Simulating participatory urban freight transport policy-making: Accounting for heterogeneous stakeholders' preferences and interaction effects

Edoardo Marcucci [a,b], Michela Le Pira [a,c,*], Valerio Gatta [a], Giuseppe Inturri [c], Matteo Ignaccolo [c], Alessandro Pluchino [d]

[a] Department of Political Sciences, University of Roma Tre, Italy
[b] Department of Logistics, Molde University College, Norway
[c] Department of Civil Engineering and Architecture (DICAR), University of Catania, Italy
[d] Department of Physics and Astronomy (DFA), University of Catania and INFN Catania, Italy

ABSTRACT

This paper proposes a novel approach to support participatory decision-making processes in the context of urban freight transport through the integration of discrete choice modeling and agent-based modeling. The methodology is based on an innovative multilayer network and opinion dynamics models and applied to the case study of Rome's limited traffic zone. Simulation results produce a ranking of plausible policies that maximize consensus building while minimizing utility losses due to the negotiation process. These results can be used to support real participatory decision-making processes on freight-related policies accounting both for stakeholders' heterogeneous preferences and their interaction effects.

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1. Introduction

Urban freight transport (UFT) is a complex world characterized by multiple and conflicting interests. Policy-makers have to deal with the three main actors in the supply chain, i.e. (1) shippers and producers who supply the goods, (2) receivers representing the demand for goods and (3) transport providers, in charge of the transportation of the goods, as well as those actors not directly involved with freight transport movements, but that can be indirectly affected by the decisions, i.e. residents, tourists and visitors (MDS Transmodal, 2012). All of them can be considered UFT "stakeholders", according to the broad definition of Cascetta et al. (2015): "people and organizations who hold a stake in a particular issue, even though they have no formal role in the decision-making process". Public authorities should try to strike a balance between private and

public objectives. This, in general, implies: maximizing freight distribution efficiency, minimizing the related negative externalities, and fostering city sustainability and livability.

The importance of adopting a participatory decision-making process is, nowadays, widely recognized. This entails a direct involvement of all the interested actors during the definition of the policy measures to be implemented (Gatta and Marcucci, 2014; Quick, 2014; Cascetta et al., 2015). The whole living lab research stream is based on this assumption (Eriksson et al., 2005; CITYLAB, 2015; Quak et al., 2016) and also supported by all the arguments related to the Sustainable Urban Mobility Plans that the EU supports (Wefering et al., 2014).

Freight quality partnerships (FQPs) are effective means to involve local governments, freight operators, environmental groups and other interested stakeholders when addressing specific freight transport-related problems. Several examples of good practices can be cited in the UK (DfT, 2003). However, FQPs are not always easily implemented or capable of providing appropriate solutions to UFT problems, as Lindholm (2014) illustrates through examples of successes and failures. Not only it is important to get an active and direct involvement of all the interested parties in the decision-making process, one has also to find the most shared, and thus supported, policy emerging from a transparent deliberative process.

From a policy-maker's perspective, considering inter-agent heterogeneity is fundamental to account for the impact each policy component might have on specific agent behavior thus helping in taking better decisions (Taniguchi and Tamagawa, 2005). Besides, in a participatory decision-making process interaction among stakeholders through deliberation is fundamental to stimulate opinion exchanges towards a shared decision (Quick et al., 2015).

This paper jointly deals with inter-agent heterogeneity and stakeholders' interacting behavior via a novel agent-specific and dynamic modeling approach. The approach proposed integrates discrete choice modeling and agent-based modeling with the intent of providing a useful tool capable of supporting participatory decision-making processes in the context of UFT policy-making.

The remainder of the paper is organized as follows: Section 2 presents the research framework while Section 3 shows the contribution of the paper to the existing literature; Section 4 describes the modeling approach used; Section 5 illustrates the results of the agent-based simulations deriving policy implications and discussion; Section 6 concludes discussing future research endeavors.

2. Research framework

Stakeholders response to policy change is a hotly debated topic. Models are widely used to test what-if scenarios and perform *ex-ante* evaluations of stakeholders' behavior before implementing specific UFT policies (Taniguchi and Thompson, 2015). The majority of all decision problems in city logistics are multi-objective. Zhang et al. (2015) capture the conflicting objectives of different stakeholders solving a bi-level optimization problem of a multi-actor, multi-commodity multimodality freight transport network. However, the strong need to include more stakeholder-related behavioral issues in city logistics modeling has led to the development of many models aimed at describing, analyzing and predicting how a stakeholder may respond to a given scenario. Hensher and Puckett (2005) propose a stated choice experiment to reveal the preferences of interactive agents along the supply chain; Holguín-Veras (2008) discusses the necessary conditions required for receivers and carriers to agree to perform off-hour deliveries, and the effectiveness of alternative policies to foster such change in competitive markets; Marcucci and Gatta (2017) investigate the potential for off-hour deliveries in the city of Rome by exploring retailers' preferences inquiring their willingness to adopt specific prototypes; Nuzzolo and Comi (2014) propose a multi-stage model aimed at investigating the relations among city logistics measures, agents and choice dimensions; Stathopoulos et al. (2012) and Bjerkan et al. (2014) report the results of a survey about stakeholders' preferences and stated behaviors that would most likely be enacted if a given policy-mix were to be introduced to improve the current freight distribution scheme in Rome and Oslo respectively; Holguín-Veras et al. (2015) provide an economic interpretation of the interactions among freight agents to predict their response to pricing and incentives measures; Marcucci et al. (2015) and Gatta and Marcucci (2016b) use discrete choice models to analyze transport provider's preferences for alternative parking policy measures.

Nevertheless, some authors show that only few effective UFT measures are successfully implemented (Jones et al., 2009). This is mostly due to the lack of knowledge characterizing many local authorities with respect to different carriers' logistical operations, and also to the unsatisfactory accounting of the interaction between local authorities and carriers (Quak, 2008). Besides, the observed significant heterogeneity in stakeholders' preferences reduces the chance of an overall policy acceptability (Gatta and Marcucci, 2014). In fact, asymmetric power relations among suppliers, carriers and receivers are often detected and they are so strong that receiver-centered policies are more likely to produce successful behavioral changes with respect to carrier-centered ones (Holguín-Veras et al., 2015).

Modeling should allow the exploration of the various interconnected decision-making processes and patterns characterizing the different stakeholders in relation to regulations and policy measures tested. Gatta and Marcucci (2014) demonstrate how an agent-specific knowledge of the effects each policy component produces can increase decision makers' awareness thus helping taking better decisions.

Researchers have started exploring freight transport problems using agent-based models (ABMs), given their capability to reproduce communities of heterogeneous autonomous agents, with certain properties and behaviors, interacting in a common environment via a set of relationships and methods of interaction (Macal and North, 2010). Davidsson et al. (2005)

provide an extensive analysis of existing ABM approaches to transport logistics; they find ABMs to be very suitable for this domain while acknowledging that their use at the strategic decision-making level seems under-researched. In the last few years, ABM capability of capturing both individual stakeholders' dynamic behavior as well of studying and understanding their response to policy measures (Taniguchi et al., 2012) has been extensively exploited. ABMs can be used to represent the diversity of roles and functions various actors play in the freight system and mimic how they interact through simulated auctions of transport contracts (Roorda et al., 2010), resulting in the generation of tours (Liedtke, 2009). Tamagawa et al. (2010) analyze the impact of pricing and incentives measures on vehicle routing and scheduling of several freight transport actors in a test network. Holmgren et al. (2012) build an agent-based simulation both for impact assessment of transport-related policy implementation and evaluation of different business strategies. van Duin et al. (2012) combine a multi-agent modeling with vehicle routing incorporating a dynamic usage of urban distribution centers and responsive behavior of the involved carriers. Anand et al. (2012) introduce a formal ontology, within the framework of ABM, aimed at systematically as well comprehensively specifying the domain of city logistics in terms of the concepts involved along with their respective relations.

3. Contribution to existing literature

Most of the modeling approaches to UFT literature examined so far focuses on evaluating policy measures' impacts on stakeholders' behavior and, subsequently, triggering their reactions, assuming that a decision is unilaterally made by a public authority.

The paper contributes to the existing literature by focusing on a possible inversion in the usually accepted sequence of cause and effect relations. In other words, one should use a participatory approach also when modeling UFT policies, whereby one simulates first and evaluates afterwards the impact a hypothesized stakeholders' interaction might have on the choice of a shared policy measure. A modeling approach for simulating stakeholder involvement in the decision-making process can support the overall participation process, by providing an *ex-ante* evaluation of the acceptability of the proposed policies, considering that involving from the outset those that will be bearing the final consequences helps finding better solutions.

The proposed methodology aims at simulating stakeholders' interaction in a participatory decision-making process about UFT policies integrating ABM and DCM approaches. Discrete choice models (DCMs) are used to investigate stakeholders' preference heterogeneity and forecast their individual choice behavior allowing for a policy acceptability analysis (Valeri et al., 2016). Agent-based models (ABMs) are used to reproduce an opinion dynamics process where stakeholders interact and modify their choices to find a shared solution.

