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No clue about bioplastics

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No clue about bioplastics.*

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Abstract

We analyze recycling decisions for bioplastics using a natural field experiment. The potential environmental benefits of these new plastics may not materialize if they are recycled incorrectly. The field experiment that we set up to test this recycling behavior exploits the setting of a lemonade tasting. In our experimental treatments, subjects are exposed to different types of bioplastics logos on their cups as well as varying amounts of recycling information. We use two types of bioplastics and compare these to conventional plastics in terms of whether subjects recycle the cups correctly. Our results show that over 90% of subjects dispose of their cup with plastic waste and that none of our treatments can snap subjects out of this default behavior. We interpret this finding as subjects having no clue how to recycle bioplastics. More generally, these results point to skepticism regarding new products or varieties whose environmental benefits depend on proper use or disposal.

Keywords: Recycling, field experiment, bioplastics.

JEL classification: C93, Q53.

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1 Introduction

We analyze recycling decisions for bioplastics using a natural field experiment. In this experiment we distinguish between two broad types of bioplastics and compare these to conventional plastics produced from fossil fuels. 'Biobased' plastics are partly or fully produced from biomass, whereas 'compostable' plastics can be decomposed by micro-organisms.[1] Since consumers may be unaware of these differences, they may not properly dispose of bioplastics. Incorrect recycling decisions may subsequently result in environmental damage, which counteracts the potential environmental benefits of bioplastics.

Bioplastics have recently been introduced on the market following a spur of innovation in the field of sustainable packaging aimed at limiting the negative environmental externalities associated with conventional plastics. Global production of bioplastics in 2018 was less than 1% of total plastics (of which 65% used for packaging). However, continued growth is expected (IfBB, 2018; European Bioplastics, 2019). In the production phase, bioplastics are generally associated with lower energy use and GHG emissions, although this effect is partly undone by the indirect effects on related land use change and externalities from agricultural production. In the consumption and disposal phase, bioplastics may not only cause improved plastics recycling, but also facilitate increased recycling rates of organic waste, via the uptake of compostable bioplastic garbage bags (van den Oever et al., 2017). In addition, continued improvement of bioplastics' biodegradation properties may relieve the problem of accumulation of plastic particles in the environment.[2]

Although the potential environmental benefits of bioplastics are undisputed, their realization is facing some obstacles. The major obstacle is that consumers may recycle bioplastics incorrectly.[3] There is suggestive evidence that consumers are ill-informed about the differences between conventional plastics and the various types of bioplastics (Sijtsema et al., 2016; Dilkes-Hoffman et al., 2019). As a result, consumers may make incorrect recycling decisions. In this paper we assess recycling behavior for bioplastics based on observed recycling decisions in an experimental setup. We do so using a natural field experiment that exploits the setting of a lemonade tasting. Experimental treatments are based on different types of (bio)plastic cups that are used for the tasting.

[1] Note that some bioplastics possess both characteristics. Also note that 'compostable' refers to products' biodegradation in an industrial composting plant under controlled conditions, the standards for which are not undisputed (Harrison et al., 2018).

[2] This accumulation problem leads to ingestion of plastic particles by, mostly, aquatic species from where they enter the food chain and may even affect human health (cf. Auta et al., 2017).

[3] A second obstacle, which we do not analyze in this paper, is that waste processors are hesitant to accept compostable plastics. They worry not only that such plastics may not meet the requirements of industrial composting and could reduce the quality of compost (Napper and Thompson, 2019), but also that accepting bioplastics may - unintendedly - cause increased pollution of organic waste with conventional plastics.

Previous research on waste recycling behavior – not limited to plastics – has studied a large class of predictors for the propensity of households to recycle. These predictors include variables related to a.o. moral norms, environmental concern, information and convenience (cf. Hornik et al., 1995; Ferrara and Missios, 2012; Miafodzyeva and Brandt, 2013; Cecere et al., 2014). Most studies rely on self-reported recycling behavior while a minority uses measurements of actual behavior, generally by assessing the composition or weight of disposed waste at recycling collection points or curbside (e.g. Fullerton and Kinnaman, 1994; Bartelings and Sterner, 1999; Dijkgraaf and Gradus, 2004). More recently, experimental methods are used to study predictors of recycling behavior. Best and Kneip (2011) use a quasi-experiment to study the impact of curbside collection vs. a drop-off system. Linder et al. (2018) use an experimental set-up to find out whether an information campaign can increase waste recycling efforts. Bernstad et al. (2013) use a similar setting and add a door-stepping campaign in order to evaluate the additional impact of oral information. van Soest and Vollaard (2019) use a natural field experiment to assess the impact of norms and enforcement on household waste recycling (see also Schultz, 1999). All of these experiments use households as the unit of treatment. One exception to such household-level analysis is Holland et al. (2006) who experiment with convenience and intentions of individual firm employees.

For bioplastics, observing recycling decisions is difficult since bioplastics do not form a separate waste category in terms of collection. As a result, assessing composition or weight of disposed waste at recycling points or curbside does not suffice, unless waste bags are opened and assessed item-by-item. A more practical approach is to measure plastics recycling at the moment of waste disposal. Such measurement is generally unreliable if based on self-reports (Huffman et al., 2014). Observations of in-house waste disposal in a natural setting appear to be impossible without introducing bias. An outside field experiment is therefore appropriate, which is the method that we employ in this paper.

Given the important role played by information in recycling behavior, we not only test recycling behavior based on the type of plastic used, but we also test the impact of information. That is, in some of our treatments, subjects receive additional information on the recycling of bioplastics. We expect such additional information to increase the rate at which subjects recycle bioplastics in the correct bin.

Our results show, however, that subjects are not responsive to information at all. In addition, they are almost completely insensitive to the presence of logos indicating the type of bioplastics used. Across treatments, over 90% of subjects dispose of their cup with plastic waste. While this is the correct recycling decision for conventional and biobased plastics, it is incorrect for compostable plastics which should be disposed of with residual waste. Both non-parametric tests and regressions confirm the insensitivity of subjects to the treatments. Correlations with survey items on moral norms and environmental concern are also very weak. Summarizing, we conclude that subjects have no clue how to recycle bioplastics and that cues like logos or recycling information on trash cans are not sufficient to snap subjects out of their default recycling behavior.

