Testing a norm-based policy for waste management

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Testing a norm-based policy for waste management: An agent-based modeling simulation on nudging recycling behavior

Andrea Ceschi, Riccardo Sartori, Stephan Dickert, Andrea Scalco, Elena M. Tur, Francesco Tommasi, Keren Delfini

Abstract

The present study uses agent-based modeling (ABM) to examine the effectiveness of a nudge policy for improving recycling behavior. In our simulation, agents’ recycling behavior is computed by components of the Theory of Planned Behaviour (i.e., attitudes, perceived behavioral control, social norms) and influenced by other agents as well as their surrounding (i.e., amount of waste in the area). The simulation, based on real data from a Taiwan community district, confirms realistic recycling trends and demonstrates the usefulness and reliability of ABM as a method to examine the effectiveness of waste management policies. An additional step in our simulation was to manipulate the amount of waste in the community to test the effect of a nudge policy based on social norms. Results showed that the policy increases recycling activity, but predominantly in low waste scenarios. This suggests that nudges, in the form of norm-based policies, can be an effective solution to enhancing people’s recycling behavior under specific circumstances.

1. Introduction

Considerable evidence exists that the amount of waste produced by our societies will continue to increase because of population growth, accelerating resource exploitation and increasing consumption. According to the 2019 World Bank report, the amount of urban waste being produced is growing faster than the rate of urbanization. By 2025, there will be 1.4 billion more people living in cities worldwide, with each person producing more than double the current average solid waste. The core of the waste problem mostly relates to emerging countries and South and East Asia, which now produce about 33 percent of the world’s total amount of waste (Idris et al., 2004; Kapur et al., 2003). In response to this, some Asian countries have developed effective waste management policies, which have resulted in Japan, South Korea and Singapore becoming leaders in the recycling industry (Shekdar, 2009). Another case in point is Taiwan, and its established recycling measures known as “Four-in-One Recycling” and “Keep Trash Off the Ground” (KTOG’), which aimed to reduce municipal solid waste, increase recycling, and improve the efficiency of the recycling industry. Under these policies, the recycling rate in Taiwan increased from 2 percent in 1999 to 17 percent in 2014 (Hsu and Kuo, 2005).

The implementation of strategies for managing the generation and recycling of waste is therefore a pressing problem for public policy. Over decades, recycling procedures have become increasingly effective (Prothero et al., 2011), and the public sector is continually examining appropriate incentives to encourage recycling behavior (Rainford and Tinkler, 2011). Some of these public policy approaches are more technical in nature, and others relate to the psychological aspects of people’s behavior.
behavior. Like for the KTOG, the overall success of a recycling stream is a favorable combination of different solutions. This includes prompting recycling by copying other people’s behavior, following social norms, as well as forging attitudes, beliefs, and values that are useful for developing a sustainable community (Griskevicius et al., 2012). The core of KTOG was indeed the community network: the Tsu-Chi Foundation (a Buddhist organization), the Homemakers United Foundation, and the Conservation Mothers Foundation are all social communities directly engaged in promoting recycling behavior. For this reason, KTOG can be defined primarily as a policy based on social norms (i.e., norm-based policy, see Chao, 2008; Derksen and Gartrell, 1993).

From this perspective, recycling can be understood primarily as a social behavior. Individual waste management is observable by other people and each household witnesses what others do. The social nature of recycling has inspired a field of research that bases its roots on Ajzen and Fishbein’s Theory of Planned Behavior (1980) and seeks to shed light on pro-environmental behavior by taking into account the relevance of social approval, peer effects and ‘warm glow’ patterns in individual motives (Abbott et al., 2013; Viscusi et al., 2014).

Our simulation analysis uses a similar approach by taking the social nature of recycling as well as environmental attitudes, perceived moral obligation, and perceived behavioral control into account when implementing public policies designed to increase recycling. The originality of our paper lies in dynamically modeling the interactions between neighborhood units that allow and endorse beliefs about recycling and related norms. We demonstrate how subjective decisions about recycling depend on social interactions and how this affects the effectiveness of public policies.

