TU Delft

Delft University of Technology

Document Version
Final published version

Citation (APA)
Tong, X., Nikolic, I., Dijkhuizen, B., van den Hoven, M., Minderhoud, M., Wäckerlin, N., Wang, T., & Tao, D. (2018). Behaviour change in post-consumer recycling: Applying agent-based modelling in social experiment. *Journal of Cleaner Production*, *187*, 1006-1013. https://doi.org/10.1016/j.jclepro.2018.03.261

Important note
To cite this publication, please use the final published version (if applicable).
Please check the document version above.

Copyright
In case the licence states “Dutch Copyright Act (Article 25fa)”, this publication was made available Green Open Access via the TU Delft Institutional Repository pursuant to Dutch Copyright Act (Article 25fa, the Taverne amendment). This provision does not affect copyright ownership.
Unless copyright is transferred by contract or statute, it remains with the copyright holder.

Sharing and reuse
Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

Takedown policy
Please contact us and provide details if you believe this document breaches copyrights.
We will remove access to the work immediately and investigate your claim.

This work is downloaded from Delft University of Technology.

Green Open Access added to TU Delft Institutional Repository

'You share, we take care!' – Taverne project

https://www.openaccess.nl/en/you-share-we-take-care

Otherwise as indicated in the copyright section: the publisher is the copyright holder of this work and the author uses the Dutch legislation to make this work public.

Journal of Cleaner Production 187 (2018) 1006–1013

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Behaviour change in post-consumer recycling: Applying agent-based modelling in social experiment

Xin Tong [a, *], Igor Nikolic [b], Bob Dijkhuizen [b], Maurits van den Hoven [b], Melle Minderhoud [b], Niels Wäckerlin [b], Tao Wang [a], Dongyan Tao [a]

[a] College of Urban and Environmental Sciences, Peking University, Beijing, 100871, China
[b] Technology, Policy and Management, Delft University of Technology, 2600 AA, Delft, The Netherlands

ARTICLE INFO

Article history:
Available online 26 March 2018

Keywords:
Community-based tool
Waste separation
Recycling
Theory of planned behavior (TPB)
Agent-based modelling (ABM)

ABSTRACT

Change in consumer behavior that leads to increased waste separation and recycling has been identified as a critical component of Chinese national strategy for constructing a "Circular Economy". Various innovative solutions at community level targeting consumer behaviors are emerging in Chinese cities, using information technology that can track the volume and quality of the sorting process. In order to evaluate the potential impact of these novel solutions, we studied the behavioral change of households by initiating an experimental recycling program in a residential community in Beijing, and developed an Agent Based Model based on Theory of Planned Behavior (TPB) to identify key factors in changing behavior. The results show that the Social Norm (SN) has a decisive effect on whether an area starts recycling or not. As to the effectiveness of intervention, the Perceived Behavioral Control (PBC) plays a large role in the determination of the recycling behavior in this study, while the role of attitude is relatively small. The model outcomes can be corroborated with observations in different communities using similar technical solutions. In conclusion, we suggest that efficient local interactions among various stakeholders are needed in forming the social norm and common space that favorite recycling activities at the community level.

© 2018 Elsevier Ltd. All rights reserved.

1. Introduction

The growth of municipal solid waste (MSW) has become a pressing environmental challenge in many cities in China. The increasing demand for waste disposal, the rise of NIMBY objections to waste processing facilities and the shortage of sites for landfills are prompting a search for alternative strategies to solve the problem (Zhang et al., 2010). The 3R concept (reduce, reuse and recycle) has been promoted in China as a key component in the national strategy for constructing a "Circular Economy", in which the change in consumer behavior that leads to increased waste separation and recycling has been identified as a critical component (The State Council, 2013).

Various programs have been initiated in cities in China since 1990s to encourage the source separation of waste at household (Tai et al., 2011). However, these efforts were generally ineffective, either due to lack of revenue for recyclers (Zhang et al., 2016a, b), or due to no incentives to participation for residents (Zhang and Wen, 2014). It is clear that the planning and provision of physical recycling facility was not enough to change the behavior of people. It is important to understand the willingness and participating behavior in waste separation and recycling (Zhang et al., 2015).

The Theory of Planned Behavior (TPB) provides a theoretical basis to investigate both internal and external factors (Boldero, 1995; Tonglet et al., 2004), as well as social norm and contexture culture effects (Botetzagias et al., 2015; Chan and Bishop, 2013; Nigbur et al., 2010), which affect the waste separation and recycling behavior in society. It has been widely used in building consistent policy framework to convey the appropriate opportunities, facilities and knowledge to recycle to the public (Davis et al., 2006), reduce barriers for physically recycling, such as time (Matsumoto, 2013), distance (Sidique et al., 2013), and inconvenience (Chu et al., 2013; Zhang et al., 2016a; b). It also provides a suitable tool in cross-regional comparison (Stoeva and Alriksson, 2017), which facilitate the transmission from local practices to the regulatory process at upper level.

* Corresponding author.
E-mail address: tongxin@urban.pku.edu.cn (X. Tong).

https://doi.org/10.1016/j.jclepro.2018.03.261
0959-6526/© 2018 Elsevier Ltd. All rights reserved.

