both treated and control group, while the latter have significantly lower segregation rate. In contrast, in a full-scale operation, a ragpicker would have spent the full day collecting from all households in a few neighborhoods without the need to record households' behavior. If we consider a scaled-up intervention with similar effectiveness in improving waste segregation, i.e., with segregation rates between 71.4% in TI and 93.8% in T2, and assume that ragpickers work 8 hours a day and are three times faster than in our experiment, then 64 - 84 kg of clean recyclables will be collected by them on a daily basis. Extrapolating their present daily earnings from selling recyclables which lie between 7 and 30 INR/kg, we see that ragpickers can earn 448 - 2520 INR per day. Thus, if households continue segregating at the rates we see at the end of experiment, organizing ragpickers to provide a reliable and credible segregated collection service as we did is likely to be financially feasible.

Furthermore, the collection service could have generated larger social welfare benefits than what the financial analysis reveals. In the follow-up survey, we also elicited the households' willingness-to-pay (WTP) for the collection service through double-bounded dichotomous choices. We asked households if they are willing to pay a certain monthly fee for the same separated waste collection services as we provided before. We use eight fee levels in the WTP questions: 200, 160, 130, 100, 70, 40, 10 and 0 INR per month. The enumerator started with the question with 100INR per month and then jumped up or down based on their answers. Based on their answers, we can put each household's WTP for the collection service into one of the nine ranges: >200; 160-200; 130-160; 100-130; 70-100; 40-70; 10-40; 0-10 and <0. We allow the WTP to be negative as we admit the possibility that the collection service might cause welfare loss to some. There are 1171 households that gave valid answers to the WTP questions. We find that almost all households are willing to pay a positive amount for the collection service. Over 80% are willing to pay less than 100 INR per month. Only 4 households show negative WTP.

Following Allcott and Kessler (2019), we assign a unique value to each WTP range for each household in the sample and calculate that the mean WTP of the households in the sample is 57 INR per month.[16] This means that as long as a ragpicker could serve 263 households on a monthly basis, the welfare gain

[16] In order to get a point estimate of the WTP, we assign a unique value to each WTP range. For the seven interior ranges, we use the mean of the endpoint as the WTP. For example, we assign a WTP of 180 for the households on [160, 200] and 55 for those on [40, 70]. For the two unbounded ranges, we assume the conditional distribution of WTP is triangular with initial density equal to the average density on the adjacent range (Allcott & Kessler, 2019). This practice gives us 205 as the conditional mean WTP for households on [200, ∞). For households on the negative range, because a very small number of households are on the range and the very small negative value calculated as a result, we decide to assign 0 as the mean WTP for simplicity.

of the households from the service alone would exceed the reserve wage of the ragpicker, making it socially beneficial to do so. Because the collection service in our experiment only required the ragpicker to visit a household every four days, serving 263 households a monthly basis is well within the a ragpicker's capacity. Under our previous assumption, in full scale, a ragpicker could collect from 270 households per day, meaning over 1,000 households on a monthly basis. The potential welfare gain could be large. Further adding the positive externalities of waste segregation for both the ragpickers and the environment to the calculation, we believe that the involving the ragpickers as waste collectors is socially beneficial. The WTP of the households also suggests that alternative form of service provision can also be feasible. If the government wants to incorporate the informal sector into its municipal waste management structure or introduce private companies to provide similar services, a subsidized scheme or fee levied on the households could be a viable and beneficial policy.

Our guaranteed waste collection service is independent from the municipal efforts. We are also aware that the municipal government often have existing waste management infrastructure to be utilized. In the context of Palwal, the auto-tippers service the five wards in our study already have different compartments but are currently underutilized. It is possible for the government to provide a similar segregated collection using the existing equipment and infrastructures. However, it is unclear to what extent such effort form the government can be perceived as reliable and credible by the households. Future research is needed to explore these interactions.

6. Conclusion

In many developing countries, proper waste management such as waste segregation at source has long been plagued by vicious circle of "no segregated collection, no segregation at source": government shy away from segregated collection effort because there are few who segregate; and households do not segregate once they see waste are mixed by the collector. India is no exception. Despite the ambitious legislation of Solid Waste Management Rules 2016, we observe few households are actually segregating. This study aims to provide insights on the potential solution to this chicken-egg problem. In particular, we study the effect of provision of household-oriented campaign on households' waste segregation behavior conditional on provision of a credible segregated waste collection service.

Our study provides some very interesting results from a policy perspective. First, we see only slight increase in segregation rate over time in our control group, suggesting that providing the segregated collection service alone, without the household-side campaign, has little impact on households' segregation behavior. Part of the chicken and egg story seems to be right: only providing the service is not enough. Second, we find that the one-shot campaign including provision of information and dustbins brings about a very large effect on waste segregation behavior. Even in absence of reminders, the effect does not fade away, but rather grows over time. Previous research in similar settings (e.g., Wadehra and

Mishra, 2018) finds that household intervention alone wouldn't have much success either. Taken together, it seems that the vicious circle that has trapped India and many other developing countries into the undesired "no-collection, no-segregation" state cannot be broken by one-sided effort. A combined approach with both the collection service and household campaign might be the only way out. Thirdly, our results show that reminders have an incremental effect over the course of the experiment, implying that some households might need more sustained information campaigns to change their behavior.