Given the prominent role of social norms in influencing recycling behavior, communities and governments need to identify ways to develop and estimate the impact of norm-based policies. One such possibility is to create so-called ‘nudges’ to motivate people to show the desired behavior (Gregor and Lee-Archer, 2016; Weinmann et al., 2016; Wilson et al., 2016). Still, the implementation of a policy is a delicate matter, and in some documented cases has failed, or worse, backfired (e.g., Baldwin, 2015; Spiegler, 2015). Studies show that the impact of norm-based policies does not follow predictable linear trends, with periodic decreases in recyclables production (Chao, 2008). Evaluating the impact of norm-based recycling policies should therefore also focus on the psychological drivers of people’s recycling decisions, including environmental beliefs and introjected morality concerning sustainability as well as contextual factors like environmental degradation. Indeed, research on social norms and littering confirms that people in a ‘dirty’ environment tend to recycle less than those exposed to a ‘clean’ environment (Gialdini et al., 1990; Drackner, 2005; Fiorillo, 2013).

In the current paper, we propose a novel and integrative way of testing norm-based policies using an agent-based modeling (ABM) simulation. We first present a brief overview of the theoretical framework leading to the current research on recycling behavior, and then examine the effectiveness of a norm-based policy in specific conditions. Under a set of assumptions based on theories of social norms, planned behavior and psychological modeling, we recreate interactions in the waste chain (i.e., householders, garbage trucks, and collection centers). The results of the ABM simulation are used to examine and estimate the potential extent of the recycling policy effects and are compared with time series statistics derived from Taiwan recyclables production data. Moreover, the simulation tests policy efficacy in a highly degraded environmental scenario by taking into account the impending forces operating in such a setting.

2. Theory

2.1. Psychological modeling: surrounding and peer influence

Research shows that the surrounding environment has a crucial influence on people's recycling behavior. For example, individuals recycle less in dirty settings (Fiorillo, 2013; Drackner, 2005) and litter on the street is seen as a disincentive to using appropriate bins for recycling (Geller et al., 1977; Keizer et al., 2008; Krauss et al., 1996; Ramos and Torgler, 2012; Reiter and Samuel, 1980). Recycling functions in a conditionally collaborative way, such that people are discouraged from recycling if they observe environmental degradation (i.e., surrounding influence). A similar dynamic can occur when observing other people’s behavior directly (Galdiuni et al., 1990), resulting in demotivation to recycle as a consequence of the norm set by others (i.e., peer conformity). These behavioral spillover effects are based on peer and surrounding influences (Bandura, 2001) and can start negative littering feedback loops that turn a community into a dirty neighborhood (Dur and Vollaard, 2015). In this process, the key determinants for reproducing others’ (lack of) recycling behavior depend on the sensitivity towards social norms.

2.2. From social norms to a policy for improving recycling

Social norms signal what is typical or normal behavior, and motivate action by providing evidence of what is likely to be effective, adaptive, and appropriate in a social setting (Göckneritz et al., 2010). Social norms can influence individuals’ behavior by observing others (i.e., descriptive norms) and beliefs about what is the right course of action (i.e., injunctive norms). Government institutions increasingly apply strategies that use social norms to activate recycling behavior, which appeared to be even more effective than financial incentives (Mannetti et al., 2004).

Social norms are the theoretical building blocks of policies based on nudge strategies. The concept of nudging (Thaler and Sunstein, 2008) refers to any aspect of the choice architecture that alters people’s behavior in a predictable way, without forbidding any option or significantly changing their economic incentives. In the context of recycling, providing households feedback about their own recycling performance in relation to the communities’ performance can increase people’s sensitivity towards social norms regarding recycling (Milford et al., 2015; John et al., 2013) and subsequently increase recycling behaviour. The study by Nomura et al. (2011) showed that when feedback is given on the recycling performance of the entire community (i.e., nudge based on descriptive norms) rather than for each individual household (i.e., nudge based on injunctive norms), it increases the likelihood of participation in the recycling scheme. These findings support the notion that the inner personal circle regarding to individual and moral values exerted by family, friends and neighbors plays an important role in increasing the likelihood to recycle (Aceti, 2002). Reviews of results collected in laboratories show that the average increase in recycling rates due to social norm nudges is close to 19 percent (Galdiuni et al., 1990; Hansen and Jespersen, 2013; John et al., 2013; Schultz, 1999).