This paper presents the joint efforts between Peking University and Delft University in a social experiment of community-based recycling program to couple social experiments and agent based simulations based on TPB in exploring key factors of a household's decision to recycle or not. The aim of this study is to identify policy levers at the community level, which could upscale the local best practice applicable in more cities in developing countries. The next section describes our social experiment conducted in Hongfuyuan (H community), Beijing, as well as the agent-based model generalized upon it. In section 3, we present the actual result of the social experiment and the simulation result of the model with different settings. In section 4 we discuss the implication of the results to the waste separation and recycling policy in China. In conclusion, we explore the potential to couple the social experiments and agent based simulations in future.

2. Methods

We used a social experiment method in a community-based recycling program in Beijing. The community level was chosen for three reasons. First, the local social interactions at the community level could be most decisive in the formation of social norm and self-identity, which has been explored in existing research in developed countries (Botetzagias et al., 2015; Martin et al., 2006; Nigbur et al., 2010), but not received much attention in China, yet. Second, it is a practical level to involve various stakeholders in a manageable way to initiate an experimental program. Third, successful practices at the community level could be generalized into business model that can be copied in other places. In order to do so, we combined the social experiment with the agent-based modelling technique to reveal the possible results under different settings as suggested in community-based action research (Poteete et al., 2010). Recent development of mobile internet solutions technologically enables personalized incentives and feedback in waste separation and recycling, which effectively improves the data access to monitor the behavior change in social experiment.

2.1. Socio-economic historical context

Given the importance of understanding individual behavior in its context, we start by exploring the socio-historical context of the case study. The study area locates in Hongfuyuan (H community) in northern suburb of Beijing, just between two waste villages, Dongxiaokou and Qiliqu (Tong and Tao, 2016), and Asuwei, the largest comprehensive waste disposal center (Fig. 1). The land of H community belongs to a local village. In late 1990s, under the leadership of the village head, the villagers collectively decided to demolish all the old cottages, and to build a new town with mixed functions, including a residential zone, a recreational complex, an education zone, and an industrial zone (Kong et al., 2015). In the following decade, Beijing experienced dramatic urban expansion. Consequently, the population living in the new town grew from less than 1,000 in 2000 to more than 30,000 in 2015.

H community consists of four areas, North Area, West Area, East Area, and South Area. The North Area was excluded in the experiment, because it was built late and separated from the other three areas by a major road. The East Area was first established to accommodate the original villagers. After relocating all the local villagers to the East Area, the village built new apartments in the West Area and sold collectively to the staff of some large *Danwei*[1] (Chai, 1996; Bray, 2005), including state-owned companies near the village, and the new built colleges in the education zone. Thus, the average education level is higher in this neighborhood. Both East Area and West Area are acquaintance society with frequent social interactions. The South Area was most recently developed. The apartments were sold separately to independent households on the market, thus formulated a stranger-society with less social interactions among residents (Fig. 2).

The evolution of the waste management in this dramatically urbanized village can be a miniature of the transition of urban waste management in China in last 30 years. The waste separation and recycling was included in the initial planning of the new town in late 1990s. A small piece of land in the northern part of the village was designated for waste sorting and recycling. Some local villagers, who lost farmland during the urban development, did waste separation and recycling for residents living in the new town. However, as the villagers got rich from the real estate development, nobody would like to do the scavenging anymore. The village outsourced the waste collection and recycling to a group of migrant junk-buyers, who took care of the waste collection so as to enjoy the privilege to buy old junks in the community. The recyclables were sorted and sold in the waste villages nearby (See location in Fig. 1).

However, as the population growing, the revenue from the scavenging can hardly cover the cost for waste collection and transportation. Therefore, the village built a cleaning company in charge of the public sanitation with annual cost over 1 million yuan in 2011. The waste collection and transportation was separated from the recycling business. The cleaning company collected all the mixed waste from the dustbins, and transported to Asuwei, the comprehensive waste disposal center established by the municipal government (See location in Fig. 1). The migrant workers continued their junk-buying business in this community by paying a small administrative fee to the village. As economic growth has slowed down in China in recent years, the market value of recovered materials decreased significantly. The junk-buyers refuse to accept the low-value recyclables, leaving increasing waste to be collected and transported by the cleaning company. The value of waste reduction and separation at the generation source is obviously appreciated by the administration, but actions should be taken at the community level.

We aimed at establishing a waste separation system at the source of generation for the whole community. However, in order to test the effects of the new program on the behavior change, we started from a small experiment by recruiting around 500 households to participate in volunteer, roughly 5% of the whole population.

2.2. Social experiment

We cooperated with Chengdu Green Earth, a social corporation who developed a system based on mobile phone application to provide incentives according to the sorting performance of the users. They developed the system in their community-based recycling program in Chengdu in 2011, which was supported by the local government with public expenditure on community services. They provide barcode sticker tags to households. The households have two options to deliver their waste. One is to put their sorted garbage into different bags according to the category of materials, attach the barcode tag to each bag, then put the bags into the recyclables container near their apartments. The other is to submit their sorted recyclables during the on-site collection events on weekend. During these events, the staff from Green Earth will

[1] *Danwei* is a term translated from Chinese (单位) denoting the socialist working place in China. Apart from salary, *Danwei* used to provide employees a comprehensive package of welfare and services including housing. Even after marketization, the legacy of *Danwei* still has influence on social economic relations in urban China.