We went back to the households six months after the conclusion of the main experiment to assess whether households continued segregating in the absence of segregated waste collection service. We see a significant decline in waste segregation in the treatment group after 6 months without the segregated collection service. This is not surprising because many people would give up when they saw the waste were mixed gain during collection. What is interesting is that compared to the control group, the treated households were still much more likely to continue segregating even without the segregated collection service, implying that part of the treated households might have formed a habit of waste segregation as a result of our intervention.

When interpreting the results we find in this study, we want to be clear that the large positive effects should be considered as the result based on a reliable and credible segregated waste collection system. The intent was to provide credible and reliable service and the service is perceived by the households as such. The use of ragpickers and perhaps the fact that the service is organized independently by academic researchers from the local government may have helped shape households' perception of the service. In this sense, we would like interpret the large effects as households' responses or demand for segregating under ideal collection service provision. To what extent a similar service provided by local government or NGOs or private companies can produce similar results may depend on how households perceive or trust these services and their providers. How to proper influence households' perception and building trust under different waste collection systems and local contexts are for future studies.

Given the role and particular form of the segregated collection service we provided in this study, we examine the financial feasibility of the ragpicker collection service to ascertain if the collection service can be scaled up and sustain itself without any external financial support. Using the segregation rates of the one-shot campaign group (T1) at the last round (round 12), we estimate that ragpickers would collect 64-84 kgs of inorganics and could earn between 448-2520 INR per day. This calculation thus implies that mobilizing ragpicker to become waste collectors is potentially viable. The attractiveness of involving the informal sector into waste collection of clean recyclables goes well beyond the income of ragpickers, and should be explored further.

Whenever we are confronted by large and highly significant results, one should worry about Hawthorne effects and experimenter demand effects. The particular form of having ragpickers to go door to door to collect segregate waste and having enumerators go along with the ragpickers may have triggered the

large reactions for the households. While we cannot completely discard this effect, we believe that both treatment and control were similarly intervened and could have reacted similarly to being observed, yet we find no evidence of behavioral change in the control. In addition, Hawthorne effects are typically weaning over time, yet in our case we actually see an increase in activity. Finally, 6 months after the experiment is over, we still see persistency of our results, even without experimenters present. From a policy application perceptive, having workers, promoters or inspectors to go along with waste collectors for a certain period of time as part of the collection services is not unheard of or meritless. Vollaard and van Soest (2024) shows how a short-term waste segregation inspection campaign can improve segregation behavior. In the municipality of Indore, India, the municipality also had a volunteer/ NGO worker go along with the garbage collector vans and tell households how to segregate if they hadn't for a certain period of time. The volunteer collected information on any concerns of residents such as street lighting, clogged drains. This helped develop institutional trust in residents which in our study came from our enumerators. This particular form of service provision can be useful for promoting waste segregation if it can generate persistent effects. In this paper we have departed from a carefully executed experimental design and, given our large and highly significant results, we attempted to dissect them as exhaustively as possible, looking at the persistency, consistency and composition of our estimates. We hope that taken together, our results provide a consistent and robust narrative of the effect of our treatment on waste segregation behavior, with important policy implications for our study site and other such sites in developing countries that face similar challenges with waste collection and segregation.

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Appendix A

Table A1. Balance Check of Individual and Household Characteristics across Groups

	Control vs. T1	Control vs. T2	T1 vs. T2
Respondent's characteristics			
Age	0.179	0.146	0.006
Female	0.059	0.169	0.582
Education levels	0.660	0.962	0.608
Household characteristics			
Household size	0.891	0.877	0.774
Area of housing	0.077	0.658	0.195
No refrigerator	0.133	0.082	0.851
Have microwave	0.701	0.492	0.773
House ownership	0.038	0.065	0.773
Household income	0.582	0.697	0.867

Note: Calculated by the authors from the data. P-values from two sample Mann-Whitney test or t-test are reported in the table cells. We use Mann-Whitney test for categorical variables and t-test for continuous variables.

Table A2. Joint Balance Check of Individual and Household Characteristics across Groups