The scientific literature also suggests that in order to better understand the impact of public policies on human behavior, social norms should be modeled jointly with behavioral components such as psychological drivers (Fishbein and Yzer, 2003; Rivis and Sheeran, 2003). It is difficult to determine the precise impact of a norm-based policy on recycling behavior without considering the multifaceted psychological nature of it, including the role of attitudes and behavioral control. In the current paper we adopt a multi-causal framework for recycling behavior, which models both psychological drivers as well as the influence of social norms (i.e., Theory of Planned Behavior, Ajzen, 1991).

2.3. Theory of Planned Behavior and recycling

The Theory of Planned Behavior (TPB) is one of the most widely used theories in environmental psychology for explaining and predicting the psychological components of recycling behavior (Botetzgas et al., 2015; Chan and Bishop, 2013; Chen and Tung, 2010; Cheung et al., 1999; Kaiser and Gutscher, 2003; Mannetti et al., 2004; Pakpour et al., 2014; Ramayah et al., 2012; Tonglet et al., 2004a, 2004b; Valle et al., 2005; Vicente and Reis, 2008). The TPB in its original form (Ajzen,
of other agents’ recycling behavior (i.e., peer influence) and more in general the virtual community’s surrounding environment (i.e., surrounding influence). Consequently, a policy based on social norms would influence introjected rules, but also through social norms of psychological modeling by enhancing the simulated recycling behavior (i.e., expressed as an increasing of recyclables production over waste).

We further predict that implementing a norm-based policy should increase recycling behavior (H1). In addition to the norm-based policy, we also predict that the presence of a critical waste level in the simulation influences recycling behavior, such that agents’ recycling rate is higher when waste levels are low (H2). We assume that in scenarios with high waste levels the agents’ intention to engage in recycling is weaker because of the discouraging influence of the environmental surroundings, and in scenarios with low waste levels the agents’ recycling activities should be stronger. Moreover, we examine whether the effect of the policy on agents’ recycling behavior persists with the same magnitude even in the presence of a critical level of waste in the simulation. Finally, we also assume that the presence of a critical level of waste has a different effect on the agents’ surrounding influence. Whereas the level of rubbish should greatly affect a community’s surrounding influence (H3a), the levels of peer influence should be more affected by the presence of the policy because it is based on social norms (H3b). See Fig. 1 for a graphical representation of hypotheses.

3. Material and methods

3.1. Procedure for agent-based modeling simulation

Agent-based Mmodeling simulations range from highly structured artificial worlds with few simple rules and constraints (Kohler and Gummerman, 2001), to complex models in which agents’ behavioral components interact with different structural environments (Ghali et al., 2017; Stinchcombe, 2001). Agent behavioral components are modeled into a heterogeneous artificial population in order to simulate a specific behavior (Richetin et al., 2010). Considering the high predictive power as well as the computability of the TPB and its components, ABM is a suitable empirical technique relating to this framework. Prior research has suggested procedures to transpose TPB models into computer simulations (Hesan et al., 2014; Orr et al., 2013; Richetin et al., 2010; Sogani et al., 2005). These approaches are neither strictly based on simulation nor entirely statistical, but a mixture of the two; they make it possible to evaluate the outcome of the simulation with traditional statistical techniques, whilst maintaining ABM’s strengths. Of particular interest is the procedure suggested by Richetin et al. (2010), in which the operationalization of the TPB components into ABM are extracted and added, starting with the standardized coefficients of the corresponding statistical model. A similar method used in this study is derived from the PLS path model (Schubring et al., 2016) for specifying agent action behavior.

The agent’s behavior is an interpretation of the target construct, which describes an agent’s activity (in this case recycling), and where the agent derives probabilities regarding performing this action. The agent-based modeling defines the components of agent reasoning, which are derived from a structural model consisting of a latent-variables causal network (i.e., structural equation model). In the PLS agent concept, the agent acts by interacting with their environment, which may be environmental conditions or a neighbor’s behavior model influencing their action (Schubring et al., 2016). Each exogenous variable of the PLS path model represents one component. Concerning the TPB, the exogenous variables represent the average score of the

2 The SEM model developed by Chu and Chiu (2003) is optimal for this simulation since it is based on a survey conducted in Kaohsiung district (Taiwan) during the implementation of the KTOG program. The survey was developed in accordance with the TPB principles suggested by Ajzen (1991).