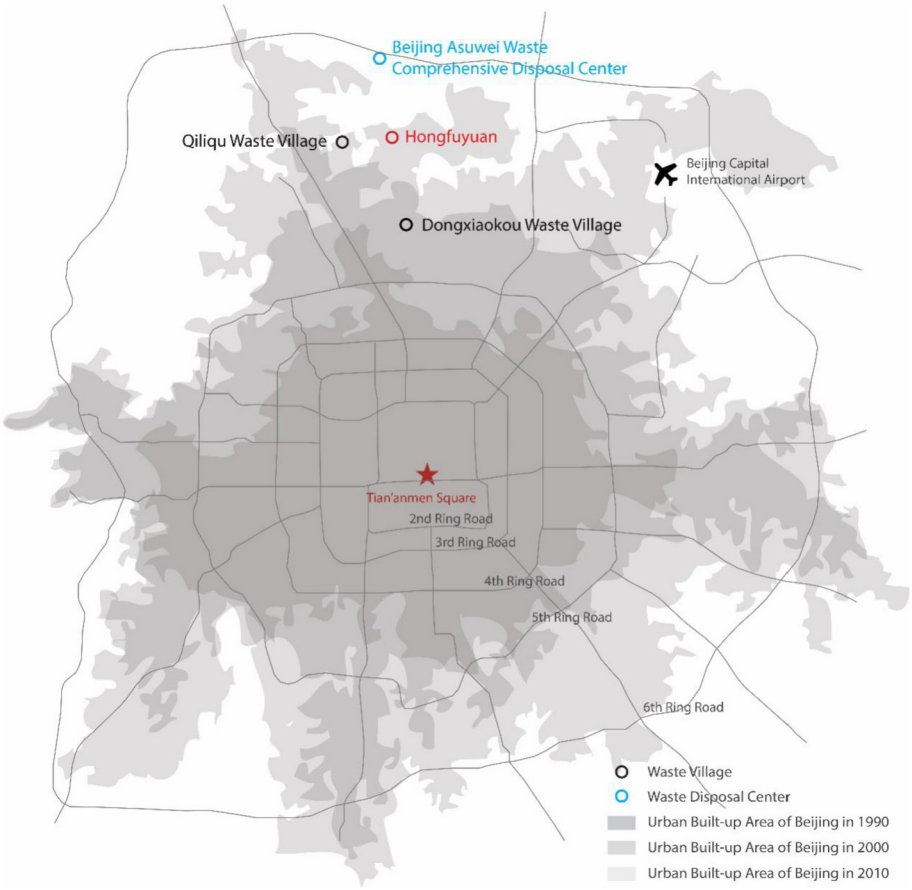


Fig. 1. The location of H community in Beijing.



Fig. 2. The map of H Community.

interact with their customers face-to-face. The staff will scan the barcode on the waste bags and input the scores according to the weight and materials. The scores will be deposited in the accounts of each household, who can use the scores to buy daily necessities.

We used this system in H community from Dec 2013 to the end of 2016 to tract the behavior of participant household. We put six recycling containers in the community near the entrance of each neighborhood (Fig. 2). Initially, we collaborated with the cleaning company of the village, who assigned a staff to collect the waste from the containers, scan the barcode, and input the information through the mobile phone application. However, the staff had technical difficulties in using the system. Since June 2014, we shifted the on-site operation of the system to a family of junk-buyers in the community, who not only collected the waste from the containers, but also offered on-call service. During the experiment, we tested different strategies to encourage the households to participate in the recycling program at different stages, including on-site promotion events and various products as incentives.

Every half year, we organized a large on-site event with special gifts for the participating households. Before each event, we called all the participants to ask them several questions on their attitudes towards this program.

2.3. Agent-based model

Based on the social experiment, we developed an agent-based model to explore the social interaction factors that influence the waste recycling and disposal behavior of households. Agent-based models are a class of tools that belong to generative science (Epstein, 2007), that are able to explore emergence of macro-level patterns from micro theories of individuals (Epstein and Axtell, 1996). Existing research has used agent-based modelling to study the effects of external policy factors, especially the charge on landfill, on the waste disposal behavior of residents in Chinese city

(Meng et al., 2016). The specific question driving our model development was to understand what the most important behavioral factors at the community level could influence a household's decision to recycle or not. And consequently: How can new collective norms favoring recycling activities be established from bottom up?

The structure of the model covers two main themes: the social interactions in the neighborhoods, and the waste management system. We characterize the three neighborhoods with different type of households to represent the spatial structure addressed above as a reflection of typical composition of neighborhoods in contemporary urban China.

The agents that will be part of our model, are **households** that are within a specific neighborhood. Each household creates recyclable waste, but it depends on the consumers' decision to throw it to the dustbin for Landfill, or participate in recycling. The recycling program offers two options: Containers or Collector. Containers are situated at certain locations throughout the village (See Fig. 2), and requires people to bring their recyclable waste to the containers themselves. In return, households may receive valuable scores. Collector can go door-to-door to collect the recyclables, and give the guidance for garbage sorting face-to-face. The collector will use the system to give scores to the households according to the material and sorting quality. All recyclables collected from the households will be sold on the recycling market. For the three choices, Landfill and Collector represent the typical ways of household waste disposal in current urban China, while Containers represent a prevalent recycling options offered by the formal municipal waste management system.