Generalizing our results, the benefits of introducing a green good can only fully materialize if it is used or recycled appropriately. If not, a type of 'rebound' or 'backfire' effect occurs which causes part of the potential environmental benefits to evaporate. This effect occurs when the adoption of a more sustainable technology (e.g. a more fuel-efficient vehicle) leads to increased use, offsetting its environmental benefits (Gillingham et al., 2013). Our setting is different in two ways from this standard setting in which rebound and backfire effects are observed. One is that we do not consider frequency (or intensity) of use but rather the one-time act of waste disposal. The second difference is that consumers may not have consciously purchased bioplastics since its predominant application is in packaging. As a result, their recycling behavior is not necessarily correlated with a purchasing decision, but rather affected by predictors like moral norms, environmental concern, information, and convenience (Miafodzyeva and Brandt, 2013). Our results show that at least three of these factors have no impact on the recycling of bioplastics. In light of increasing market penetration of bioplastics, this result should concern both the packaging industry as well as government authorities responsible for the management of bioplastics waste.

2 Experimental design

The experiment that we implemented to assess recycling behavior for bioplastics is a natural field experiment (Harrison and List, 2004). The experiment was conducted in the Vondelpark in Amsterdam, the Netherlands, on five (almost) consecutive days in April–May 2019. This park is centrally located in the city and attracts a diverse mix of Amsterdam residents. The setting of our field experiment is a lemonade tasting. The motivation for using this setting was to temporarily conceal to the subjects in our experiment that we were interested in observing their recycling decision. This decision involved a plastic cup that they were offered in the tasting. Doing so allowed us to observe this recycling behavior in a natural setting, with subjects being unaware that they were part of an experiment in addition to the lemonade tasting.

Given the background setting of a lemonade tasting, we relied on the arrival of passers-by in the park as possible subjects for our experiment. In this setting, a random sampling procedure is not possible. Instead, in deciding whom to approach and invite to participate in a lemonade tasting, we applied a quota sampling procedure aimed at obtaining a balanced sample for two observable characteristics, gender and age. At the invitation stage, tourists and other non-Dutch subjects were excluded from the survey since they would possibly not be familiar with Dutch logo's and icons for waste disposal.

2.1 Procedures

Participants in the lemonade tasting were subjects in our experiment. They were offered to take a plastic cup, half-filled with lemonade, from a full tray. Subjects were then instructed to taste the lemonade and subsequently forwarded to a second assistant holding a clipboard. Next to this second assistant, we had positioned three trash cans with icons indicating three types of waste: organic, plastics, and residual waste. Both trash cans and icons are widely used throughout the Netherlands. The assistant observed in which of the cans the subject disposed of his/her cup and then proceeded with a survey. In case the subject did not automatically dispose of the cup while approaching the assistant, a friendly nudge was given to do so.

In order to avoid confounds as much as possible, several elements of our experimental setup were fixed across all sessions, partly based on the outcome of a pilot session conducted one week prior to the start of the experiment: (1) We used only one assistant to do the surveys across all sessions in order to avoid interviewer bias. (2) Subjects could not participate simultaneously to prevent subjects influencing each other. (3) We used a fixed order in the line-up of the three trash cans in order to avoid some ordering bias (although the pilot revealed that the order of trash cans had no effect). (4) The trash cans had closed lids and each of them were non-empty (i.e. we made sure that the bottom of the can was covered by disposed cups). (5) Sessions were only planned on sunny days.

The survey that was administered after subjects disposed of their cup was kept very short in order not to annoy subjects who may have expected some simple questions on the taste of lemonade. The full survey, included in the appendix, contained the following items. First, after an opening question on lemonade taste, the survey presented a certainty question, eliciting how certain a subject was about his/her recycling decision (Likert scale 1–5). Second, depending on the treatments, subjects were asked three questions. (a) whether they had observed the logo on the cup and/or the information on the trash can; (b) in case they had observed the logo, whether they could indicate which logo was on the cup, using examples of the two bioplastics logos; and (c) whether the logo had played a role in their recycling decision. Third, subjects were asked about their moral norms towards recycling (Likert scale 1–5), as well as their environmental concern (Likert scale

1–5). Fourth, subjects were surveyed on three demographic variables: age, education, and gender.

After completing the survey, subjects were debriefed about the purpose of the research, that their recycling decision had been observed, and they were asked for consent that this information was to be used for research purposes.

2.2 Treatments

In order to assess recycling decisions for bioplastics we ran two treatments in which all cups used were either exclusively biobased or exclusively compostable, as indicated by a logo on the cup, as explained below. We refer to these treatments by the type of plastics: *Biobased* and *Compostable*. In a control treatment we used only cups without a logo, signalling conventional plastic: *Control*. In two additional treatments we test whether providing recycling information on the trash cans (details follow below) affects recycling decisions for both biobased and compostable plastics: *Biobased-I* and *Compostable-I*. Hence, in total we have five treatments, one control-, two bioplastics- and two bioplastics with information treatments. All treatments are performed using a between-subjects design with each subject participating in only one out of five treatments.

To indicate the type of plastics, we applied two standard logos to the cups that are widely used in the Netherlands, see Figure 1.[4] For compostable plastics, the 'seedling' logo was used, owned by European Bioplastics and issued by TÜV Austria and DIN CERTCO. The seedling logo applies to products that meet the harmonized European standard EN 13432. For biobased plastics, the 'OK Biobased' logo was used, also issued by TÜV Austria and DIN CERTCO. The OK biobased logo applies to products that conform to the EU norm 'NPR-CEN/TS 16137:2011' on the determination of biobased carbon content.

In our experiment, we used plastic cups that were compostable as well as biobased, meeting the requirements for both the seedling and OK biobased logos. Using one type of cup assured that there exists no difference in texture or appearance of the cups between the treatments, such that the only difference is the type of logo (none, seedling, or OK biobased) visible on the cup.