The use of ABM in this context is novel also because it is linked to sound microeconomic theory: in fact, the results of a DCM (i.e. agent-specific utility functions) are used as input to characterize the agents of the ABM model. This integrated approach allows accounting for stakeholders' effective preferences while reproducing their interaction in the decision-making process.

The model is sensitive to individual agents' attributes of convenience as expressed by the elements included in their utility function, the influence they have in the decision-making and also to the type and level of interaction among the agents. The approach proposed is used for short-term scenario analyses, where policy measures are predetermined and stakeholders are well aware of the consequences the policies implemented will have on their own objectives.

The aim of the paper is twofold. It aims at understanding, from a public policy-maker's perspective and before carrying out the real participatory policy-making process: (i) how to find a balance between conflicting private interests using push and pull measures, so to determine a subset of policy packages that would likely be accepted by stakeholders, and (ii) how to structure an efficient involvement process considering the relationships and interactions among stakeholders.

The authors are not aware of any ABM attempt to simulate stakeholders' interaction in a participatory city logistics decision-making context with the intent of finding a shared decision with respect to alternative policy measures/mix.

4. Materials and methods

This paper uses an agent-specific approach to reproduce the stakeholder-driven decision-making process with respect to UFT policy change analysis. Agent-specific results are derived from individual utility functions estimated via DCMs. An ABM is implemented to simulate the opinion dynamics process on a multilayer network. The multilayer network approach is used to reproduce the complexity of the decision-making process, with top-down and bottom-up phases and feedbacks. Next sub-sections report the details of the materials and methods used.

4.1. Agent-specific utility functions for policy change

Data used in this study refers to a research study in the city of Rome (Italy) aimed at improving the efficiency of the urban freight distribution system. The area investigated refers to the freight limited traffic zone characterized by an access fee and time windows restrictions (Marcucci et al., 2013).

Acknowledging that effective policy interventions are better promoted when local authorities are aware of stakeholders' preferences and their contrasting objectives, a behaviorally consistent UFT policy evaluation is fundamental (Marcucci et al., 2012). The agent-types considered are: (1) transport providers, representing the supply for urban distribution services; (2) own-account operators, who are retailers that instead of buying transport services from third parties self-organize/produce it; (3) retailers, who hire third parties to perform transportation services. The selection of these stakeholders' types and the exclusion, for example, of citizens and public administration reflects the specific research objective pursued that is, adopting a private point of view, determining desirable operational levers for improving urban freight transport services.

Separate and joint stakeholder meetings are the basis for understanding stakeholders' concerns about urban freight main problems (Stathopoulos et al., 2011). Moreover, these meetings allow the identification of the most appropriate attributes and levels to be used in the quantitative analysis.

Relevance, credibility and high level of shared support are the main criteria for attribute selection. In particular, policy components, included in the choice tasks administered in the stated preference (SP) exercises, are defined on the basis of: (1) number of loading/unloading bays (LUB); (2) probability of finding a loading/unloading bay free (PLUBF); (3) time windows (TW); (4) entrance fee (EF). The latter has 5 levels while all the others 3. The minimum level for LUB and PLUBF coincides with the current situation while EF has a symmetric range of variation with respect to the *status quo*. TW levels are the same in terms of amount of hours of restricted access while differing for their specific distribution over the day. Attributes and levels are specified as in Table 1. LUB, PLUBF and TW are the policy components that, thanks to preliminary focus groups organized, are considered relevant by all the stakeholders involved, while EF represents the countervailing element capable of creating realistic tradeoffs in the choice experiments administered. The relevance of loading/unloading bays issues, in terms of both number and availability, is confirmed by the fact that the majority of freight operations in the city of Rome are carried out outside dedicated loading/unloading areas. This hinders service efficiency. Notwithstanding the construction of additional loading/unloading bays has been on the political agenda for decades, it has never materialized. Stakeholder meetings confirm the crucial role played by these elements and indicate that there is more interest in policy outcomes (probability of actually finding loading/unloading bays available) than in the instruments used to pursue them (e.g. increasing the number of controls). Freight regulation in Rome already includes a time windows policy component (Nuzzolo and Comi, 2015; Nuzzolo et al., 2016).

Data acquisition is based on a stakeholder-specific multi-stage efficient experimental design (Gatta and Marcucci, 2016a). This approach, incorporating stakeholder-specific priors, guarantees a high quality data acquisition process and produces benefits in terms of attribute significance and/or reduction in sample size needed. It is particularly appropriate in this complex survey context, characterized by both difficult-to-involve interviewees, due to privacy concerns, and high opportunity costs for face-to-face interviews. Additionally, the lack of prior information concerning the sensitivities of each stakeholder type suggests adopting a gradual approach with progressive refinement of the experimental design used, incorporating a differentiation of choice scenarios by agent-type, across several waves.

Starting from business addresses lists of companies present either in the limited traffic zone (4500 for retailers and own-account) or in the Province of Rome (1100 for transport providers), a random sample is extracted and a total of 229 interviews[1] are gathered, distributed as follows: 39% retailers; 32% own-account; 29% transport providers.

Ten choice sets are presented to respondents including three alternatives, two generic policy options plus the *status quo* situation. The utility function for a generic agent (i) and a generic alternative (j) is reported below:

$$U_j^i = \beta_j^i + \beta_{lub}^i * x_{lub,j}^i + \beta_{plubf}^i * x_{plubf,j}^i + \beta_{ef}^i * x_{ef,j}^i + \beta_{tw1}^i * x_{tw1,j}^i + \beta_{tw2}^i * x_{tw2,j}^i + \beta_{tw3}^i * x_{tw3,j}^i + \varepsilon_j^i \tag{1}$$

where:

β_j^i is the alternative specific constant for the *status quo* alternative (not present for the other two generic alternatives);

$\beta_{lub}^i, \beta_{plubf}^i, \beta_{ef}^i$ are the coefficients associated respectively to number of loading/unloading bays (x_{lub}^i), probability of finding them free (x_{plubf}^i), entrance fee (x_{ef}^i);

$\beta_{tw1}^i, \beta_{tw2}^i, \beta_{tw3}^i$ are the coefficients associated to the different time windows ($x_{tw1}^i, x_{tw2}^i, x_{tw3}^i$), with non-zero values only for own-account operators.

DCMs, based on random utility maximization theory, are used to analyze choice data and estimate attribute coefficients. Multinomial logit model is typically used notwithstanding its assumption of preference homogeneity across respondents.

The multinomial logit expression, assuming an independent and identically distributed (i.i.d.) Gumbel distribution for the stochastic term, is:

$$P_i(j) = \int_{-\infty}^{+\infty} \left[\prod_{h \neq j} \exp(-e^{-(\varepsilon_{ij} + V_{ij} - V_{ih})}) \right] e^{-\varepsilon_{ij}} \exp(-e^{-\varepsilon_{ij}}) d\varepsilon_{ij} = \frac{e^{\beta' \mathbf{x}_{ij}}}{\sum_h e^{\beta' \mathbf{x}_{ih}}} \tag{2}$$

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[1] Although relatively small, the sample size is in line with the number of observations commonly acquired to get robust results. Moreover, thanks to the multi-stage efficient experimental design adopted, statistically significant parameter estimates are obtained and only a small effect on the standard errors of the coefficients would be achieved if more data were acquired.

Table 1
Attributes and levels used in the experimental design (the attributes levels underlined represent the *status quo* situation).

Attribute	Level and range	Own-account	Retailers	Transport providers
N bays (LUB)	<u>400</u>, 800, 1200	✔	✔	✔
P (%) bays free (PLUB)	<u>10</u>, 20, 30	✔	✔	✔
Time window (TW)	(1) 18–8	✔		
	(2) 20–<u>10</u>/14–<u>16</u>			
	(3) 4–20			
Annual entrance fee (EF)	200, 400, <u>600</u>, 800, 1000	✔	✔	✔

The Latent Class model is more flexible and allows to treat preference heterogeneity assuming a discrete mixing distribution of preference parameters. It makes use of two sub-models, one for class allocation, and one for within class choice. The choice probability is the expected value, over classes, of the choice probability within each class, as analytically reported below:

$$P_i(j) = \sum_{c=1}^{C} P(j|c)P(C) = \sum_{c=1}^{C} \left[\frac{e^{\beta'_c \mathbf{x}_{ij}}}{\sum_h e^{\beta'_c \mathbf{x}_{ih}}} \frac{e^{\varphi'_c q_i}}{\sum_l e^{\varphi'_l q_i}} \right] \qquad (3)$$

where q_i denotes a set of observable characteristics that enter the model for class membership (e.g. socio-economic variables) and φ'_c their relative parameters for class c. When no such covariates enter into the model, the only element used for class allocation is the constant term.