Households recycling behavior is only directly affected by observing other households, thus the formation of Social Norm is central in our model. However, the attributes of household could have impact on the calculated intention of each household through differentiating Attitudes to economic incentives and the Performed Behavior Control on their waste disposal. The attributes of each household include:

(1) **Social-economic status**: Household size (the number of people in a household), Education level, Income level, Amount of recyclable waste;
(2) **Cognitive status**: Environmental awareness, Knowledge of recycling, Recycling intention, Willingness to change (the degree to which a household is willing to change its current behavior);
(3) **Local status:** Neighborhood (each household is situated in one of the three neighborhoods addressed above), Social network (a list of households that a household interacts with), Direct neighbors (the adjacent neighbors of a household), Friends (other households in the community that are part of the social network);
(4) **Behavior constraints:** Available time for recycling (spare time is sufficient or insufficient), Available space for recycling (storage space is sufficient or insufficient), Distance to the container (the distance to the closest recycling container);

Besides the agents described above, we designed several elements as the adjustable interventions of the **Environment**, including four categories: the amount and location of containers, the available recycling methods, economic incentives, and provision of information.

At setup, the households are spread across the map and divided into three neighborhoods: *Danwei* Staff (West), Local Residents (East), and Independent Residents (South). And the attributes of each household are associated with the neighborhood it belongs to.

Each day, a household produces recyclable waste. The total amount generated each day is based on three properties: (1) Household size: a larger household increases the waste generation (positive causality), (2) Income: a higher income increases the consumption of a household and thereby the waste generation (positive causality), and (3) Level of education: higher educated households have a higher environmental awareness which decreases the waste generation per household (negative causality)

Each week, a household communicates with a certain amount of directly neighboring households and other friends. The amount and type of friends which is interacted with differs per household. This interaction leads to a certain perception of household recycling behavior in the community, also called the 'perceived social norm'. Every household thus creates their own social norm on how many households recycle their waste. Along with other variables, this influences their decision whether to recycle or not.

If the 'amount of waste' reaches a determined threshold, the household decides whether it will use one of the three available options addressed above by calculating the 'utility' for each method, based on the required time and 'economic incentives'. If situational factors are applicable, certain hard constraints become part of the household rationale. These constraints are then part of the decision tree and landfill becomes another possible outcome. Fig. 3 shows the decision tree according to the household's preference.

The next step in the line of reasoning is to calculate the intention, which can be to recycle or not to recycle. If this intention is to recycle, the possibility from intention to one of the two actions is calculated. If the intention is not to recycle, the recyclables will be disposed to landfill. Furthermore, while not all intentions result in behavior, only in 70% of the cases a recycling intention results in recycling behavior. View Fig. 4 for an overview of this procedure.

The model was implemented in Netlogo (Wilensky, 1999). The model code is available for review on OpenABM.org repository. We provide the simulation code, the data used to parameterize the model, a detailed description of all agent behavior, model verification steps, experimental design details and output analysis code. Using the experiment data of 500 households, we simulate the behavior change of approximately 10,000 households of the whole community.

3. Results

In this section, we will first present the empirical result of our social experiment; then we will discuss the outcomes of the agent-based model to explore possible outcomes under different settings.

3.1. The behavior changes in experiment

In our social experiment in H community, around 500

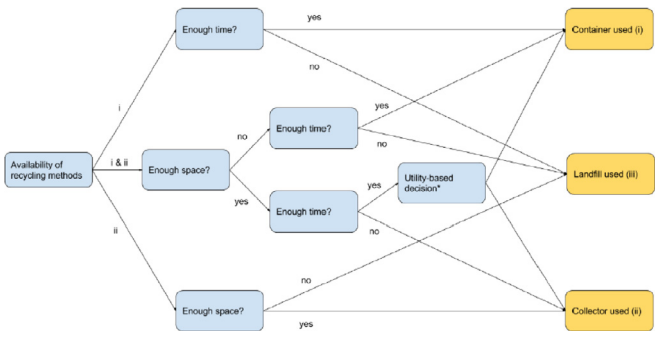


Fig. 3. Representation of Agents decision tree.

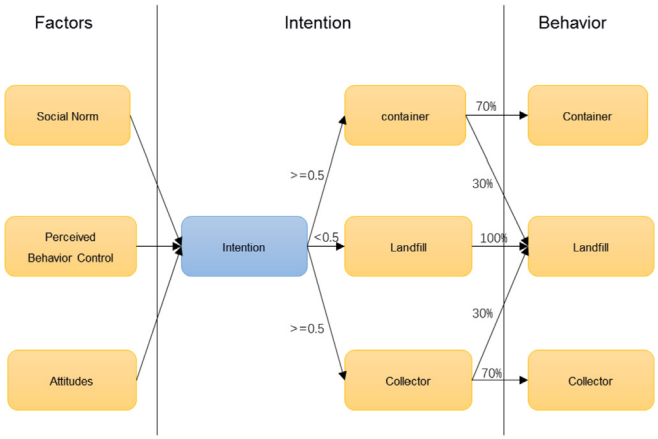


Fig. 4. Decision Tree expressed in TPB concepts.

households voluntarily registered in the system as users. At the end of the experiment, roughly 40% of the registered households participated in the recycling program. The changing behavior of the registered household in the three neighborhood shows in Fig. 5.