Guidelines for the disposal and recycling of household waste are provided by Milieu Centraal, an independent organization financed by the Dutch government to provide advice and guidelines on sustainability issues to Dutch consumers. The recommendation for biobased plastics is to dispose of these joint with conventional plastic waste (Milieu

[4]Logos were printed in the same shade of green, commonly used for both logo's, and applied using stickers of size 2×3.5 cm.

Figure 1: Seedling logo for compostable plastics and OK biobased logo for biobased plastics.

Centraal, 2019b). Most municipalities in the Netherlands facilitate separate recycling of plastics, often in combination with tins and drink cartons. The recommendation for compostable plastics, referring explicitly to products with the seedling logo, is to dispose of these with residual waste (Milieu Centraal, 2019a). There is only one exception to this recommendation. Compostable bioplastic garbage bags should be disposed of with organic waste, since these bags provide co-benefits in terms of stimulating increased recycling of organic waste.

In our experiment we allow subjects to make recycling decisions in line with these guidelines as well as making one of three possible errors: (1) disposing of biobased plastics with residual waste; (2) disposing of compostable plastics with plastic waste; (3) disposing of any type of plastics with organic waste. For this purpose we used three trash cans of a type commonly used throughout the Netherlands, that were labeled using standard icons (issued by Rijkswaterstaat, the executive agency of the Ministry of Infrastructure and Water Management) to indicate the type of waste: organic, plastics, and residual, see Figure 2.[5]

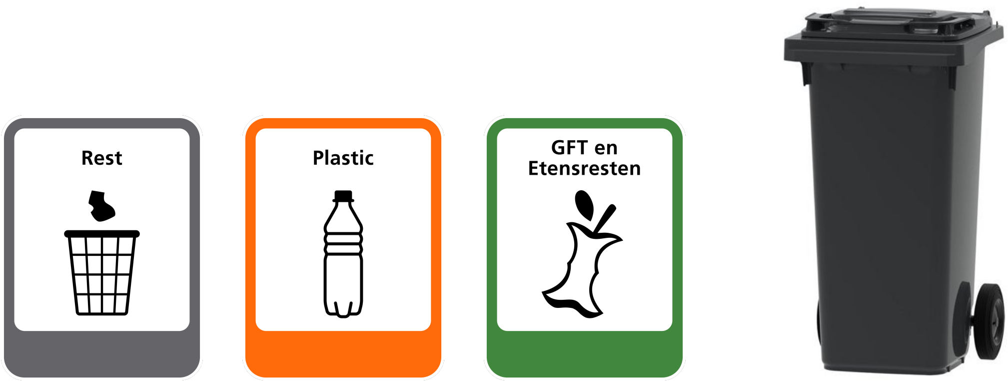

Figure 2: Trash can and icons used to indicate the type of waste on the trash cans.

[5]Icons were applied using stickers of size 20×25 cm.

In *Biobased-I* and *Compostable-I*, we extended these icons with additional information on items that should or should not be disposed of, customized for each trash can. To make the information explicitly relevant to our experiment we adapted standard texts and added biobased and compostable plastics to these categories in three instances that we deemed most relevant based on the pilot experiment, see Figure 3.[6]

Figure 3: Additional information used in *Biobased-I* and *Compostable-I* to indicate the types of waste that should or should not be disposed of, customized for each trash can.

3 Empirical strategy

Our outcome variable of interest is a binary variable reflecting whether the plastic cup was recycled in the correct trash can by subject i, denoted r_i, with $r_i = 1$ indicating correct recycling and $r_i = 0$ not. We derive two main hypotheses based on comparison of the expected levels of the average correct recycling rate between the five treatments. Denote this rate by $\bar{r}_t = \sum_{i \in N_t} r_i / n_t$ for treatment t featuring subjects $N_t = (1, 2, \ldots, n_t)$.

Since the norm for conventional plastics recycling is well-known among the Dutch population, we expect this rate to be close to 1. To simplify the below argumentation assume that $\bar{r}_{\text{Control}} = 1$. For both *Biobased* and *Compostable*, we expect this rate te be lower. The main reason for this expectation is that subjects may react differently to the bioplastics treatments in the sense that they may or may not observe the logo on the cup. Using standard terminology from the literature on causal inference, those that do are 'compliers' while those that do not are 'non-compliers'. Starting with *Biobased*, our intention was

[6]Icons were applied using stickers of size 20 × 70 cm, positioned directly below the standard icons.

to treat all subjects with the same treatment conditions. Non-compliers under *Biobased*, however, are not expected to behave any differently from subjects under *Control*. Given similar recycling recommendations for conventional and biobased plastics (i.e. dispose of these joint with conventional plastics), this implies a similar $\bar{r}_{\text{Biobased}} = 1$ for these subjects under *Biobased*. Compliers may behave differently. Under *Biobased*, observation of the logo may induce some of these subjects to switch their recycling decision from the default, plastics waste, to one of the other two waste categories. Denote the fraction of switchers by α_{Biobased} and note that both types of switching are incorrect. As a result, since switchers will lead to $\alpha_{\text{Biobased}} n_{\text{Biobased}}$ subjects with $r_i = 0$, we have $\bar{r}_{\text{Biobased}} = 1 - \alpha_{\text{Biobased}} < 1$.

Recall that the recommendation for compostable plastics is to dispose of these with residual waste. Non-compliers under *Compostable* are not expected to behave differently from subjects under *Control*. Given differing recycling recommendations for conventional and biobased plastics, however, under *Compostable* these subjects will have $\bar{r}_{\text{Compostable}} = 0$. That is, their recycling decision is incorrect. For compliers we expect again some switching of their recycling decision from the default, plastics waste, to one of the other two waste categories. While switching to organic waste is incorrect, switching to residual waste is correct. Denote the fraction of correct switchers by $\alpha_{\text{Compostable}}$. As a result, since switchers will lead to $\alpha_{\text{Compostable}} n_{\text{Compostable}}$ subjects with $r_i = 1$, we have $\bar{r}_{\text{Compostable}} = \alpha_{\text{Compostable}} > 0$.