An agent-specific approach is needed not only when acquiring data but also when estimating DCMs. Marcucci and Gatta (2013), focusing on own-account operators, find that TW have a significant impact on their preferences, while this is not true for the other two agent-types. Transport providers are more interested in LUB than PLUBF (Marcucci et al., 2015) while the opposite is true for retailers (Marcucci and Gatta, 2014).

Preference heterogeneity is also relevant within a single agent category. Following Marcucci and Gatta (2012), where a sophisticated approach for detecting heterogeneity is applied, Table 2 reports the results of latent class model estimations for each agent category. Transport providers can be split into three classes having different preference structures, while retailers and own-account operators are both characterized by two classes. Starting from the three models presented, individual-specific posterior estimates of the coefficients are obtained by averaging class parameter estimates weighted by person-specific conditional class probabilities. This represents a valuable input for ABMs, usually, not fed with sophisticated agent-specific data accounting for personal heterogeneity in preferences.

4.2. Agent-based model of opinion dynamics for policy change

The proposed ABM aims at simulating multi-stakeholder decision-making processes about UFT policies. The paper assumes that stakeholders cooperate in a participatory decision-making process aimed at consensus building through a cycle of meetings where the policy measures are discussed and collectively deliberated so to balance conflicting interests. Each simulation reproduces the decision between the *status quo* and a given policy measure. The modeling approach assumes that stakeholders initially choose the policy they prefer according to the associated utility. Once the dynamic process starts, they can modify their opinion depending on the interactions with other actors. Their willingness to change is increased by repeated cycles of interactions. It expresses a cooperative attitude where a decrease in utility is accepted in exchange for the higher goal of a collective interest towards a shared solution.

The model links stakeholders in a social network, where the nodes represent the agents and the links are the relationships among them. The interaction process is simulated by means of an opinion dynamics model, reproducing the opinion flows through the network of relationships.

Statistical physicists working on opinion dynamics aim at defining the opinion states of a population, and the elementary processes that determine transitions between such states. The behavior of social agents is simplified with respect to reality, but can be useful in understanding the conditions under which a social interaction can lead to consensus or emerging collective phenomena. Opinion dynamics models have been largely used in the last years to capture the opinion evolution within groups of agents both on regular and complex network topologies. A comprehensive review of the main models and their usefulness can be found in Castellano et al. (2009). Besides, stakeholder engagement in transport decisions has been studied via ABMs to simulate the opinion dynamics on stakeholder networks (Le Pira et al., 2015, 2016, 2017) proving that interaction can be beneficial in finding a convergence of opinions in heterogeneous groups.

In the following subsections, the structure of the network chosen for the simulations is presented (Section 4.2.1) together with a description of the main steps of the model (Section 4.2.2). The details of the routines of the model are given in Appendix A.

Table 2
Latent class model estimations for each agent category.

Attributes	Own-account				Retailers				Transport providers					
	Class 1		Class 2		Class 1		Class 2		Class 1		Class 2		Class 3	
	coeff	t-stat	coeff	t-stat	coeff	t-stat	coeff	t-stat	coeff	t-stat	coeff	t-stat	coeff	t-stat
ASC_SQ	−0.167	−1.335	−0.643	−3.763	−0.49	−3.747	−0.486	−2.518	−0.487	−1.44	−0.476	−1.202	−0.805	−2.934
LUB	0.0002	0.9318	−2E−04	−0.639	−4E−04	−1.229	0.0018	8.2995	0.0031	4.2739	0.0027	5.1348	0.0007	2.2203
PLUBF	0.0118	1.7858	0.0108	0.7936	0.001	0.0839	0.0712	7.0179	0.0973	2.8214	0.1077	6.9641	0.0178	0.564
EF	−0.004	−12.83	−0.007	−9.004	−0.005	−12.58	−0.003	−6.46	−0.022	−7.811	−0.003	−4.294	−0.006	−7.699
TW1	−0.27	−2.663	−3.141	−9.097										
TW2	−0.198	−2.417	0.7224	4.2583										
TW3	0.4683	4.6263	2.4181	8.669										
Model for classes														
Intercept	0.2686	2.0729	−0.269	−2.073	0.0338	0.212	−0.034	−0.212	0.0983	0.5225	0.0875	0.2907	−0.186	−0.533
rho-sq.	0.376				0.397				0.576					
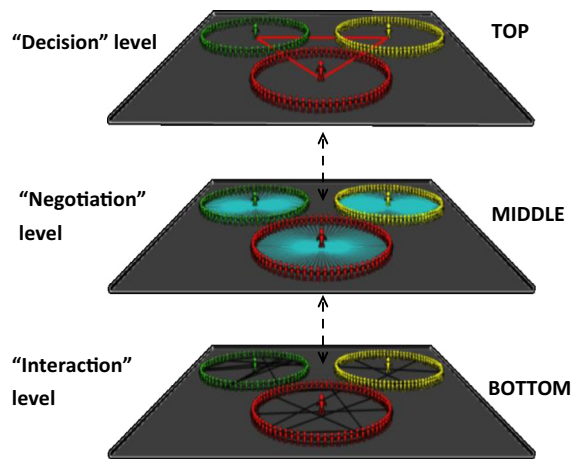
Fig. 1. Multiplex network of UFT stakeholders.

4.2.1. The multilayer network approach

The participation process for UFT policy-making is described by means of a multilayer network, where each layer represents a different level of description and details of the process. Multilayer networks constitute more realistic graphs with multiple interconnected levels, which generalize the single-level networks, allowing for a more realistic and effective representation of complex phenomena (Boccaletti et al., 2014). In the case of socio-economic systems, such as decision-making processes, a particular type of multilayer network should be used, the so called "multiplex" network, where each node belongs to all the layers but the relationships among them can change within the layers.

The UFT policy-making problem involving heterogeneous stakeholders is represented as a multiplex network with three layers whose structure is reported in Fig. 1:

- the bottom layer is the "interaction" level, where all the stakeholders are linked in "small world" networks with the other members of the same category. The "small world" network is a typical social network characterized by high levels of communication efficiency thanks to its structure of regular network "rewired" with some long-range links (Watts and Strogatz, 1998); it has been chosen to represent the communication within each stakeholder category due to its similarity with real social networks;
- the middle layer is the "negotiation" level, where an agent of each category acts as the spokesperson and is directly linked with all the other members of the same category. The topology is a "star" network, with a hub directly linked with all the other nodes; the "star" network represents quite well the meetings of trade unions and associations where the members communicate their preferences to a delegate (e.g. Confcommercio, the Italian traders' association or Federazione Auto-trasportatori Italiani F.A.I., the Italian carriers' association);
- the top layer is the "decision" level, where the spokespeople of the three categories are linked with each other and interact supporting the opinion of their constituency. The topology is a "fully connected" network, representing a focus groups where each delegate is in charge of representing the interests of her category in front of other delegates and they all discuss to find a shared decision.

The agents are all active at the same time. Indeed, the interrelationship between the layers is guaranteed by the presence of all nodes in the three layers. The structure of the network allows at the same time vertical bottom-up and top-down feedbacks.

The next subsection describes how the model simulates the network dynamics.

4.2.2. Agent-based model description

The simulation model has been implemented and run using the NetLogo software environment (Wilensky, 1999), particularly suitable for ABMs. The model consists of several routines and can be described in two main steps: (1) setup of the initial conditions and (2) opinion dynamics process. The details of the routines can be found in Appendix A, while a more qualitative description is presented in what follows.

The stakeholder-agents pertain to three categories: retailers, transport providers and own-account providers. As discussed in Section 4.1, the choice of including only the private sector in the model is linked with the aim of the simulated policy-making process, i.e. determining desirable operational levers for improving urban freight transport services. In this respect, the policies simulated are not intended for citizens, but for the private sector. In a wider study, where sustainability is the final aim, the public sector should also be considered along with other decision-making elements. Each agent is endowed with an individual utility function in line with the econometric results previously obtained (Section 4.1). Other three agents are created in the network as spokespeople for each category, representing the prevalent will of their respective group. Each spokesperson would influence the others according to the influence of her category; in this respect, each of them is endowed with an integer parameter I_c that reflects the ability to influence the other spokespeople in the negotiation process. The agents are linked in the three layers according to the topologies described in Section 4.2.1 ("small world" networks in the bottom layer, "stars" in the middle layer and a "fully connected" network in the top layer).