3 Here we mean “complex” in the sense of a complex system, that is to say, a system with non-trivial self-organizing and emergent behaviors (see, for example, Mitchell, 2009), instead of the more mundane definition of “complex” as a synonym for “difficult” (see, for example, Papadimitriou, 2020).
indicators used to measure the components: environment attitudes (\(AT\)), moral obligation (\(PMO\)), subjective norms (\(SN\)), and perceived behavioral control (\(PBC\)). These components may have varying values within simulation experiments, representing distinguishable product characteristics. High component values of personal drivers (\(AT\) and \(PBC\)) increase the probability of action (i.e., recycling), while others (\(SN\)) are highly dependent on environmental conditions. The calculation includes the total effect values to account for the specific agent, in this case normally distributed, and the latent variable scores to account for the product component values. The total effect values are the strengths of each criterion’s influence. For the TPB, its components determine the latent variable \(Bl\) score. Consequently, they depend on the agent type and the strength of the criteria in terms of the total impact in the same circumstances (Schubring et al., 2016).

### 3.2. The Planned Recycling Behavior model (PRB_1.2)

We developed an ABM simulation model of Planned Recycling Behavior (PRB_1.2)\(^4\) aiming to reproduce a district community in a square plane space measuring 5000*5000 points. The individuals and objects of the simulation are modeled as agents \(i \in \Theta\), where \(\Theta\) denotes the population or set of agents. The population is closed in time, such that the set of agents does not change during the simulation. In the plane, they can perceive other agents inside the Euclidean ball of radius \(\delta > 0\) centered on the agent. We call this radius the area of influence, and it is equal for all agents. Agents’ activities, based on their type, consist of producing rubbish, producing recyclables, transporting/moving rubbish, and eliminating it from the system; in these behaviors they can be reciprocally influenced by others. The activities are performed by three different types of agents: householders, garbage trucks, and waste processing plants. For this specific simulation, agent parameters (number of householders, garage trucks, daily waste production, etc.) come from scaling the actual data from a Kaohsiung (TW) community district (Diong, 2012). The scaling of the agents’ characteristics is derived from coefficients related to the TPB and taken from a Structural Equation Model (SEM) on motivations for recycling behavior developed by Chu and Chiu (2003), also based on a Kaohsiung survey. The SEM values of these constructs are assigned to the agents’ decision-making process through a stochastic computation and used in the simulation as probabilistic factors of behaving. The SEM presents four important coefficients which determine recycling behavior: environmental attitudes (\(AT\)), moral obligation (\(PMO\)), subjective norms (\(SN\)), and perceived behavioral control (\(PBC\)). The simulation is designed to explore different scenarios in which two independent variables were manipulated. The first independent variable is the presence of the nudge policy. The public policy employed in the current model is based on social norms, which diversely affect the values of the TPB determinants of recycling. The policy nudge the agents to be influenced by others’ behavior or by simply working on norm values, also influencing agents’ moral obligation and subjective norms. Coefficients and the increment of recycling rates (i.e., higher production of recyclables over rubbish, see Table 1) are extracted from a literature review of experiments about nudging social norms in recycling behavior (Cialdini et al., 1990; Hansen and Jespersen, 2013; John et al., 2013; Schultz, 1999).

Householders. Under the KTOG policy, citizens keep their household waste at home until garbage pick-up trucks come, and so residents are modeled as householders (one for each building). All the household agents present in the community produce rubbish or recyclables. Every household \(i \in \Theta\) has an initial amount \(\xi_i^0 \in \mathbb{R}\) of rubbish and \(\rho_i \in \mathbb{R}\) of recyclables. At every time \(t\), every householder \(i \in \Theta\) increases their level of rubbish or recyclables by a certain amount \(\xi_i^t\) and \(\rho_i^t\), normally distributed in the population, so that \(\xi_i(t + 1) = \xi_i(t) + \xi_i^t\) or \(\rho_i(t + 1) = \rho_i(t) + \rho_i^t\). At each time \(t \in \mathbb{N}\), the agent selects a strategy to follow until

### Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Scale values</th>
<th>Data source and references</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of household agents present in a community</td>
<td>1100</td>
<td>Parameters for a Kaohsiung City district (Diong, 2012)</td>
</tr>
<tr>
<td>Starting twice a week average recyclables production per household</td>
<td>4.8 kg</td>
<td></td>
</tr>
<tr>
<td>Critical rubbish (CR) level per household</td>
<td>25 kg</td>
<td></td>
</tr>
<tr>
<td>Coefficient of environmental attitudes ((AT))</td>
<td>0.18</td>
<td>Standardized and normalized regression coefficients extracted from Chu and Chiu’s study (2003)</td>
</tr>
<tr>
<td>Coefficient of subjective norms ((SN))</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Coefficient of perceived behavioral control ((PBC))</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>Coefficient of perceived moral obligation ((PMO))</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Average increase in recycling rate as a result of social norm nudge experiments</td>
<td>(\approx 0.19)</td>
<td>Increase estimated based on several nudge’s experimental studies (see Cialdini et al., 1990; Hansen and Jespersen, 2013; John et al., 2013; Schultz, 1999)</td>
</tr>
</tbody>
</table>

\(^4\) The entire model, code and documentation are available on the www.comses.net website. For more information, please see Ceschi, A. et al. (2015) and Scalco, A. et al. (2017). It should be noted that other cities can be simulated by changing the parameters.
the next step based on the algorithm Planned Recycling Behavior (PRB_1.2) described in Schema 1. In the following section, we describe the details for each part of these processes.

**Garbage trucks.** The model includes a transportation system which removes garbage from household agents and transports it to the collection points. These pick-up trucks heuristically design their routes by going to the agent that minimizes the ratio of distance divided by the amount of garbage (recycled or non-recycled). For this reason, two different types of trucks were designed: one type collects only recycled rubbish, and the other collects only non-recycled rubbish. Both garbage trucks give priority to resident agents with higher rubbish levels. After a certain amount of rubbish is collected, garbage trucks go to the nearest waste processing plant.

**Waste processing plants.** There are two types of collection points in the simulation: one for unseparated (i.e., non-recycled) garbage and one for recycled garbage. The waste processing plant progressively eliminates the garbage deposited by the trucks following a linear decay function. Note that the waste processing plants are designed to operate like waste incineration plants, thereby removing garbage over time (not just storing it). This feature was applied to establish a sustainability limit in the model.

**4. Results**

Data was collected for 15 simulation runs for each of the four experimental conditions to ensure sufficiently reliable outcome values. After an initial simulation assessment (t = 100 units), we found the variability of outcome parameters was reasonable. Each time unit represents one of the twice-a-week collection days in the simulation, and each simulation lasts for a period equal to 741-time units, the equivalent of 6 years. This should be long enough to observe the effects of the norm-based policy and compare them with the time series analyses obtained in the field. For each of the four environmental situations, we observed three variables: the recyclable production as the outcome of recycling behavior, the surrounding influence level (SI), and the peer influence level (PI).

**4.1. Validation of the simulation results based on second-order approximation**

Graph 1 compares the evolution of the average value of recyclables production in the simulation when the norm-based policy is applied (vs. not applied) and waste levels are not critical. The vertical axis represents units of recyclables production and the horizontal axis represents the timeline. The agents’ surroundings and peer levels (average values) are presented below in the graph. A comparison of the conditions when the policy is applied versus when not applied shows that the surrounding influence is similar in both conditions and remains relatively stable over time, whereas peer influence changes considerably and is higher when the policy is applied. Recyclables production also shows a similar and meaningful difference between scenarios due to the policy effect. The increase in recyclables is about 15 percent when the policy is applied, indicating an increased probability that an agent recycles in that condition. This is in line with data collected in the field during the application of the KotG policy in Kaohsiung. Data from a time series study by Chao (2008) suggests that the impact on the long-term growth of recyclables production is only marginally significant. The effect of the policy may therefore be short-lived, as Chao explains: “At the time the KotG sorting had just begun, the amount of recyclables increased rapidly but then dropped down” (p. 867). This indicates that the simulation closely replicates circumstances with policy implementation in the field.

Graph 2 compares the evolution of the average value of recyclables production in settings where the state of rubbish equates to a critical

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5 The first 100 time units were for assessment simulation training.