We synthesize the above argumentation by comparing $\bar{r}_t$ between treatments:

$$\begin{cases} \bar{r}_{\text{Compostable}} < \bar{r}_{\text{Biobased}} < \bar{r}_{\text{Control}} & \text{if } \alpha_{\text{Biobased}} + \alpha_{\text{Compostable}} < 1, \\ \bar{r}_{\text{Biobased}} < \bar{r}_{\text{Compostable}} < \bar{r}_{\text{Control}} & \text{otherwise.} \end{cases} \quad (1)$$

Factors that may induce switching from the norm include socio-demographic variables such as age, education, and gender. A large literature has assessed the major determinants of recycling behavior (cf. Hornik et al., 1995; Schultz et al., 1995). Generally, the impact of socio-demographic variables on such behavior appears to be weak. If anything, recycling efforts increase with education and being female. More importantly, a recent meta-analysis finds that variables measuring moral norms, environmental concern, and information are among the four strongest predictors of recycling behavior (Miafodzyeva and Brandt, 2013). The fourth predictor, convenience, can be ignored here, because the level of convenience is fixed in the setting of our experiment. Both moral norms and environmental concern are items in our survey, while information is one of our treatment variables. As a result, we expect each of these to induce switching with higher scores on moral norms and environmental concern increasing correct recycling. Similarly, we expect subjects under

Biobased-I and *Compostable-I* to feature a higher average correct recycling rate.

$$\bar{r}_{\text{Biobased}} < \bar{r}_{\text{Biobased-I}}, \tag{2}$$

$$\bar{r}_{\text{Compostable}} < \bar{r}_{\text{Compostable-I}}. \tag{3}$$

Based on the inequalities in (1)–(3), we formulate the following two hypotheses.

Hypothesis 1 (Bioplastics)**.** Bioplastics cause recycling errors compared to conventional plastics. The average correct recycling rate will be higher under *Control* than under *Biobased* and *Compostable*. The ordering of the two bioplastics treatments depends on the compliers' recycling decisions under these treatments.

Hypothesis 2 (Predictors)**.** Information, moral norms, and environmental concern are conducive to correct recycling. The average correct recycling rate will be higher under *Biobased-I* than under *Biobased*. It will also be higher under *Compostable-I* than under *Compostable*. Under all treatments, correct recycling is positively correlated with subjects' individual scores for moral norms and environmental concern.

To model the impact of logos and information on bioplastics recycling, we follow the potential outcomes framework (Rubin, 1974). We have a setting with multiple treatments that vary along two treatment variables. Given this setting, let $Y_i(t)$ denote the potential outcome for subject i receiving treatment t. The treatment effect (TE) on subject i of treatment j versus treatment k is denoted $Y_i^j - Y_i^k$. Only one of these outcomes is realized and can be observed while the other is the unobserved counterfactual. As a result, the TE can not be identified and we move to estimate the average treatment effect (ATE) which measures the same effect at the sample level: $ATE^{jk} = E\left[Y_i^j - Y_i^k\right]$.

If treatment is independent of potential outcomes and under constant treatment effects, we can identify the ATE. However, although our quota sampling procedure assures as good as random assignment, we are facing possible biased treatment effects due to non-compliance. Not all subjects may observe the logo on the cup. As a result their recycling behavior may be different from those that do.

For this reason, we move to two alternative treatment effects. The first of these is the intent-to-treat effect (ITT), which measures the impact of being assigned to treatment j versus treatment k, ignoring compliance. We do so using a binary variable Z_i^t that takes the value one if subject i is assigned to treatment t and value zero otherwise. We can write the ITTs as:

$$ITT^{jk} = E\left[Y_i^j | Z_i^j = 1\right] - E\left[Y_i^k | Z_i^k = 1\right]. \tag{4}$$

Since we are interested in the impact of compliance on treatment effects, we also estimate the local average treatment effect (LATE). The LATE measures the impact of treatment j versus treatment k for the compliers only, using assignment to treatment as instruments (Imbens and Angrist, 1994; Angrist et al., 1996). We do so using a binary variable D_i^t that takes the value one if subject i complies with treatment t and value zero otherwise. We measure compliance as subjects stating that they have observed the logo on the cup in the survey immediately following the disposal of their cup. We can write the LATE as:

$$LATE^{jk} = \frac{E\left[Y_i^j | Z_i^j = 1\right] - E\left[Y_i^k | Z_i^k = 1\right]}{E\left[D_i^j | Z_i^j = 1\right] - E\left[D_i^k | Z_i^k = 1\right]}. \tag{5}$$

The LATE scales the ITT by the effect of treatment assignment on treatment compliance. Note that in our experiment, non-compliance is one-sided. That is, subjects cannot observe a logo on the cup when it is not there. As a result, there are no 'always-takers', and the LATE corresponds to the average treatment effect on the treated (ATT): $ATT^{jk} = E\left[Y_i^j - Y_i^k | D_i^j = 1\right]$.

Our experimental setup and quota sampling procedure imply that four assumptions of the instrumental variable approach to identify the LATE are automatically satisfied. These are (1) the exclusion restriction, (2) independence of the instrument (i.e. assignment to treatment) and potential outcomes, (3) monotonicity, and (4) the SUTVA (stable unit treatment value assumption, which requires that subjects' potential outcomes are unrelated to other subjects' treatment assignment). On monotonicity, note that there is no possibility for subjects to switch from one assigned treatment to another. Hence, we only have subjects of type 'complier' or 'non-complier'. A final requirement is (5) the first stage requirement, which we will verify in the results section.