Each simulation reproduces the decision-making process between only two alternatives: *status quo* (SQ) and a given policy change (PC), characterized by different combinations of the attribute levels' used in the experimental design (Section 4.1). It is assumed that the agents, being involved in a participatory decision-making process aimed at consensus building, while interacting will show a certain availability to change their opinion in order to find a shared solution. The agent-specific utility functions are fundamental to characterize (1) agents' initial preferences towards the two policies and (2) their willingness to change opinions during the interaction process. Each agent initially chooses the policy (the *status quo* or a given policy change) which produces the highest utility for her. The assumption of this deterministic – instead of probabilistic – choice is reasonable since it only represents the initial opinion setup in the network that is likely to change during the simulation thanks to repeated interactions. In this respect, each agent is endowed with a certain willingness to change (WTC) opinion, which is a parameter chosen to reproduce the agents' attitude to change mind, as a function of the utility associated with the two policies. It should not be confused with the well-known econometric estimation of willingness to pay (Gatta et al., 2015). In fact, WTC is not directly related to any monetary estimation. The higher the utility difference between the two alternatives, the less the agent would be willing to change her opinion.[2] In other words, according to the gap of utilities associated with the two policies, she will be a "strong" or a "weak" supporter of her idea. In the following, we simply refer to a generic agent as a "strong" or "weak" supporter, meaning that she has respectively a low or a high WTC.

The interaction process is cyclical and goes sequentially through the different layers: at the beginning of the simulation, once each agent at the bottom layer has chosen the preferred policy (according to her utility function), in the middle layer the spokesperson of each category collects the opinions of her group and assumes the one supported by the majority, according to a majority rule (Galam, 2002). The spokespeople represent the will of their groups, so the strongest the supporters of a group are, the least the spokesperson will be willing to change her opinion in front of the others. In this respect, at each step each spokesperson is characterized by (1) the opinion of her group, (2) a certain WTC, dependent both on the average WTC and on the degree of consensus inside her group and (3) a parameter reflecting the influence of her category with respect to the others. At the top layer the opinion dynamics follows a pressure mechanism: each spokesperson "defends" the opinion of her group in front of the other spokespeople by exerting a certain pressure, directly related to the influence of her category. This negotiation can lead to a change in the opinion of some of them if they (i.e. the group they represent) are not "strong" supporters. After this bottom-up dynamics, a top-down process ensues, where each spokesperson comes back to her group (in the middle layer) and tries to convince the group about the result of the negotiation with the other spokespeople at the top layer by exerting a pressure to change opinion. As a result, the agents with the same opinion of the spokesperson will strengthen it, while the others will become "weaker" supporters and, possibly, change opinion. Finally, at the bottom layer, each agent of a given group interacts with her neighbors (i.e. the directly linked agents) with the same pressure dynamics described in the middle and top layer. The result of this interaction is a new configuration of opinions in the stakeholders' networks. This bottom-up/top-down process goes on until a stationary state is reached, i.e. when there are no more opinion changes in the networks: this can either mean that a total consensus is reached or that two categories (out of three) are polarized towards the same policy. Fig. 2 reproduces the above-described opinion dynamics in 4 steps, considering a given decision-making process between a generic policy A and B. To facilitate the reader's comprehension, only a category (i.e.

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[2] Suppose that one has the possibility to choose between the perceived best policy and the perceived worst one (high utility difference): the preferred policy will be strongly supported and the willingness to change it will be very low. On the contrary, if one could choose between two policies, which are quite the same in terms of perceived utility, then it will be easier to change idea and switch the choice from the first best to the second best (low utility difference and high WTC).
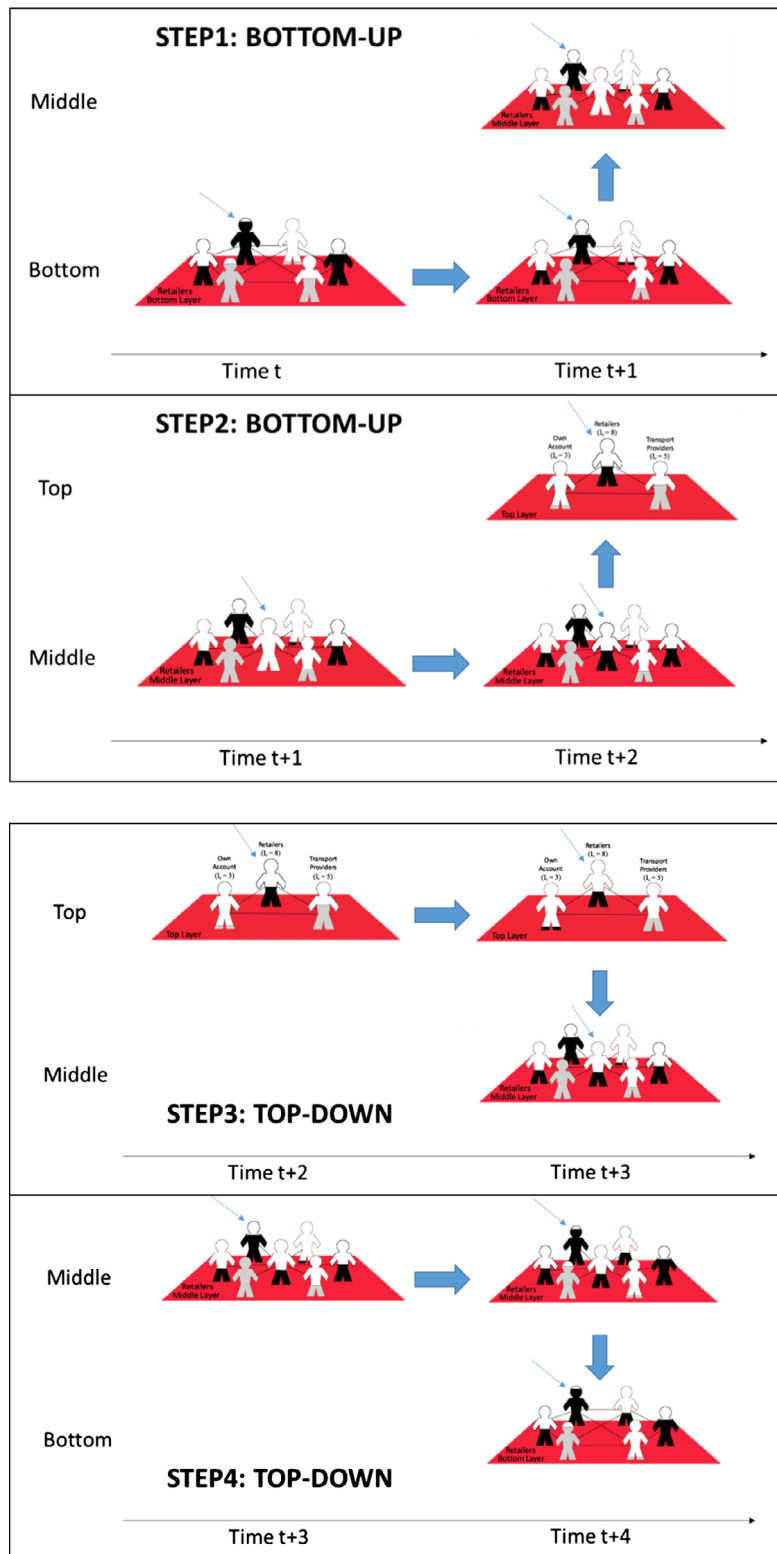
Fig. 2. Example of the 4-steps opinion dynamics process.

retailers) is reproduced in the bottom and middle layers (while in the top layer the three categories are present at the same time):

- Step 1: at a generic time t the agent i (indicated by the arrow) is a strong believer of policy A, as represented by the almost black filling of her figure. In the bottom layer, she is linked to other 3 agents (i.e. neighbors) of the same category. Two of them are supporters of policy B. At time t + 1, as a result of the interaction with the neighbors, agent i has been influenced by the others and her belief becomes "weaker" than before. At the same time, in the middle layer, all the agents of the category communicate their opinion to the spokesperson, that is neutral about the decision (shape with no filling) and will assume the opinion of her group.
- Step 2: at time t + 2 the spokesperson (indicated by the arrow) assumes the opinion of the majority of her group (in this case policy A), and she will support this opinion in front of the other spokespeople in the top layer. Her ability to support the opinion depends on how strong or weak the belief of the majority of her group is (indicated in the figure by the filling of the spokesperson).
- Step 3: at time t + 3, after negotiation, the spokespeople modify their opinion or, alternatively, reduce the strength of the belief in their opinion (as in the case of retailers' spokesperson). Then, at the middle layer, they will come back to their respective groups trying to convince them of the opinion resulting from the negotiation with the other spokespeople.
- Step 4: at time t + 4, agent i shares the same opinion of the spokesperson, so she will become a "stronger" supporter.

The cyclic mechanism implemented in the proposed ABM reproduces quite well a participatory policy-making approach where consensus building is the result not only of the negotiation among spokespeople, but also of subsequent interactions with the groups they represent and opinion exchange flows inside the same groups. It is evident that this cyclic interaction process, where agents simultaneously interact with all the other agents they are connected to, is simplified with respect to the real stakeholder engagement. Further research will be developed to investigate alternative model assumptions. Nevertheless, the multilayer structure, the networks chosen and the opinion dynamics mechanism adopted are well suited to reproduce a hierarchical process and investigate the consensus building dynamic formation.