	T1	T2	T1	T2
Age	-0.00820**	0.00311	-0.00821*	0.00534
	(0.00418)	(0.00408)	(0.00473)	(0.00462)
Female	-0.256*	-0.173	-0.221	-0.0906
	(0.134)	(0.133)	(0.149)	(0.149)
Edu: Up to class 5	0.254	-0.0126	0.401	0.0281
	(0.227)	(0.226)	(0.250)	(0.251)
Edu: Up to class 8	0.120	0.0513	0.193	0.232
	(0.221)	(0.217)	(0.245)	(0.237)
Edu: Up to class 10	-0.224	0.0381	-0.147	0.0706
	(0.209)	(0.198)	(0.226)	(0.214)
Edu: Up to class 12	0.0636	0.0287	0.212	0.243
	(0.211)	(0.207)	(0.236)	(0.231)
Edu: Diploma and certificate	0.0231	0.139	0.0988	0.252
	(0.276)	(0.270)	(0.296)	(0.290)
Edu: Graduate	-0.0236	-0.149	0.0938	-0.121
	(0.211)	(0.209)	(0.241)	(0.240)
Edu: Post graduate and above	-0.263	-0.0990	-0.245	-0.0273
	(0.252)	(0.243)	(0.287)	(0.276)
Household size	-0.0110	-0.00713	-0.0148	-0.00261
	(0.0242)	(0.0237)	(0.0279)	(0.0276)
No refrigerator	-0.350	-0.326	-0.238	-0.308
	(0.238)	(0.237)	(0.253)	(0.256)
Have microwave	0.0316	0.0897	-0.0969	0.0653
	(0.193)	(0.189)	(0.226)	(0.219)
House ownership	0.411**	0.205	0.447**	0.280
	(0.180)	(0.176)	(0.208)	(0.205)
Area of housing			0.00150	0.0000885
			(0.000996)	(0.000975)
Household income: Rs. 30000-59999			-0.0205	-0.0875
			(0.144)	(0.143)
Household income: Rs. 60000-99999			-0.108	-0.0427
			(0.238)	(0.233)
Household income: Above Rs. 1 lakh			0.0869	0.285
			(0.383)	(0.368)
Constant	0.207	-0.114	-0.0827	-0.420
	(0.362)	(0.356)	(0.430)	(0.426)
Joint test of coefficients are 0	chi2(13) = 19.45	chi2(13) = 10.21	chi2(13) = 21.87	chi2(13) = 13.60
	p = 0.1099	p = 0.6764	p = 0.1898	p = 0.6949

Note: Calculated by the authors from the data.

* There are missing values for the area of housing. Only 1171 households with valid information in total, with 394 in Control, 366 in T1 and 411 in T2.

** There are households refused to provide income information. There are 1088 households that provided income information with 369 in Control, 342 in T1 and 377 in T2.

Appendix B: Brochure to households (original in Hindi and English translation)

कूड़ा कचरा अलग-अलग कैसे करें?

ठोस अपशिष्ट प्रबंधन के नए नियमों के अनुसार

हरे डब्बे (डस्टबिन) में क्या-क्या डालना है?

रसोई-घर (किचेन) के कूड़े/कचरे

- सब्जी या और फल के छिलके
- पके हुए खाने या खाने के बाद बचा हुआ खाना अंडे के छिलके
- चिकन और मछली के हड्डी के टुकड़े
- सड़े हुए सब्जी या फल
- चाय / कॉफी बैग या बचे हुए पत्तियाँ
- पिज्जा पेपर के प्लेट या डिस्पोजेबल

गार्डन/घर के आहार के कचरे

- पेड़ पौधे के पत्तियाँ और खर-पतवार
- पशु के मल मूत्र और गोबर
- घास

नीले डब्बे (डस्टबिन) में क्या-क्या डालना है?

प्लास्टिक (गंदा होने पर धोया जाना चाहिए)

- प्लास्टिक के थैली, कवर, बक्से या बर्तन
- शैम्पू, टूथपेस्ट, कॉस्मेटिक के पैकेट
- दूध या दही के थैली

पेपर कागज (गंदा होने पर धोया जाना चाहिए)

- गिफ्ट कार्ड
- पत्रिका या अन्य खाने के डब्बे
- पेपर के कप और प्लेट

मेटल

- फॉयल पेपर
- टिन या मेटल के डब्बे (केन)

अन्य सूखे कचरे

- रबर /थर्मोकोल
- बोतल

How to Segregate Waste?

As per Solid Waste Management Guidelines

What goes in the green box?

Kitchen waste	Vegetable/fruit peels
	Cooked food/leftovers
	Egg Shells
	Chicken/Fish bones
	Rotten fruits/Vegetables
	Tea bags/coffee grinds
	Leaf plates
Garden Waste	Fallen Leaves/twigs
	Puja flowers/garlands
	Weeds

What goes in the blue box?

Plastic (must be rinsed if soiled)	Plastic covers/boxes/bottles
	Chips/Toffee wrappers
	Milk/Curd Packets
Paper (must be rinsed if soiled)	Cardboard Cartons
	Tetra boxes and pizza boxes
	Papers cups and plates
Metal	Foil Containers
	Metal Cans
Other Dry Waste	Rubber/Thermocol
	Hair

हमें घर पर कूड़े/कचरे को अलग-अलग क्यों करना चाहिए?
कूड़े को जलाएं नहीं!

गीले कूड़े/कचरे से आपके किचन गार्डन के लिए खाद बनाया जा सकता है

#रोड/सड़क पर बदबू या गंदगी नहीं रहेगी

पहले से अलग-अलग कर देने से जमादार या मजदूरों का काम कम हो जाता है

WHY SHOULD WE SEGREGATE AT HOME?

Handy compost for your kitchen garden

No more stinky roads

Saves manpower