We estimate both the ITT and the LATE in a regression framework using the following regression equations.

$$r_i = \beta_0 + \beta_1 Z_i^{\text{Biobased}} + \beta_2 Z_i^{\text{Compostable}} + \beta_3 Z_i^{\text{Biobased-I}} + \beta_4 Z_i^{\text{Compostable-I}} + \beta_5 X_i + \epsilon_i, \tag{6}$$

$$r_i = \beta_0 + \beta_1 \hat{D}_i^{\text{Biobased}} + \beta_2 \hat{D}_i^{\text{Compostable}} + \beta_3 \hat{D}_i^{\text{Biobased-I}} + \beta_4 \hat{D}_i^{\text{Compostable-I}} + \beta_5 X_i + \epsilon_i. \tag{7}$$

Both regression equations are estimated on the whole sample. The dependent variable is the binary variable r_i – indicating a correct recycling decision – and X_i are control variables. The reference observation is a subject in the *Control* treatment (i.e. no logo on the cup and no additional information on the trash cans). In Equation (6), estimated using OLS, coefficients β_1–β_4 reflect the ITT of each of four treatments compared with *Control*. In

Equation (7), estimated using 2SLS, we replace Z_i^t by $\hat{D}_i^t$, which reflects subjects having observed the logo on the cup, instrumented by presence of a logo in the assigned treatment. In other words, these are the compliers. Coefficients β_1–β_4 now reflect the LATEs for the compliers. Despite the binary nature of our outcome variable, binary endogenous variables and binary instruments, we model both the first and second stage as linear. A series of papers has demonstrated that 2SLS generates consistent estimates even when a non-linear model seems more applicable (cf. Angrist, 2001; Basu et al., 2018).

4 Results

To analyze our data, we first summarize and use non-parametric tests to assess recycling behavior. Subsequently we estimate treatment effects in a regression framework.

Our sample consists of 200 subjects. We had to remove 1 observation who turned out to be a minor, so we are left with 199 subjects, 39 in the *Biobased* treatment and 40 in each of the remaining four treatments. Table 1 provides the summary statistics for the key variables on which subjects were surveyed. Our sample is representative of the general Dutch population in terms of age. Our sample is slightly biased in terms of gender and education. Females are over-represented and the average education score of 2.71 is higher than the national average score of 2.39. Based on earlier studies that find no or limited impact of socio-demographic variables on recycling behavior, we do not expect that this bias will affect our results. If anything, recycling efforts increase with education and being female. We will control for these socio-demographic characteristics in our below regressions. Kruskal-Wallis tests indicate that the five treatment groups do not differ in any of the variables listed in Table 1.

Table 1: Summary statistics.

	mean	sd	min	max
Age (yrs)	42.94	15.87	18	81
Female (dummy)	0.61	0.49	0	1
Education (1–3)	2.71	0.56	1	3
Moral norm (1-5)	4.37	0.97	1	5
Environmental concern (1-5)	3.56	0.93	1	5
N	199			

Table 2 provides a tabulation of our results in terms of the main outcome variable, whether the plastic cup was disposed of in the correct trash can. A clear pattern emerges with the vast majority of subjects choosing the default option of disposing of their cup with plastics waste, independent of the assigned treatment. That is, there are hardly any switchers. Pooling treatments by type of bioplastic, we find $\alpha_{\text{Biobased}} = \frac{6}{79}$ and $\alpha_{\text{Compostable}} = \frac{1}{80}$ (note that the latter only measures correct switching to residual waste), such that the first inequality of (1) applies. While the default option is the correct decision for conventional and biobased plastics this is not so for compostable plastics. As a result, subjects under *Compostable* and *Compostable-I* are mostly disposing their cup incorrectly. Given the strong effects reported in Table 2, it seems almost superfluous to assess treatment

Table 2: Frequencies of recycling behavior by treatment (marked numbers indicate the correct decision for each treatment).

	Organic	Plastic	Residual	Total
Control	0	[38]	2	40
Biobased	1	[37]	1	39
Compostable	4	36	[0]	40
Biobased-I	1	[36]	3	40
Compostable-I	1	38	[1]	40
Total	7	185	7	199

effects using non-parametric tests. For completeness, we still do so by comparing each treatment with *Control* in terms of correct recycling. Because of rather low values in some cells of Table 2, we use Fisher's exact test. The p-values from one-sided tests confirm that the rates of correct recycling under *Biobased* ($p = 0.68$) and *Biobased-I* ($p = 0.34$) do not differ from *Control*. More precisely, given these values, we do not reject a non-random association between treatments and our outcome variable. For the two treatments based on compostable plastics, we do reject such a non-random association. Both for *Compostable* and *Compostable-I* we find $p = 0.00$ using one-sided Fisher's exact tests. This result provides partial support for Hypothesis 1.

4.1 Regression results

Next, we move to the results from our regression framework. Table 3 provides estimates of the treatment effects. The ITT is reported in models (1) and (2) and estimated by OLS,[7] while the LATE is reported in models (3) and (4) and estimated by 2SLS. Coefficients

[7]The results found are consistent with marginal effects obtained from estimation using logistic regression, although this estimation is partly hampered by perfect prediction.

on the four treatments are to be interpreted as the change in the probability of correct recycling behavior when a subject is assigned to that treatment as compared to *Control*. Unsurprisingly, the ITT in model (1) is consistent with the results of Table 2. The coefficients on *Biobased* and *Biobased-I* are small and insignificant, while those for *Compostable* and *Compostable-I* are close to -1 (i.e. -100%) and significant. Treatment coefficients are hardly affected by the inclusion of our control variables in model (2). These results confirm on the one hand that being assigned to one of the two biobased plastics treatment has virtually no effect on recycling behavior. On the other hand, being assigned to one of the two compostable plastics treatment has a very strong and negative effect. Information on the trash cans does not appear to affect the ITT for compostable plastics. We use Wald tests to compare the coefficients for treatments with and without information on the trash cans. Reporting only the results for model (2), we do not reject equality both for biobased plastics ($F(1,189) = 1.07$, $p = 0.30$) and for compostable plastics ($F(1,189) = 0.37$, $p = 0.54$).