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**Schema 1.** Example of an agent’s reasoning in the simulation, based on algorithm PRB_1.2: Process I: the agent’s behavior is driven by social norms (SNr) because these are higher than personal drivers (EAr, PMOr, PBCr). Process II: the agent’s behavior is steered by personal drivers because these are higher than social norms. Process III: based on high levels of EAr, PMOr, and PBCr, the agent produces more recyclables than rubbish. Process IV: based on low levels of personal drivers, the agent does not recycle. Process V: the agent, by observing other agent behaviors and the garbage level of the simulation, computes the “peer influence” in recycling (PI), the “surrounding influence” (SI), and relative probabilities via two decay functions, based on human sensitivity characteristics. Process VI: due to the low level of p(PI) and p(SI), the agent does not recycle.

**Graph 1.** Recyclables production, and peer and surrounding influence levels over time when norm-based policy is applied or not and rubbish levels are not critical.
5. Discussion

The implementation of strategies for managing the generation and recycling of waste is a paramount topic for public policy. Many interventions are being tested worldwide to probe the effectiveness of such policies. The public sector is continually examining appropriate incentives to encourage recycling behavior (Rainford and Tinkler, 2011). This current research was designed to examine the effectiveness of norm-based policies to increase recycling behavior by using an ABM simulation. According to our simulation results, the norm-based policy significantly increases the amount of recyclables. As such, our findings are consistent both with the mainstream literature on experimental nudge recycling as well as with actual attempts to create successful public policies in order to address the recycling challenge (Dobson, 2011; Ramayah et al., 2012). The 15 percent increase in recyclables registered when the policy was introduced in the no-rubbish scenario corresponded with the results obtained in the field with the implementation of KTOG (Cialdini et al., 1990; Hansen and Jespersen, 2013; John et al., 2013; Schultz, 1999). The time series analysis based on the KTOG effect showed that the policy measure indeed exerted a substantial influence, but also in different ways in terms of recycling growth. The cities involved showed different trends, such as an initial boost in recycling, or a declining long-term trend, mostly depending on the environmental conditions and social mindset towards recycling. According to Derksen and Gartrell (1993), people are surrounded by a social context that has a significant effect on recycling behaviors. Additionally, pro-environment attitudes enhance the effect of context on separate collection behaviors, and that is the reason why a policy-based program can change the subjective proneness towards recycling on a
neighborschip. Indeed, the KTOG measure is based on social context influence. It is the impact of social norms that facilitates a community to participate in recycling (Hopper and Nielsen, 1991). However, using a model and computational simulations, our results show that the peer effect is not systematically positive. In fact, this effect depends on the environmental policies implemented, and on the composition of the considered population, as well as households’ beliefs about whether society is more environmentally friendly than it is self-indulgent and greedy (Kirakozian and Chatlier, 2016).

Both our simulation as well as data collected in the field show that the growth of recycling rates is not linear. Norm-based policies seem to ignite a recycling boost, but the growth rates decline over time. If recycling is based only on progressive imitation behavior, it is unclear why in the first scenario the norm-based policy only increases the amount of recyclables in the beginning. Similar evidence from data in the field shows an immediate boost in recycling in the initial stage, and in the later period a declining trend in recyclables production followed by an assessment. It is possible that after a certain point of engagement, people grow tired of participating in recycling activities. An alternative explanation that is based on our simulation is that the amount of rubbish sitting idle in the system also has a (negative) impact on recycling activity. The norm-based policy increases recycling to a greater extent in normal environmental conditions compared to conditions when the amount of rubbish is at a critical level. In our model, this effect is attributed to the state of the surrounding community influence. The visual impact of seeing too much garbage around immediately lowers the motivation to recycle, embodied in a double-edge effect of descriptive social norms (Botzetagias et al., 2015; Eriksson et al., 2015; Hansen and Jespersen, 2013). This explains the initially decreasing production of recyclables in Graph 2, which eventually increased again as the simulation progressed and the environment started to become cleaner.

The fact that rubbish affects recycling trends is also confirmed by time series statistics for Taiwan cities where KTOG has been applied. Cities like Taichung and Taipei, considered highly contaminated at the time, showed a different recycling trend compared to Kaohsiung. In those cities, the policy was not effective initially, and it took years before seeing any results. Social norms, especially descriptive ones, weakened policy development because the most prevalent behavior was oriented towards not recycling and, more importantly, because the presence of litter on the street was a disincentive for recycling. By the time the policy started to achieve some results, the processes underlying psychological modeling had become an incentive to recycle. The fact that the impact of the policy is reduced by the state of the surroundings is supported by the idea that injunctive social norms are a pre-requisite for the smooth implementation of policies based on descriptive social norms. The combined results of our simulation suggest that the impact of the policy is slightly noticeable in the level of peer influence, whereas the impact of rubbish is particularly visible in the surrounding influence. Both policy and rubbish levels affect recycling behavior, with public policies based on social norms working particularly well when rubbish is present at a normal level.