Differentiated responses in behavior change can be detected in the three neighborhood, which corresponded to the changing incentives we provided at different stage. At the first stage, we set up the first container in East Area in Dec. 2013 to test the system. The experiment of all three areas formally started from March 1st 2014. We had on-site promotion event every weekend during the first month. The residents can register on our system on the event through the mobile phone. However, before April 1st 2014, we provided no economic incentives to the participating households. All the scores of the participating households are devoted to the charity organization. The second stage, after April 1st 2014, we stop the on-site promotion events at weekend. The staff from the cleaning company helped to collect the recyclables from the containers. There was no on-call service for pickup at home. In addition, the households could use their scores in the system to exchange daily necessities. At stage 3, we cooperate with a family of junk buyers in the community from September 2014. The husband took charge of the container. He started to use our system in his own junk-buying business by providing on-call services. He also helped his old customers in the community to register on our system. Thus, the households had two options for recycling: containers and collectors. Using collector is increasingly popular among the participants. The wife continued our on-site events at weekend by redeem the scores of the households with daily necessities.

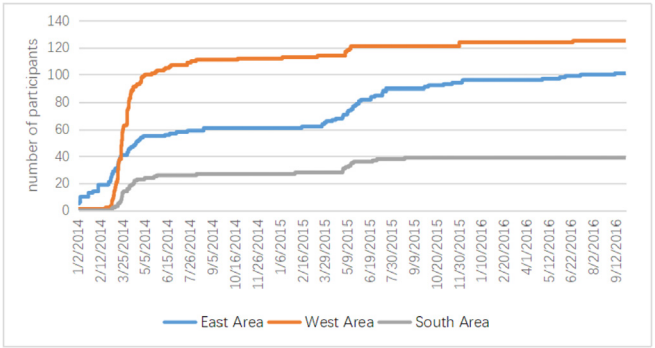


Fig. 5. The number of participants.

In order to encourage the participation, we raised incentives in April 2015 by introducing organic vegetables as gift for households with high accumulated scores. This incentive had significantly improved the participation, especially in the East Area.

Fig. 6 shows the accumulated scores of households in each building during the experiment. The participation was generally higher in buildings around the containers in East and West Areas, which indicated the importance of convenience to the users (Sidique et al., 2013). However, in South Area, most of the users preferred on-call services, therefore, the location of containers was insignificant.

3.2. Simulation results of the agent-based model

The agent-based model helps us to analyze the impacts of various factors on the recycling behavior in a more systematic way. Using the EMA workbench, 2,000 experiments with different input parameters were run. The output of the experiments consists of a time series of the participation rate of the three choices: Landfill, Collector and Container for every tick (day) in the model.

3.2.1. Overall possibilities

The overall result of all 2,000 simulation experiments shows that in the best case more than 60% of the households are participating in a recycling program. In a quarter of the simulations between 25% and 62% of the households are participating after 1,000 days. In at least 25% of the experiments, nobody is participating in a recycling program after 1,000 days. On average over all experiments, around 15% households are using a recycling program after 1,000 days. In Fig. 7, the result of every 20th experiment is plotted as a line over time to represent the character of the whole data set.

Furthermore, a violin plot in Fig. 7 represents the probability density of the outcomes after 1000 days. It is striking that many of the model outcomes have a participation rate in the recycling program of less than 10%. It is also notable that there are almost no outcomes between a participation rate of 10% and 25%. However, a number of experiments result in a participation rate up to 25%–60%. The mode outputs are thus bimodally distributed, showing



Fig. 6. The Spatial Distribution of accumulated scores of the participating households.

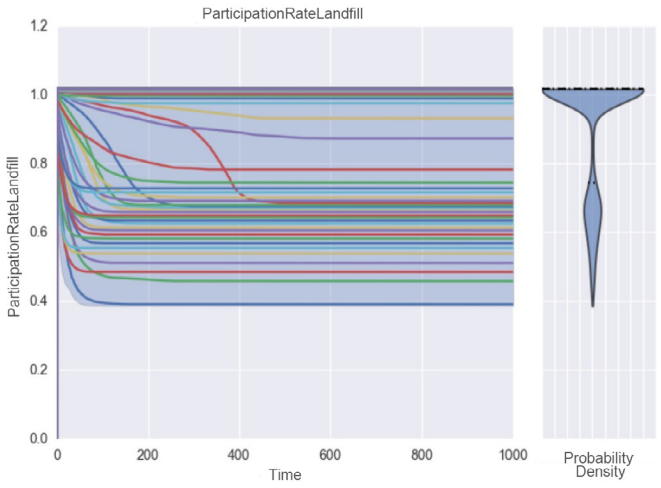


Fig. 7. The distribution of model outcomes.

that within the model, possibility exists for two end states. The most probable cases are very low participation in the recycling program, which reflect the current situation in China.

The above outcomes were resulted from varied parameters during experimentation. Table 1 shows the correlation between the input and output variables, which indicates that the weight of Social Norm (SN) and Perceived Behavioral Control (PBC) have the most influence on the output variables of the model.

The SN has a decisive effect on whether an area starts recycling or not. If for some reason, a large share of the households decides to recycle, the social norm can accelerate this trend. On the other hand, if the participation rate is low, the social norm represses recycling. Since most of the 2,000 experiments results in low participation rates, the increase of the weight of social norm in the model could reduce the participation rate for recycling on average.

The PBC is based on the knowledge of recycling and the willingness to change. It plays a positive and significant role in this study. When PBC has a high relative weight in comparison with the other components of the intention determination, it is more likely that a household will recycle.

3.2.2. Scenario analysis of the model

We present two scenarios to show the possible effects of interventions on the behavior change in the community. The two scenarios are: (1) Baseline, and (2) New scheme (The settings and results are presented in Table 2).