Next section illustrates and discusses the results of the simulations. The outcomes of different simulation runs, starting from the same initial conditions (i.e. multiple events), can differ to some extent since a random component is introduced in the bottom layer. In fact, though the simulated networks are always small world topologies, the neighbors of each agent can change at each simulation run according to a random rewiring of links and a random assignment of utility functions to the agents. Averages over several runs will be therefore taken to improve the robustness of the results, which will be used to derive some policy implications.

5. Simulation results, policy implications and discussion

Table 3 summarizes the policy changes to be compared with the *status quo* (SQ). The rationale behind the choices made is the following: different scenarios for improving LTZ accessibility and usability conditions were considered by varying the attributes' levels used in the experimental design (Section 4.1), within the range defined by two extreme scenarios, i.e. "the worst case scenario" (WCS), where the entrance fee is maximized vis. a vis. the provision of no other improvements, and "the best case scenario" (BCS), with maximum attribute improvements for the three categories vis. a vis. no increase in the entrance fee.

Given the heterogeneity of the stakeholders involved, different scenarios more in line with one of the three categories are tested. The *a priori* with respect to what each category likes best is derived from the extensive investigations performed by Marcucci and Gatta (2013, 2014, 2016). In particular, according to the results of these previous works, transport providers in Rome are more interested in the number of loading/unloading bays (LUB), therefore the "transport-provider-oriented scenario" (TPS) considers the maximum increase in the LUB while keeping the other *status quo* conditions unchanged. Similarly, "retailer-oriented scenario" (RES) is the one where only the probability to find the bays free (PLUBF) is maximized, being the most important point for them. Based on previous analysis, own-account members seem mostly interested in time windows (TW), therefore "own-account-oriented scenario" (OAS) considers only a change in the time window attribute.

The increase in the entrance fee in these stakeholder-oriented scenarios is limited to 200 € (EF = 800 €), since simulations with a higher entrance fee (1000 €) end with a total consensus towards *status quo*, suggesting that stakeholders are not willing to pay this higher amount independently of the compensation that could be offered.

Table 3
Policy changes considered for simulations.

Attribute	SQ	WCS	BCS	TPS	RES	OAS	2BCS	3BCS	WTPS
LUB (number)	**400**	400	1200	1200	400	400	1200	1200	795
PLUBF (%)	**10**	10	30	10	30	10	30	30	19.5
TW (level)	**(2)**	(1)	(3)	(2)	(2)	(3)	(3)	(3)	(3)
EF (€)	**600**	1000	600	800	800	800	800	1000	766

Table 4

Description of the main components of the ABM, the data used for simulations and the model assumptions.

ABM component		Description	Data source	Model assumptions
Agents	Number and type	91 Retailers, 67 transport providers, 74 own-account, 3 spokespeople	SP survey (229)	3 spokespeople
	Utility functions	See Eq. (1)	SP survey (229)	Agent-specific DCM
	Influence	Integer number	–	Assumed only for spokespeople
	Willingness to change	See Eq. (5) and (6) in Appendix A	–	Based on utility functions
Environment	Decision-making structure	Multilayer network	–	Hierarchical multilayer decision-making process (Boccaletti et al., 2014)
	Policy simulated	See Table 3	Scenarios from SP survey	–
Interactions	Agents' relationships	Fully connected, star, small world networks	–	Prototypical social networks (Watts and Strogatz, 1998)
	Top-down opinion dynamics	See Fig. 7 in Appendix A	–	Incremental pressure mechanism
	Bottom-up opinion dynamics	Majority rule	–	Majority model (Galam, 2002)

Three plausible scenarios are also considered: a "second-best case scenario" (2BCS), which is a second-best option, meaning that the improvements considered in the BCS are counterbalanced by an increase in the entrance fee of 200 € (EF = 800 €) (i.e. a push and pull measure); a "third-best case scenario" (3BCS) with a further increase in the entrance fee with respect to the previous case (EF = 1000 €); a "willingness-to-pay-oriented scenario" (WTPS), deriving from considerations about agents' heterogeneous willingness to pay, is also tested.

This last scenario is particularly interesting because it is based on the results of a previous study (Gatta and Marcucci (2014). In particular, by using stakeholder-specific DCM the authors found that, under certain conditions, each stakeholder category would have paid the same amount (166 €) to have an increase in the number of bays (+395), an increase in the probability to find them free (+9.5%) and a different time window (TW3). Starting from these considerations, WTPS is based on an entrance fee of 766 €, 795 LUB, 19.5% PLUBF, TW3.

Table 4 summarizes the: (1) main ABM components, (2) data used for simulations and (3) model assumptions.

5.1. Simulation results

Results are expressed in terms of policy ranking based on a dynamic parameter that we called "global satisfaction". At time t, the global satisfaction $S(t)$ is defined as the product between the degree of consensus $C(t)$ and a (normalized) overall utility[3] $u(t)$, i.e.:

$$S(t) = C(t) * u(t) \in [0, 1] \tag{4}$$

where $C(t) = \frac{agents\ of\ majority\ (t)}{total\ number\ of\ agents} \in [0, 1]$ is represented by the percentage of agents in favor of the majority policy and $u(t) = \frac{|U(t) - U_{min}|}{|U_{max} - U_{min}|} \in [0, 1]$ is the normalized overall utility. $u(t)$ is equal to 1 if all the stakeholders can support their preferred policy and, therefore, their utility would be maximized ($U(t) = U_{max}$); on the other hand, it is equal to 0 if all the stakeholders are willing to accept the least preferred policy and, therefore, their utility would be at its minimum ($U(t) = U_{min}$).

Global satisfaction is an overall parameter that can be interpreted as a performance indicator of the interaction process, i.e. an acceptability measure of the final result for the three categories.

Given the agent-specific approach adopted, the authors are aware that a relative satisfaction would be more appropriate to take into account the heterogeneity of the stakeholders involved. In fact, political acceptability is a big concern for policy-makers and the redistributive effects of policies among groups of citizens should be explicitly included, as citizen-candidate game approaches assume (see for an example Marcucci et al., 2005). Nevertheless, at this stage of the research, a global satisfaction parameter alone is assumed sufficient to describe our interactive participatory decision-making process. As visible in Fig. 3, due to the interaction and the opinion change, the degree of consensus usually shows an increasing trend, while the overall utility generally decreases. As a consequence, the global satisfaction $S(t)$, being the product of these two quantities, initially increases in time, rapidly reaching a maximum, then slowly decreases. It is, therefore, possible to monitor and record the maximum value reached, which expresses the optimal combination of consensus and utility during a single simulation run. Results are averaged over 10 simulation runs to test their robustness.

Apart from the two baseline scenarios, i.e. BCS and WCS, whose results are trivial since they are, from the beginning, respectively totally supported and totally rejected by all the agents, the other policies tested produce some interesting

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[3] Note that the utility functions, consistently with the forecasting nature of the scenario analysis performed, include the deterministic component of Eq. (1) (Section 4.1) based on the LC agent-specific coefficients.
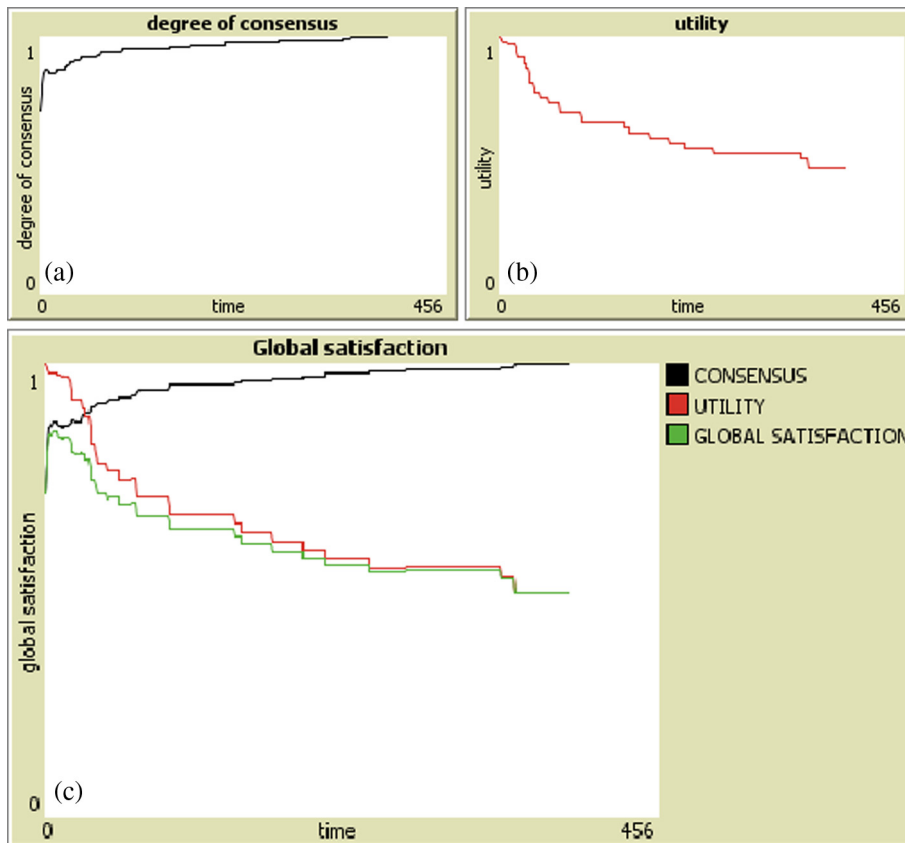
Fig. 3. Plots of degree of consensus (a), overall utility (b) and global satisfaction (c) for own-account-oriented scenario (OAS) (one simulation run).

results. The interaction process related to stakeholder-oriented policies (TPS, RES, OAS) always ends up with the majority in favor of policy change (with respect to the *status quo*) with a partial or total consensus.