The LATE in models (3) and (4) confirm the ITT findings. Note that we report only the second stage results, while the first stages are discussed below. All treatment effects keep their sign and become stronger. Despite being stronger than the ITT, the LATE are also less precise, particularly the coefficient on *Compostable-I*. Again, information does not play a big role and again, we use Wald tests to compare the coefficients for treatments with and without information on the trash cans. Reporting only the results for model (4), we do not reject equality for biobased plastics ($\chi^2(1) = 0.00$, $p = 0.96$) while for compostable plastics we are close to rejection ($\chi^2(1) = 3.40$, $p = 0.07$). This result provides partial support for Hypothesis 1 but not for Hypothesis 2.

The reason that the LATE are stronger than the ITT is, surprisingly, that compliers are no better in recycling than non-compliers. Figure 4 illustrates this feature. For both types of bioplastics, the ratio of correct vs. incorrect recycling decisions is lower for compliers than for non-compliers. Apparently, the bioplastics logos on the cups are not informative to the subjects in our experiment.

There are two possible explanations for the strong negative effect on *Compostable-I* as compared to *Compostable*. One is a treatment effect on the compliers while the other is just noise in small samples. We can reasonably rule out the treatment effect. Recall from Section 3 that treatment effects for compostable plastics should induce more switching away from the default, plastics waste, which can only increase the average correct recycling rate. Hence, if information provision on the trash can has any effect, it would mitigate the strong negative effect under *Compostable*. Since we find the reverse, we expect that this is a result of noise. This conclusion is backed up by the low number of subjects that report having observed the information on the trash can. Only 10/80 subjects did so, of which 6

Table 3: Treatment effect regressions of correct recycling behavior.

	OLS (ITT)		2SLS (LATE)	
	(1)	(2)	(3)	(4)
Biobased	−0.001	0.003	−0.004	0.081
	(0.047)	(0.046)	(0.138)	(0.200)
Compostable	−0.950***	−0.957***	−2.000***	−1.992***
	(0.046)	(0.046)	(0.340)	(0.357)
Biobased-I	−0.050	−0.046	−0.143	0.072
	(0.046)	(0.046)	(0.163)	(0.210)
Compostable-I	−0.925***	−0.929***	−4.111***	−4.200***
	(0.046)	(0.046)	(1.212)	(1.165)
Age		−0.000		−0.004
		(0.001)		(0.004)
Female		0.088***		0.295**
		(0.031)		(0.131)
Education		−0.032		−0.332**
		(0.027)		(0.152)
Moral norm		−0.001		−0.093
		(0.015)		(0.076)
Environmental concern		−0.005		−0.112
		(0.016)		(0.079)
Constant	0.950***	1.030***	0.950***	2.631***
	(0.033)	(0.122)	(0.034)	(0.570)
N	199	199	199	199

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Coefficient estimates from OLS and 2SLS regression models with correct recycling behavior as the dependent variable (and robust standard errors in parentheses). The reference treatment is *Control*, with no logo on the cup and no additional information on the trash cans. OLS measures the ITT while 2SLS measures the LATE. Treatment names refer to OLS coefficients of treatment assignment in models (1) and (2) and second-stage coefficients of treatment compliance, instrumented by treatment assignment, in models (3) and (4). Performance of the first stages are discussed in the main text but not reported here.

under *Biobased-I* and 4 under *Compostable-I*.

We test for under-identification and weak identification in the first stages of our just-identified model (4).[8] The Kleibergen-Paap *LM* statistic is calculated to test for under-identification. The test statistic equals 23.85 with $p = 0.00$, so that the null of under-identification is rejected. A standard approach to test for the presence of weak identification

[8]Results for model (3) are almost identical and are omitted here.

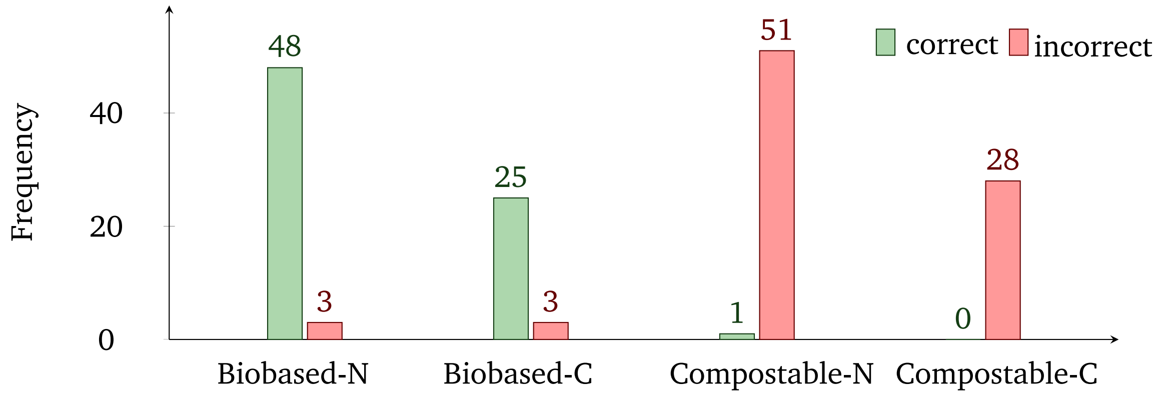

Figure 4: Frequency of correct and incorrect recycling decisions by type of bioplastics and by compliers (C) vs. non-compliers (N).

in a model with multiple endogenous regressors is to calculate the Cragg-Donald F statistic. This test statistic should then be compared against critical values as tabulated by Stock and Yogo (2005). However, since Stock and Yogo (2005) do not provide such values for more than 3 endogenous regressors, this approach is not perfect in our model with 4 such regressors. The standard work-around is to extrapolate these critical values, which would suggest, given our Cragg-Donald statistic of $F = 4.66$, that the null of weak identification is rejected. Skeels and Windmeijer (2018) suggest that it might be better, instead, to focus on the Sanderson-Windmeijer F statistics to test for the presence of weak identification of individual regressors. These test-statistics, one for each treatment regressor, are equal to $F = 72.49$, $F = 78.06$, $F = 76.06$, and $F = 55.85$. Since each of these imply $p = 0.00$, the null of weak identification is rejected. Summarizing, we do not suffer from weak instruments in the first stages.