5.1. Practical implications: an integrative policy method

Our study investigated the determinants of recycling behavior through simulation, performed via agent-based modeling. The practical implication concerns policy development – specifically, testing the effectiveness of a norm-based policy to be used in waste management. Agent-based models allow the simulation of the effectiveness of various recycling campaigns under identical conditions (a macro or top-down analysis) and, at a later stage, specific public policies under different conditions (a micro or bottom-up analysis). Starting with the results obtained in the laboratory, we recreated similar effects to those obtained with KTOG by considering a specific Taiwan scenario. We stress that realistic policy modeling should always take into consideration the intricacy of the cognitive mechanisms of the agents it simulates, as well as the external environmental factors. This is arguably one of the strengths of ABM that interactions with multilayered inputs can be integrated with existing models. Importantly, ABMs do not use linear dynamics without considering the basis of psychophysics (Weber, 1834). Considering all these aspects makes the model somewhat elaborate but also closer to reality and more predictive for policy modeling.

The stochastic simulation, combined with more standard statistical analyses, revealed that both the nudge policy strategy and the initial level of rubbish affect recycling. Public policies designed to motivate recycling behavior by nudging people’s social norms need to take into account that such policies do not readily work in environments with high waste levels. It is not enough to increase the awareness of environmental issues or remind people that recycling is a good idea per se. Likewise, public policies and social marketing campaigns that put a sustainable lifestyle at the center of residents’ focus of attention are unlikely to be successful in the long-term if these policies are implemented in a dirty environment. These recommendations are in response to the call by Prothero et al. (2011), who contend that more knowledge about public policies (and how they influence residents) is needed to effectively engineer sustainable consumption on a macro-level.

Although the current paper effectively links laboratory studies on recycling nudges to norm-based public policy, the results of our simulation need to be evaluated bearing in mind several potential limitations. The first is the critique intrinsic to any family of models, including agent-based models. Human beings are more complicated than the agents stylized in the stochastic model. Yet, by reducing community residents’ motivations to those of stylized agents, complex interactions can be codified. The second limitation is the number and choice of variables in the model. In order to make the model manageable, we restricted the number of independent variables, even though we are aware that variables like education, income, age and the household demographic and socio-economic characteristics can play an important role in predicting recycling behavior (Ma et al., 2019). Likewise, other aspects such as local customs and culture, lifestyles as well as consumption habits impact recycling behavior (Gu et al., 2018) and could have been included in a more complex model. The choice of variables in our study was informed by the object of interest: nudges based on social norms. Future studies could also include other nudges such as administrative and economic incentives to recycle (Mak et al., 2018). The third limitation is the quantification of the parameters used in the model. These parameters were elaborated based on the Chu and Chiu (2003) model and refer to a specific region of Taiwan, therefore might not fully reflect the peculiarities of other areas on the planet. The employed methodology, however, is not geographically limited as other cities can be readily simulated with different parameter values.

6. Conclusions

Using an ABM approach, we investigated the effects of social norms on recycling behavior. Although social norms represent a potent source for increasing people’s motivation to recycle, our results also support the notion that the amount waste already present in the streets is an important moderator variable that policy makers need to take into consideration. We recommend that future research on the interplay between the psychological drivers and surrounding influences makes use of similar simulation techniques to examine the effects of public policies. One potential avenue would be to distinguish between injunctive and descriptive norms, which in our simulation were both targeted by the implemented public policy approaches. Moreover, the sequence in which different types of nudges are applied can potentially matter: nudges inspired by descriptive social norms could be more powerful if preceded by nudges inspired by injunctive social norms.
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Authors contribution statements
A.C. conceived of the presented idea. A.C. developed the theory and performed the computations. S.D. verified the analytical methods. All authors discussed the results and contributed to the final manuscript.

Declaration of competing interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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