It is quite surprising that the policy which favors only own-account agents reaches a higher level of global satisfaction if compared with the others; in fact, TPS and RES are good policies for both transport providers and retailers, while negatively impact only own-account agents. This result can be explained by a general *a priori* tendency towards policy change and a lower elasticity of own-account agents to pay more with respect to the other two categories.

2BCS and WTPS perform very well in terms of global satisfaction, the former being a package of measures that globally improves LTZ accessibility with a slight increase in the entrance fee, and the latter representing an optimal combination of measures that generates a balance in the willingness to pay of the different categories.

Results are quite different from 2BCS to 3BCS where the only difference is an additional increase in the entrance fee: when the entrance fee is higher some simulations end with an opinion convergence towards the *status quo*, others towards policy change. In this case it is not possible to produce any reliable prediction on the expected final outcome of the overall interaction process.

For the other cases, it is possible to provide a policy ranking based on global satisfaction (Table 5).

As noticed, 2BCS and WTPS are the best performing in terms of global satisfaction, while the stakeholder-oriented policies show lower values. It could be argued that, even though 2BCS is more favorable than WTPS, the latter is the most likely accepted scenario by all the stakeholders, being the "right" combination of attributes that satisfies all the three categories.

It is also interesting to consider the simulation time steps needed to reach the maximum satisfaction values (Fig. 4).

Even if simulation elapsed time does not have any precise contextual meaning, i.e. it is not a real time, it can still give an idea of how much effort an interaction process would imply to reach a satisfactory level (in terms of tradeoff between consensus and utility). In this respect, the high variability of the simulation time, which produces the high relative standard deviation (see Table 5), is a consequence of the randomness introduced in the bottom layer, where both the neighbors of the agents and their utility functions change at each simulation run. This, however, does not affect the final global satisfaction value, confirming the robustness of the results.

There is a notable difference among the policies with respect to the time needed to reach the maximum global satisfaction. For instance, the TPS policy shows at the beginning of the simulation the maximum global satisfaction and interaction would lead to a loss of utility that is not compensated by the increase in the degree of consensus.

Table 5
Policy ranking based on global satisfaction (averaged over ten simulation runs) (RSD = Relative Standard Deviation).

Ranking	PC vs SQ	Global satisfaction [0,1]		Time step		Degree of consensus [0,1]		Utility [0,1]	
		Mean	RSD	Mean	RSD	Mean	RSD	Mean	RSD
1	2BCS	0.96	0.00	62	0.99	1.00	0.00	0.96	0.00
2	WTPS	0.95	0.00	28	0.57	1.00	0.00	0.95	0.00
3	OAS	0.85	0.02	6	0.31	0.87	0.03	0.98	0.00
4	RES	0.70	0.05	143	1.99	0.78	0.16	0.91	0.10
5	TPS	0.60	0.00	0[a]	0.00	0.60	0.00	1.00	0.00

[A] in this case global satisfaction always reaches its maximum value before the beginning of the interaction process, at t = 0.

Fig. 4. Maximum global satisfaction per policy change and time needed to reach it (averaged over ten simulation runs).
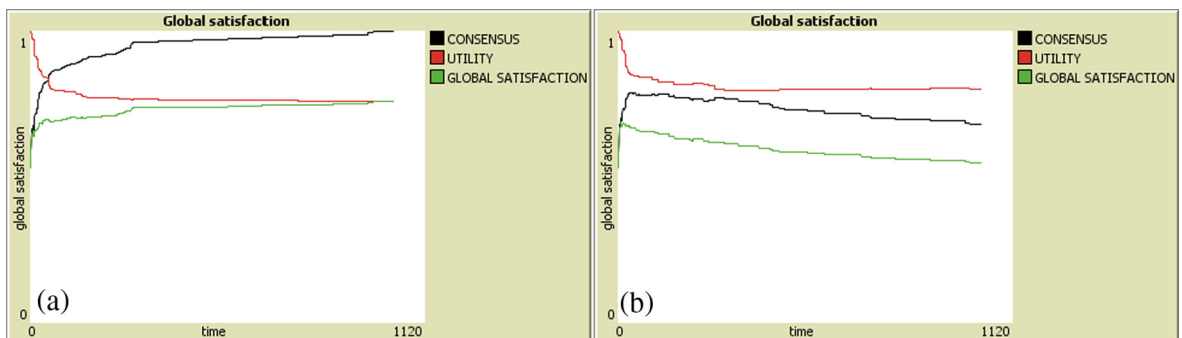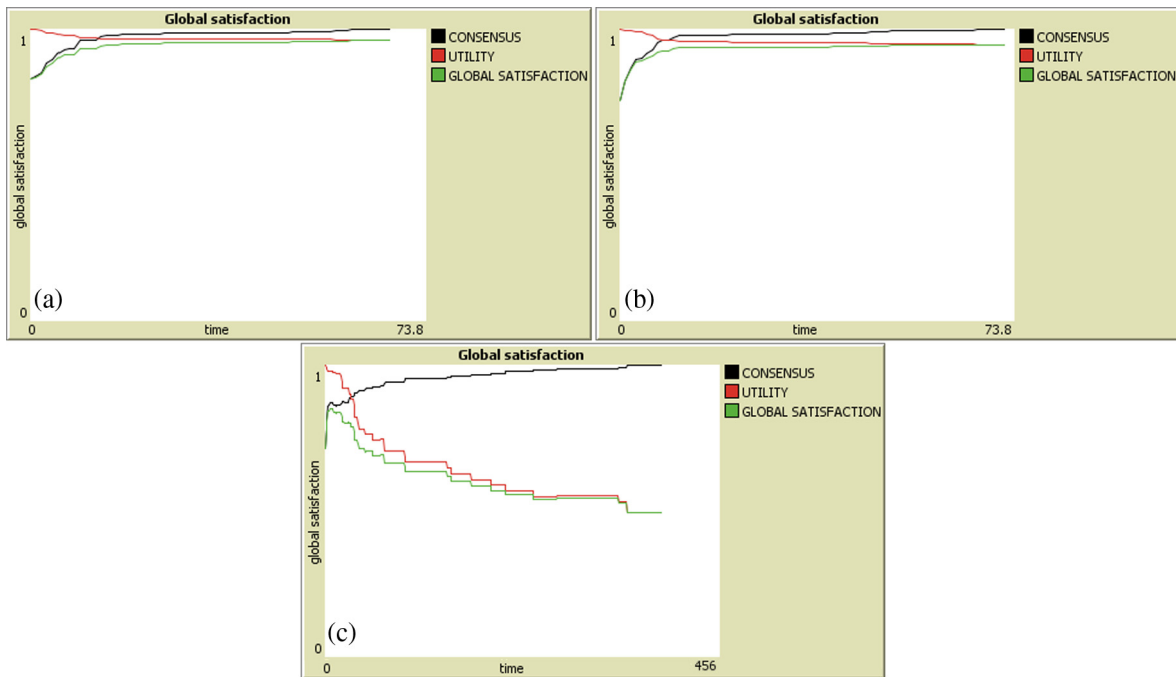

Fig. 5. Plots of degree of consensus, utility and global satisfaction for RES in the case of final total consensus (a) and final partial consensus (b) on policy change (one simulation run).

On the contrary, the RES policy, on average, takes much more time and this is because in some cases the simulation ends with a total consensus, in other cases with a partial one. While in the first case global satisfaction reaches its maximum when all the nodes turn in favor of policy change, in the other case the maximum value is reached after few interaction steps (Fig. 5) and further interaction leads to a lower degree of consensus. This result is a bit controversial because it implies that an extended interaction can be both beneficial or detrimental with respect to global satisfaction, therefore suggesting that one should not have an excessive number of meeting cycles since this could produce a divergence (instead of convergence) of opinions. An excessive number of meetings could lead to group polarization rather than to group agreement.

The OAS policy shows good values of degree of consensus and overall utility, suggesting that it would be more globally accepted with respect to the other two stakeholder-oriented policies.