3.2.2.1. Scenario 1: Baseline. In this Scenario, we set the parameters to emulate the condition of the real world experiment (Fig. 8). The participation rate is expected to be high in the *Danwei* region, since their attitude is higher on average than in the other regions. The participation rate is expected to be higher around the containers,

Table 2
The settings and results of the two scenarios.

		Baseline	New scheme
Input	Available Recycling Methods	Both	Collector
	Container Incentives	30	0
	Collector Incentives	30	30
	Transformation into Behavior	100	100
	Weight of Attitude	4	1
	Weight of Social Norm	1	1
	Weight of PBC	1	3
Output	% Households using containers	26.74%	0
	% Households using collectors	17.22%	59.08%
	% Households using landfill	56.05%	40.92%
	Total amount of waste	1.96*10^11	1.96*10^11
	Brought to container	3.97*10^10	0
	Collected recyclables	2.28*10^10	9.32*10^10
	Landfill waste	1.34*10^11	1.03*10^11
	Average attitude	0, 50	0, 44
	Average social norm	0, 44	0, 59
	Average PBC	0	0, 55

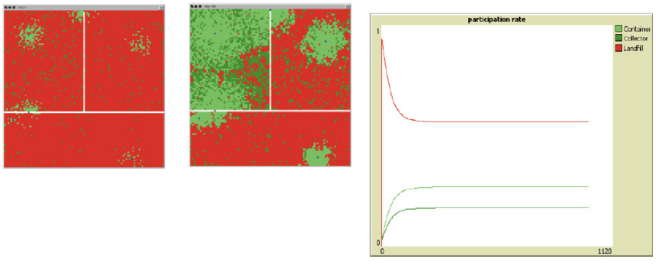


Fig. 8. Simulation result of scenario 1.

due to the higher convenience. The result confirms the hypothesis, proving that the supposed relation between variables in this model can reflect the real condition in the social experiment.

3.2.2.2. Scenario 2: new scheme. The research program supporting the experiment completed in the end of 2016. We tried to continue the recycling activities with other resources. During our research, the similar community-based recycling solutions have been increasingly used in cities in China. Some of them provide the platform for the urban junk-buyers, who can use the system to access customers with reward scores according to the recyclables. The containers are eliminated. This is closer to the traditional recycling business in cities. But it creates the possibility to raise incentive to collectors according to their contribution on waste reduction in cities. The results show that with a higher perceived behavior control, the presence of collectors in the community could possibly lead to a participation rate up to 59.08% without other interventions (Fig. 9). This result confirms the findings of Timlett and Williams (2008) that the personalized incentives and feedback were highly cost-effective at behavior change to engage with residents at the point of service delivery by the collection crews.

Table 1
Correlations between input and output variables.

Input/Output	Participation rate landfill	Participation rate collector	Participation rate container
Collector incentives	−0.05	0.3	−0.18
Container incentives	−0.12	−0.25	0.27
Weight of attitude	–	–	–
Weight of SN	0.5	−0.33	−0.35
Weight of PBC	−0.4	0.28	0.25

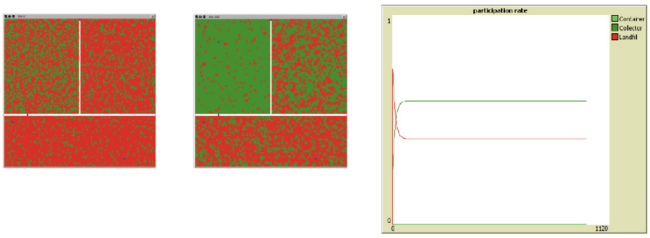


Fig. 9. Simulation result of scenario 2.

4. Discussion

4.1. Possible interventions at the community level

Currently, the policy on waste sorting for recycling in China centered around the planning of recycling facilities. However, our social experiment shows that the provision of recycling facilities alone could trigger little behavior change. Intensive face-to-face interactions between the research team and our participating households in the community are crucial to raise the awareness and form the social norm, which could lead to concrete behavior response.

The overall outcomes of the simulation experiments correctly represent the general reality of waste separation in Chinese cities. That is, in a high probability, the community-based waste separation program will result in a very low participating rate. Just like in the developed countries, the regulatory pressures to move away from landfill is a critical external factor pushing the local communities shift to recycling (Davoudi, 2000). Improving charge on landfill could be an effective way at the municipal level in some cities in China (Meng et al., 2016). However, even without considering the possible external pressure of landfill cost, the outcomes of our simulation model demonstrate the possibility of considerable high participating rate (40–60%), in which the social norms exert the decisive role. The possible achievement through local efforts at community level was confirmed by the result of recycling programs in different communities using the same system (Table 3).

An even more inspiring case took place in 2016 in Xinzhuang, a rural community not far away from our experimental site. Seven mothers initiated a grassroots waste separation and recycling program within around 500 households, among which half are families who have children going to a local private school, which offers Waldorf education favoring close community interaction and collaboration; half households of local villagers planting strawberry. There are intensive social interactions among the residents due to the education connections and local social networks. In addition, the families share common value on sustainability. With 3 months' preparation, the whole village established a waste separation and recycling system at the community level with nearly 100% participation of the households. This case confirms the result of our model that a pro-recycling social norm could possibly be built in the neighborhood through local collaboration.

4.2. Scaling up local experiences

Given the results in our experiment, we generalized several key elements for scaling up the local experiences into wider policy strategies.