4.2 Robustness

We further assess the regression results by presenting and discussing the results of three robustness checks as well as further assessing the impact of two important predictors of recycling behavior: moral norms and environmental concern. In the robustness checks, we first pool treatments. Second, we change the measurement of compliance. Third, we check our results in light of how certain our subjects are of their recycling decision.

Pooling treatments by type of bioplastics Given the low number of subjects that reported to have observed the additional information on the trash cans under *Biobased-I* and *Compostable-I*, we check whether our results are robust to pooling the four treatments into two, based on the type of bioplastic. The results are reported in Table A1. They are very much in line with the main regression results. The (pooled) treatment coefficients, both the ITT and LATE, lie largely in between the treatment coefficients as reported in Table 3, with lower standard errors, as expected. All other coefficients for the pooled model are comparable in size to those of Table 3, again with lower standard errors.

How compliance is measured Rather unconventionally, our experiment does not allow us to directly observe treatment compliance. The reason is that compliance is based on visual perception. Compliers observe the logo on the cup while non-compliers do not, and it is next to impossible for the experimenter to record this difference. Instead, we rely on subjects' self-reporting such compliance in the survey immediately following the disposal of their cup. To partially test the impact of such self-reporting, we exploit subjects' answers to two follow-up questions. Recall from Section 2.1 that if subjects stated that they had observed the logo on the cup they were subsequently asked whether they could indicate which logo was on the cup and whether the logo played a role in their recycling decision. Across the four treatments involving bioplastics, 56 out of 159 subjects (35%) reported to have seen the logo on the cup. These are the compliers as used in the regressions of Table 3. A subset of these, 50 out of 56 subjects (89%), were able to correctly indicate which logo was on the cup by pointing to one of the two logos, printed on a sheet of paper. We denote these as revealed compliers. Finally, a next subset of these, 10 out of 50 subjects (20%), stated that they made their recycling decision based on the logo. We denote these as strong compliers.

In Table A2, we report the results across the three models based on the three measures of compliance. Model (4) is model (4) of Table 3, and included for comparison. Model (4') presents the results for revealed compliers. Both levels and significance of the treatment coefficients are largely unaffected compared to model (4). Model (4") presents the results for strong compliers. Treatment coefficients are inflated and less precise, while some variation is now being picked up by control variables. These results are due to noise in a small sample of strong compliers.

Certainty Recall from Section 2.1 that subjects were presented with a certainty question, eliciting how certain they were about their recycling decision (Likert scale 1–5). Results from this survey item inform us to what extent (in)correct recycling decisions are made out of ignorance. One may be tempted to include this measure as a control variable in our regressions, following the logic that subjects that are less certain make more random decisions or rather stick to the default option (Li and Mattsson, 1995). However, this approach may be prone to endogeneity. Dekker et al. (2016) suggest that a latent construct ‘decision uncertainty’ may be simultaneously determining the outcome of interest (in our case, the recycling decision), as well as stated certainty. However, Dekker et al. (2016) also suggest that in some cases the ‘naive’ approach of including certainty as a control variable may be sufficient, because alternative approaches are complex and computationally costly.

Table A3 shows the results when certainty is included as a control variable in models (2) and (4) of Table 3. Comparison of the results with those of Table 3 shows that inclusion of certainty does not affect the treatment variables in terms of level nor their significance. Certainty picks up some significance in the ITT but not in the LATE. This is caused by positive correlation of certainty with correct recycling behavior but not with compliance. While average certainty is rather high (4.4/5), it is slightly lower for compliers (4.2) and decreases further for subjects that switch from the default, plastic waste. For compostable plastics, switchers’ certainty equals 3.7 while for biobased plastics, it equals 2.0 (independent from compliance). Apparently, subjects that switch from the default are not so sure about this decision, irrespective of having observed the logo on the cup.

Other predictors Our main regression results from Table 3, as well as the regressions in the robustness checks, do not show any impact of two common predictors of recycling behavior: moral norms and environmental concern. The specific survey item for moral norms is phrased as *“Do you consider waste separation a useful activity?”* (Likert scale 1–5), while for environmental concern it is phrased as *“Are you generally concerned with sustainable consumption?”* (Likert scale 1–5), consistent with standard items that measure moral norms and environmental concern in recycling behavior (Miafodzyeva and Brandt, 2013). Average scores are quite high: 4.4 for moral norms and 3.6 for environmental concern. Zooming in on both variables, we find that correct recycling decisions are only weakly correlated with each of them; positive for moral norms and, surprisingly, negative for environmental concern. However, both of these correlations are highly non-significant. Combined with our results on certainty, we conclude that lack of norms or concern is not the bottleneck for subjects’ recycling behavior in the setting of our experiment. This result does not provide support for Hypothesis 2.

5 Conclusion

We conducted a natural field experiment to assess subjects’ recycling behavior for bioplastics. We find partial support for Hypothesis 1. That is, we find that the average correct recycling rate for conventional plastics and biobased plastics is very high, but for compostable plastics it is very low. This result is completely driven by subjects not changing their default behavior for products that contain the seedling logo. While biobased plastics are to be disposed of joint with conventional plastic waste, compostable plastics are to be disposed of with residual waste. Since the vast majority of subjects is apparently unaware of this recommendation, they opt for the default, i.e. plastics waste, independent of the type of plastics. Compliers (i.e. subjects that report having observed the bioplastics logo on the cup) are not different in this regard from non-compliers. Also, we find no support for Hypothesis 2. That is, standard predictors of recycling behavior (information, moral norms, and environmental concern) do not appear to have any effect on recycling behavior of bioplastics.

We conclude that subjects are generally ignorant of bioplastics recycling. This conclusion corroborates previous evidence that consumers are ill-informed about differences between conventional plastics and the various types of bioplastics. We add evidence that providing information in the form of logos or recycling information on trash cans is not sufficient to snap subjects out of their default recycling behavior for plastics. As a result, the potential environmental benefits of bioplastics may not materialize.

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Appendix A: Survey

(Translated from Dutch.)