In any case, if compared with the first two ranked policies in terms of entire interaction processes, they look quite different, showing comparable values of maximum "global satisfaction" and ending the three of them with a total consensus, but with a completely different loss of utility (much bigger for OAS than for 2BCS and WTPS) (Fig. 6). This supports the idea that the first two policies should be preferred to the third one and confirms that simulation time can be used to infer how many interactions steps are needed in real participation processes (e.g., how many meetings) to build consensus while guaranteeing a satisfactory level of stakeholder utility.

Fig. 6. Plots of degree of consensus, utility and global satisfaction for 2BCS (a), WTPS (b) and OAS (c) (one simulation run).

5.2. Sensitivity analysis according to power relations among stakeholders

A sensitivity analysis was also performed to test the robustness of the results by changing the influences of the three stakeholder categories. In absence of sound data, the authors drew on findings from previous studies on this topic. In particular, the work of Holguín-Veras et al. (2015) was taken as reference for the intensive discussion about power relations among the different actors involved in the supply chain. According to Holguín-Veras et al. (2015) "understanding the behavioral response of the freight carriers to pricing and incentives requires careful study of the interactions among the various economic agents involved in supply chains", considering suppliers, carriers and receivers as the main actors involved. In our model we do not consider the behavior of suppliers since the decisions concern the last mile distribution, involving pre-eminently carriers and receivers. Receivers decide when activities in the supply chain take place and they play a prominent role being the generators of the demand for freight and of the freight traffic (Holguín-Veras et al., 2015). In this sense, it is shown that the most efficient policy measures should target generators of the demand (i.e. retailers) and not the carriers. Besides, a change that produces positive impacts on some agents and negative on others makes negotiation necessary while the agents with the most clout (i.e. receivers) could manage to impose their preferred solution on the others. In this respect, our analysis can be considered as an *ex-ante* assessment of the effect that an interaction might produce in the final decision in a negotiation-like decision-making process. In our model, further complexity is added by the "hybrid" category of the own-account operators that play the double role of carriers and receivers.

In absence of data and bearing in mind that, in general, retailers (i.e. receivers) are more influential than transport providers (i.e. carriers), we re-run simulations by varying the influence of the three categories. In particular, each set of simulations considers one category 4 times more influential than the others. We tested the policies where at the beginning of the simulation the spokesmen shared different opinions between each other. For this reason, WTPS and 2BCS are not reported here, since the three spokesmen at time t = 0 were already polarized towards policy change and the results of the simulations did not change. In particular, the stakeholder-oriented policies show some differences in results as reported in Table 6: if retailers and transport providers are considered more influential, then policy change is the outcome of the simulations for the three proposed scenarios. If own-account are the most influential, simulations terminate with the majority in favor of *status quo*. These results can be ascribed to the reluctance of own-account towards any measure that foresees a compensation of an additional fee that does not imply an improvement of what they consider important (e.g. number of bays and probability of finding them free).

It is also interesting to test how stakeholders' influence impacts on the final result of 3BCS, since the results of the simulations were not clear, as discussed in the previous section. Also in this case, own-account agents are the most reluctant to pay an additional fee but, even when retailers are considered more influential, simulations end, in 60% of the events, in favor of the *status quo*. The results significantly change if transport providers are considered more influential, with all the simulations ending towards policy change.

Table 6
Results of the simulations (policy change – PC – or *status quo* – SQ) according to the different power relations (over ten simulation runs).

PC vs SQ	RET max influence	TP max influence	OA max influence
OAS	PC (10/10 events)	PC (10/10 events)	PC (10/10 events)
RES	PC (10/10 events)	PC (10/10 events)	SQ (6/10 events)
TPS	PC (10/10 events)	PC (10/10 events)	SQ (10/10 events)
3BCS	SQ (6/10 events)	PC (10/10 events)	SQ (10/10 events)

Table 7
Comparison of different approaches to UFT decision-making (DM = decision-makers; Exp = experts; Sh = stakeholders).

	Decision-making approach	Actors involved	Pros	Cons	Potential of success
1	Traditional	DM + Exp	Time	Unilateral decision-making	–
2	Participatory	DM + Exp + Sh	Transparent process	Time consuming and difficult to perform	+
3	Participatory + DCM	DM + Exp + Sh	Transparent preference-driven process based on sound microeconomic data	Effort for data acquisition	++
4	Participatory + ABM	DM + Exp + Sh	Transparent interaction-driven process guided by simulations	Effort for model implementation	++
5	Participatory + ABM + DCM	DM + Exp + Sh	Transparent process guided by sophisticated data on preferences and simulations of interaction effects	Effort for data acquisition and model implementation	+++

According to the results of the simulations and to the *a priori* literature findings, it could be argued that 3BCS would not be accepted by stakeholders since the most influential are against it. Besides, RES and TPS policies would not be accepted if own-account had the maximum influence, while OAS would be accepted whatever the most influential category is. In conclusion, the sensitivity analysis performed mostly confirms the policy ranking of Table 5 and produces some insights on the implication different power relations among the categories have on final results. This should be considered as a first step towards a more detailed study investigating, in a more comprehensive and rigorous way, this important issue.[4]

5.3. Policy implications and discussion

Simulation results suggest some recommendations and policy implications.

In general, the simulated stakeholders accept all the scenarios of LTZ accessibility improvements if this involves only a slight entrance fee increase, even if the improvements are oriented towards one of the three categories. When the entrance fee is further increased, it is nearly impossible to reach a consensus on policy change, confirming that policy-makers should not force restrictive measures (e.g., the entrance fees) if they are not enough counterbalanced by complementary incentives (e.g., number of facilities). As expected, the best policy in terms of global satisfaction is the one that maximizes at the same time the improvements for the three categories while slightly increasing the entrance fee. If we consider an excessive entrance fee increase even in this "one scenario fits all", simulations do not provide us with any precise suggestion since the results are not clearly directed towards any policy change. Besides, by considering different influences for the three categories, their heterogeneity is further stressed and results can change. In general, receivers are more influential than carriers, but if we consider transport providers more influential than both retailers and own-account, then the results of our simulations show that the "one scenario fits all" with a higher increase of entrance fee would be accepted. This suggests that in real processes policy-makers should recognize the heterogeneous influences of the categories, which surely have an impact on the final decision. A package of measures that matches the heterogeneous willingness to pay of the categories is, generally, a successful policy, well accepted by stakeholders, thanks to the balance between increase in the entrance fee and improvements for all the stakeholders involved. This confirms that an agent-specific approach is necessary to find an optimal solution accounting for different stakeholders' preferences.

Table 7 summarizes the added value of the proposed modeling approach (5) for a well-thought participatory UFT decision-making process with respect to other approaches: (1) traditional non-participatory unilateral decision-making process; (2) transparent, but time consuming and difficult to perform, participatory process; (3) preference-driven participatory approach guided by DCM; (4) interaction-driven participatory approach guided by ABM. The effort required by the integrated approach (5), both for data acquisition and model implementation, is compensated by the potential success of the participatory decision-making process, since scenario simulation results both produce information on specific subsets of policy packages that would probably be accepted by stakeholders and suggest how to structure an efficient involvement process considering the relationships and interaction among stakeholders.

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[4] The authors are very thankful to one of the anonymous referees that raised this important issue.

6. Conclusion

This paper presents an innovative approach based on a combination of DCMs and ABMs to reproduce and support participatory decision-making processes about UFT policies. Agent-specific utility functions (from agent-specific DCM) have been used to characterize stakeholders' choices (i.e. retailers, transport providers and own account providers) and an ABM has been developed to simulate the opinion dynamics process on a multilayer network. The multilayer approach has been chosen since it is an innovative and more realistic way to model the policy-making process.

Simulations aimed at analyzing the interaction dynamics in a consensus building process about UFT policies. The case study refers to a regulatory decision-making process in the LTZ in the city of Rome. Each simulation reproduced the decision between the *status quo* and a policy change. Results show that interaction among stakeholders is beneficial in achieving convergent opinions and providing a policy ranking based on the maximization of consensus building and the minimization of utility losses. Some policy implications are discussed on the base of the results obtained. The different influence of stakeholder categories is important in affecting decision-making process outcomes and should not be underestimated. A good policy is the one that provides a package of measures integrating the diverse stakeholders' interests thus suggesting that an agent-specific approach is fundamental to deal with the variety of interests involved in the UFT policy-making process.

Further research is needed to enhance the realism and accuracy of the model. Possible improvements relate to the: (1) introduction of the public sector in the decision-making process (e.g. citizens and consumers), (2) explicit consideration of the relationships among the different categories (e.g. based on contracts between retailers and transport providers or social proximity) and of their influence in the decision-making process, (3) simulation of the choice between more than two alternatives, (4) examination of results in terms of relative satisfaction per each category so to take into consideration the political acceptability of policies related to specific groups of citizens, (5) validation of the main elements of the model via observations or involving stakeholders in a participatory modeling approach (see e.g. Voinov and Bousquet, 2010; Anand et al., 2016), (6) general relaxation of model assumptions considering, for example, different power between stakeholders.