First, the participating rate can be used as an indicator for local government to support this kind of social programs. During our experiment, similar programs are increasingly popular in many cities in China. For example, Beijing Huanwei, the largest state-owned city sanitation company in Beijing, have initiated similar programs in the city since Dec. 2015, and now covering around 1,000 communities (Beijing News, 2016). However, most of these programs are highly relying on subsidy from local governments. Our experiment shows that, in the long run, the social norm and the perceived behavior control are critical factors influencing household's behavior. There are various ways to achieve a high participating rate in the community. Roughly a participating rate of 40–60% could be taken as a successful implementation target for enjoying the subsidy.

Second, the integration of the community-based approach with the Extended Producer Responsibility (EPR) could be a feasible way to provide an alternative financial support to these programs. EPR is an environmental policy approach intended to create incentives for product innovation with lower environmental impacts throughout the lifecycle by extending a producer's responsibility, physical and/or financial, for a product to its post-consumer stage, and shifting the cost of waste management from local government to consumers and producers (Lindhqvist, 2000). It's a challenge to integrated the EPR system with the traditional municipal waste management system, because the EPR system requires higher visibility of specific waste flows from the consumers. The information technology used in our social experiment could provide a better approach to track the waste flows from the households, which open opportunities for new business model for post-consumer recycling (Tong et al., 2018).

4.3. Inclusiveness

It is a special challenge to include the informal sectors into the urban waste management system in developing countries. In our experiment, the participant of the migrant junk-buyers is critical in sustains the experiment for 3 years. Just as the experiences in developed countries has shown: the personalized incentives and feedback were highly cost-effective at behavior change to engage with residents at the point of service delivery (Timlett and

Table 3
The performance of the recycling program in different communities.

	A community in Chengdu April 2015	C Community in Beijing inner city April 2014	H community April 2014	H community May 2015
Governance structure	PPP between municipal government and community recycling firm	Demonstration projects by municipal government and certified recyclers	Community recycling program initiated by Research team	community recycling program run by migrant junk-buyer
Registered Households/total households	1397/3000	108/2250	512/10,000	595/10,000
Average collection per household (kg/h.m)	9.34	1.34	4.35	5
Participant rate	50.5%	27.8%	37.9%	15.6%
Sorting correct rate	83.7%	97.2%	48.8%	68.9%

Williams, 2008). The on-site services provided by the migrant junk-buyers in our program helped to increase the engagement of the residents. It's economically and environmentally more effective to use the subsidy to leverage the role of informal collectors in building the common space for recycling in urban communities.

5. Conclusion

This research shows the large potential that coupled social experiments and agent-based simulations have in exploring the policy effectiveness for intervention in community-based recycling program. The social experiment at the community level is generally action oriented to stimulate a group of people to work together on specific goals. The strength of the community-based tool is to fit the special local context when introducing any intervention. While the agent-based modelling helped to generalize the findings from the social experiment under specific context, and test the suitability by changing conditions.

Our research also confirms the effectiveness of many factors that affect recycling activities identified in existing research conducted in developed countries also applicable in China, such as the opportunities and knowledge to recycle, time for recycling, distance to recycling facilities, and face to face interactions between residents and collection crews. The TBP could be a proper framework to integrate these factors and enable the share of experiences among different cultural contexts.

The results show that the social norm has a decisive effect on whether an area starts recycling or not. As to the effectiveness of intervention, the perceived behavioral control plays a large role in the determination of the recycling behavior. The role of attitude is relatively small. This finding is especially meaningful under current situation in China. The policies to promote waste separation and recycling at sources generally take the top-down approaches in China, including raising awareness through public media and planning physical recycling facilities at the municipal level. Recent research suggested to include the cost of landfill into waste disposal fees and charge directly to the individual consumer. However, how can pro-recycling environment be built at the local level? Our model shows that a general social norm uninterested in recycling actually depress the intention of individual household to participate in waste separation and recycling. Without systematic collective action at the community level, this situation will hardly change. Successful cases, although unusual, show the strength of local actions in forming the pro-recycling environment within a close neighborhood.

The changing waste regime and the introduction of new technology jointly bring opportunities for new business models of post-consumer recycling in China. With increasing number of social companies are actively engaging in the community-based recycling program with various IT solutions, this research suggests the local government could use the participation rate as an indicator to evaluate the performance of such kind of program and encourage various stakeholders to collectively build a common space in the city for the development of circular economy.

Acknowledgements

The social experiment was supported by grants from the China National Natural Science Foundation ('Technological Transition through Extended Producer Responsibility in Electronics Industry' [41271548]). The agent-based modelling work is the result of an experimental teaching collaboration between Peking University and Delft University.

References

Beijing News, 2016. Intelligent Waste Separation Expands to 1000 Residential Communities. Xinhua News (In Chinese). http://www.bj.xinhuanet.com/bjyw/2016-03/09/c_1118273059.htm.

Boldero, J., 1995. The prediction of household recycling of newspapers: the role of attitudes, intentions, and situational Factors1. J. Appl. Soc. Psychol. 25 (5), 440–462.

Botetzagias, I., Dima, A., Malesios, C., 2015. Extending the Theory of Planned Behavior in the context of recycling: the role of moral norms and of demographic predictors. Resour. Conserv. Recycl. 95, 58–67.

Bray, D., 2005. Social Space and Governance in Urban China: The Danwei System from Origins to Reform. Stanford University Press, Stanford.