Survey info

1. Name surveyor ...
2. Date ...
3. Survey number ...
4. Type of mug ... (Conventional, Biobased, Compostable)

Disposal observation

5. Disposal in which trash can? ... (Residual, Plastic, Organic)

Introductory question

6. What taste did the lemonade remind you of? ... (Open)

Certainty

7. I see that you disposed of your cup in ... *(state observed trash can)* how certain are you about this disposal decision? ... (Likert scale 1–5).

Information

8. *(Only Biobased-I and Compostable-I:)*
   (a) Did you read the additional information on the trash cans? ... (Yes, No)

Compliance

9. *(All treatments except Control:)*
   (a) Did you observe a logo on the cup? ... (Yes, No)
   (b) (If 9.a yes) Can you indicate which logo was on the cup by pointing to one of the two logos on this sheet of paper? ... (Correct, Incorrect)
   (c) (If 9.a yes) Did you make your disposal decision based on this logo? ... (Yes, No)

Moral norms and environmental concern

10. Do you consider waste separation a useful activity? ... (Likert scale 1–5),
11. Are you generally concerned with sustainable consumption? ... (Likert scale 1–5),

Socio-demographics

12. Age ... (Years)
13. Gender ... (Male, Female, Other)
14. Education ... (Open)

Other

15. Any other comments ... (Open)

(Surveyor reads the debriefing text.)

Appendix B: Additional results

Table A1: Treatment effect regressions of correct recycling behavior: treatments pooled by type of bioplastics.

	OLS (ITT)		2SLS (LATE)	
	(1') Pooled	(2') Pooled	(3') Pooled	(4') Pooled
Biobased (pooled)	−0.026	−0.022	−0.073	0.032
	(0.040)	(0.040)	(0.128)	(0.152)
Compostable (pooled)	-0.937^{***}	-0.943^{***}	-2.679^{***}	-2.715^{***}
	(0.040)	(0.040)	(0.418)	(0.421)
Age		−0.000		−0.003
		(0.001)		(0.004)
Female		0.086^{***}		0.268^{**}
		(0.030)		(0.125)
Education		−0.034		-0.263^{**}
		(0.027)		(0.128)
Moral norm		−0.004		−0.046
		(0.015)		(0.067)
Environmental concern		−0.005		−0.058
		(0.016)		(0.067)
Constant	0.950^{***}	1.045^{***}	0.950^{***}	2.026^{***}
	(0.033)	(0.121)	(0.034)	(0.510)
N	199	199	199	199

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Compare Table 3. Coefficient estimates from OLS and 2SLS regression models with correct recycling behavior as the dependent variable (and robust standard errors in parentheses). The reference treatment is *Control*, with no logo on the cup and no additional information on the trash cans. OLS measures the ITT while 2SLS measures the LATE, using pooled data by type of bioplastic. Treatment names refer to OLS coefficients of treatment assignment in models (1') and (2') and second-stage coefficients of treatment compliance, instrumented by treatment assignment, in models (3') and (4').

Table A2: Treatment effect regressions of correct recycling behavior: three measures of compliance.

	2SLS (LATE)		
	(4) Compliers	(4') Revealed compliers	(4") Strong compliers
Biobased	0.081	0.048	−2.623
	(0.200)	(0.187)	(6.350)
Compostable	−1.992***	−2.101***	−12.829*
	(0.357)	(0.393)	(6.946)
Biobased-I	0.072	0.034	0.692
	(0.210)	(0.285)	(1.160)
Compostable-I	−4.200***	−4.727***	−39.503
	(1.165)	(1.448)	(38.245)
Age	−0.004	−0.002	0.012
	(0.004)	(0.004)	(0.008)
Female	0.295**	0.266*	0.784***
	(0.131)	(0.141)	(0.154)
Education	−0.332**	−0.227	−0.257
	(0.152)	(0.149)	(0.183)
Moral norm	−0.093	−0.105	−0.498**
	(0.076)	(0.084)	(0.250)
Environmental concern	−0.112	−0.110	−0.069
	(0.079)	(0.086)	(0.120)
Constant	2.631***	2.317***	3.077***
	(0.570)	(0.550)	(1.058)
N	199	199	199

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Compare Table 3. Coefficient estimates from 2SLS regression models with correct recycling behavior as the dependent variable (and robust standard errors in parentheses). The reference treatment is *Control*, with no logo on the cup and no additional information on the trash cans. 2SLS measures the LATE. Treatment names refer to second-stage coefficients of treatment compliance, instrumented by treatment assignment. Model (4) is model (4) of Table 3.

Table A3: Treatment effect regressions of correct recycling behavior: including certainty as a control variable.

	OLS (ITT)	2SLS (LATE)
	(2') Certainty	(4') Certainty
Biobased	0.039	0.166
	(0.040)	(0.197)
Compostable	-0.932^{***}	-1.948^{***}
	(0.040)	(0.356)
Biobased-I	−0.039	0.084
	(0.040)	(0.190)
Compostable-I	-0.910^{***}	-4.127^{***}
	(0.040)	(1.139)
Certainty	0.099^{***}	0.083
	(0.012)	(0.053)
Age	−0.001	−0.005
	(0.001)	(0.004)
Female	0.070^{***}	0.275^{**}
	(0.026)	(0.129)
Education	−0.001	-0.303^{**}
	(0.023)	(0.149)
Moral norm	0.005	−0.084
	(0.013)	(0.073)
Environmental concern	−0.001	−0.105
	(0.014)	(0.077)
Constant	0.495^{***}	2.151^{***}
	(0.124)	(0.600)
N	199	199

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Compare Table 3. Coefficient estimates from OLS and 2SLS regression models with correct recycling behavior as the dependent variable (and robust standard errors in parentheses). The reference treatment is *Control*, with no logo on the cup and no additional information on the trash cans. OLS measures the ITT while 2SLS measures the LATE. Treatment names refer to OLS coefficients of treatment assignment in model (2') and second-stage coefficients of treatment compliance, instrumented by treatment assignment, in model (4').