Chan, L., Bishop, B., 2013. A moral basis for recycling: extending the theory of planned behaviour. J. Environ. Psychol. 36 (Suppl. C), 96–102.

Chai, Y., 1996. Danwei-centered activity space in Chinese cities - a case study of Lanzhou. Geogr. Res. 15 (1), 30–38 (In Chinese).

Chu, Z., Xi, B., Song, Y., Crampton, E., 2013. Taking out the trash: household preferences over municipal solid waste collection in Harbin, China. Habitat Int. 40, 194–200.

Davis, G., Phillips, P.S., Read, A.D., Iida, Y., 2006. Demonstrating the need for the development of internal research capacity: understanding recycling participation using the Theory of Planned Behaviour in West Oxfordshire, UK. Resour. Conserv. Recycl. 46 (2), 115–127.

Davoudi, S., 2000. Planning for waste management: changing discourses and institutional relationships. Prog. Plann. 53 (3), 165–216.

Epstein, J.M., 2007. Generative Social Science. Studies in Agent-Based Computational Modeling Princeton University Press, Princeton.

Epstein, J.M., Axtell, R.L., 1996. Growing Artificial Societies: Social Science from the Bottom up. MIT/Brookings Institution, Cambridge MA.

Kong, H., Sui, D.Z., Tong, X., Wang, X., 2015. Paths to mixed-use development: a case study of Southern Changping in Beijing, China. Cities 44, 94–103.

Lindhqvist, T., 2000. Extended Producer Responsibility in Cleaner Production. IIIEE Dissertations 2000. IIIEE, Lund University, Lund, p. 2.

Martin, M., Williams, I.D., Clark, M., 2006. Social, cultural and structural influences on household waste recycling: a case study. Resources. Conserv. Recycl. 48 (4), 357–395.

Matsumoto, S., 2013. The opportunity cost of pro-environmental activities: spending time to promote the environment. J. Fam. Econ. Issues 35, 119–130.

Meng, X., Wen, Z., Qian, Y., 2016. Multi-agent based simulation for household solid waste recycling behavior. Resour. Conserv. Recycl. 2016.1009.1033" https://doi.org/10.1016/j.resconrec.2016.1009.1033.

Nigbur, D., Lyons, E., Uzzell, D., 2010. Attitudes, norms, identity and environmental behaviour: using an expanded theory of planned behaviour to predict participation in a kerbside recycling programme. Br. J. Soc. Psychol. 49 (2), 259–284.

Poteete, A.R., Janssen, M.A., Ostrom, E., 2010. Working Together: Collective Action, the Commons, and Multiple Methods in Practice. Princeton University Press, Princeton.

Sidique, S.F., Lupi, F., Joshi, S.V., 2013. Estimating the demand for drop-off recycling sites: a random utility travel cost approach. J. Environ. Manag. 127 (Suppl. C), 339–346.

Stoeva, K., Alriksson, S., 2017. Influence of recycling programmes on waste separation behaviour. Waste Manag. 68 (Suppl. C), 732–741.

Tai, J., Zhang, W., Che, Y., Feng, D., 2011. Municipal solid waste source-separated collection in China: a comparative analysis. Waste Manag. 31 (8), 1673–1682.

The State Council, 2013. The Strategy of Circular Economic Development and the Immdiate Action Plan. Beijing (In Chinese). http://www.gov.cn/zwgk/2013-02/05/content_2327562.htm.

Timlett, R.E., Williams, I.D., 2008. Public participation and recycling performance in England: a comparison of tools for behaviour change. Resourc. Conserv. Recycl. 52 (4), 622–634.

Tong, X., Tao, D., 2016. The rise and fall of a "waste city" in the construction of an "urban circular economic system": the changing landscape of waste in Beijing. Resour. Conserv. Recycl. 107, 10–17.

Tong, X., Tao, D., Lifset, R., 2018. Varieties of business models for post-consumer recycling in China. J. Clean. Prod. 170 (Suppl. C), 665–673.

Tonglet, M., Phillips, P.S., Read, A.D., 2004. Using the Theory of Planned Behaviour to investigate the determinants of recycling behaviour: a case study from Brixworth, UK. Resour. Conserv. Recycl. 41 (3), 191–214.

Wilensky, U., 1999. NetLogo. Center for Connected Learning and Computer-based Modeling. Northwestern University, Evanston, IL. http://ccl.northwestern.edu/netlogo/.

Zhang, D., Huang, G., Yin, X., Gong, Q., 2015. Residents' waste separation behaviors at the source: using SEM with the theory of planned behavior in Guangzhou, China. Int. J. Environ. Res. Publ. Health 12 (8), 9475–9491.

Zhang, D.Q., Tan, S.K., Gersberg, R.M., 2010. Municipal solid waste management in China: status, problems and challenges. J. Environ. Manag. 91 (8), 1623–1633.

Zhang, H., Wen, Z., 2014. Residents' Household Solid Waste (HSW) Source Separation Activity. A Case Study of Suzhou, China.

Zhang, H., Wen, Z., Chen, Y., 2016a. Environment and Economic Feasibility of Municipal Solid Waste Central Sorting Strategy: a Case Study in Beijing.

Zhang, S., Zhang, M., Yu, X., Ren, H., 2016b. What keeps Chinese from recycling: accessibility of recycling facilities and the behavior. Resour. Conserv. Recycl. 109 (Suppl. C), 176–186.