In conclusion, the paper proves the effectiveness of an agent-specific dynamic approach to model participatory UFT policy-making. A well-known methodology, i.e. DCM, is used to enrich an ABM, providing sophisticated data and attempting an integration of the two approaches, which has not been investigated yet.

Appendix A. ABM routines

A.1. Setup (t = 0)

At time t = 0 the multilayer network is created. The generic agent i can associate utility values to the two alternatives according to her utility function. Subsequently, each agent will choose the policy which maximizes her utility and she is endowed with a certain willingness to change "WTC" (wtc^i), considered as a function of the difference between the utility associated with the two alternatives: *status quo* (U_{sq}^i) and policy change (U_{pc}^i):

$$wtc^i(t = 0) = 1 - \frac{|U_{pc}^i - U_{sq}^i|}{|\Delta U_{max}|} \in [0, 1] \tag{5}$$

where ΔU_{max} represents the maximum difference of utility between the two alternatives. It is important to notice that ΔU_{max} is, for each pairwise comparison between *status quo* and a policy change, the maximum value – associated with one agent in the network – of difference between the utilities associated to the two simulated policies. It is here used as a normalization parameter, so that the WTC of the node with the maximum difference would be 0 while, at least in principle, the WTC of an agent with $U_{sq} \approx U_{pc}$ would be nearly 1. The higher the utility difference between the two alternatives, the less the agent would be willing to change her opinion. WTC is not linear, reflecting the fact that people are less likely to change opinion when they move away from their comfort region. To give an example: suppose that, for a given scenario, the difference of utilities between the two simulated policies for agent j is twice as much as that of agent i, respectively 8 and 4, while ΔU_{max} (associated with another agent k) is 10. Then, $wtc^i = 0.6$ while $wtc^j = 0.2$, meaning that agent i will be three times more willing to change her opinion than agent j, proving that it is more probable to change opinion if the two policies are very similar in terms of utility and much less probable when they are very different.

A.2. Opinion dynamics (t > 0)

Once the initial conditions are set up, the simulation of the dynamic interaction can start. It goes forward through the interplay between two distinct opinion dynamics (OD) processes, which act in sequence realizing a cyclic global process: a bottom-up OD, in which the information flows from the bottom layer to the top one; and a top-down OD, in which the information follows the inverse path, from the top to the bottom layer.

The bottom-up opinion dynamics is based on a majority rule (Galam, 2002): once all the agents at the bottom layer have chosen the preferred policy, the generic spokesperson of the category c assumes, at the middle layer, the policy of the majority of her group and she is also endowed with a certain WTC, which, contrary to the other agents, is not related to her utility, since she has to represent interests of her group. In fact, it is assumed that spokespeople will be more willing to negotiate with the others at the top level, and eventually to change opinion, if their group is "divided" between the two policies (meaning that there is no clear majority) or if the group is, on average, very willing to change. Therefore, their WTC will depend both on the average WTC of their group at time t ($\overline{wtc_c}$) and on the number of nodes supporting the non-preferred policy at time t (%minority):

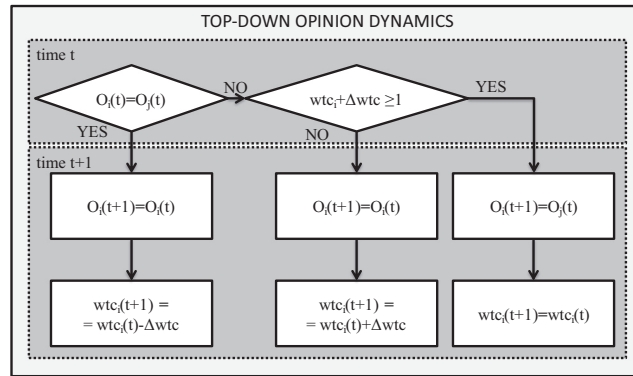$$wtc_c^{sp}(t) = \frac{|\%minority(t) + \overline{wtc_c}(t)|}{2} \in [0, 1] \tag{6}$$

Fig. 7. Algorithm of the opinion dynamics model between any two agents i and j ($O_i(t)$ = opinion of agent i at time t).
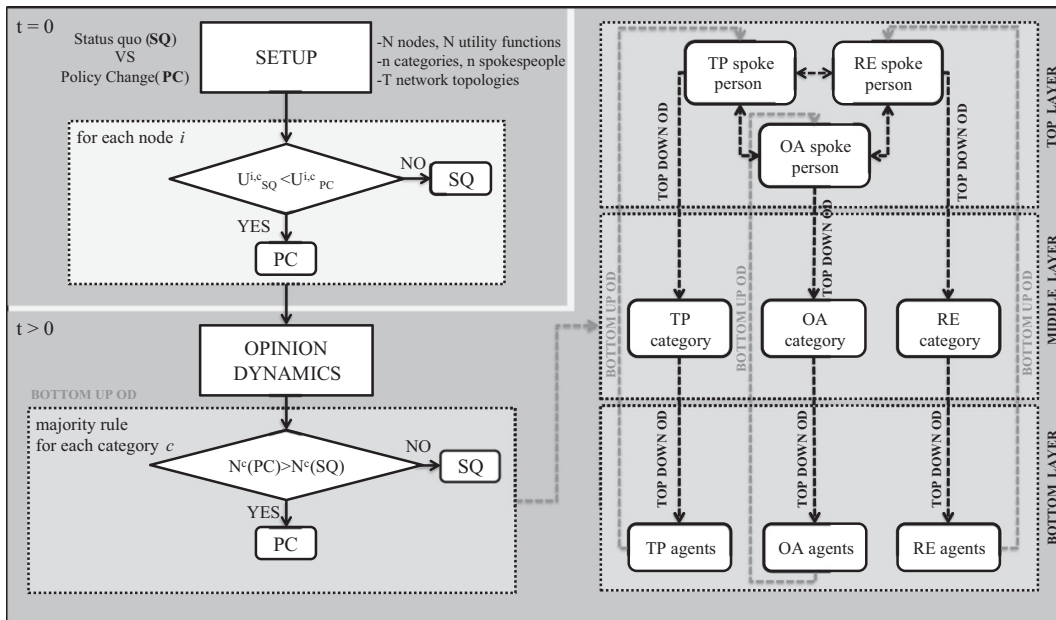

Fig. 8. Description of the main routines of the agent-based model (TP = transport providers; OA = own-account operators; RE = retailers).

The top-down opinion dynamics is based on an incremental algorithm with thresholds that determine the opinion change. At each time step t, the interaction between any two connected agents i and j occurs as follows: agent i receives a given "pressure" from agent j in terms of increase of her WTC $(+\Delta wtc)$ if the opinion of j is different from that of i; vice versa, i will strengthen her opinion by reducing her WTC $(-\Delta wtc)$. In the next time step, the preferences of the agents are updated: if the new WTC of agent i overcomes a threshold $(wtc^i(t+1) \geqslant 1)$, then she will change opinion; otherwise, she will maintain the same opinion of the previous step (Fig. 7).

This "pressure" mechanism acts in each one of the three layers, while the information goes from the top to the bottom:

1. at the top layer the spokespeople interact with each other by exerting a pressure that is related to the influence of the category they represent (i.e. if retailers are more influential than transport providers, they will exert more pressure towards the others); for this reason, in the top layer, we multiply the pressure $\Delta wtc(\approx 10^{-1})$ by I_c and, based on the received pressures, the spokespeople will maintain or change their opinions;
2. at the middle layer all the agents receive a pressure from the spokespeople and, according to it, they update their opinions;
3. at the bottom layer the agents of each category interact with their neighbors (i.e. the directly linked nodes) and, eventually, update their opinions; in both the middle and the bottom layer we consider a smaller value for the pressure, i.e. $\Delta wtc \approx 10^{-2}$, reflecting the difference in the type of interaction with respect to the top layer.

After the top-down process, the agents communicate the updated majority preference established at the bottom layer to the spokespeople, so that the bottom-up dynamics can be repeated again. This bottom-up/top-down process goes on until a stationary state is reached, i.e. the stopping rule consists of no changes in the agents' opinions to any further extent: this can either mean that a total consensus is reached or that two categories (out of three) are polarized towards the same policy.

Fig. 8 summarizes the main routines of the model with the detail of the top-down/bottom-up process based on the opinion dynamics (OD) mechanisms above described:

References

Anand, N., Meijer, D., van Duin, J.H.R., Tavassazy, L., Meijer, S., 2016. Validation of an agent based model using a participatory simulation gaming approach: the case of city logistics. Transp. Res. Part C 71, 489–499.

Anand, N., Yang, M., van Duin, J.H.R., Tavasszy, L., 2012. GenCLOn: an ontology for city logistics. Expert Syst. Appl. 39 (2012), 11944–11960.

Bjerkan, K.Y., Sund, A.v.B., Nordtomme, M.E., 2014. Stakeholder responses to measures green and efficient urban freight. Res. Transport. Bus. Manage. 11, 32–42.

Boccaletti, S., Bianconi, G., del Genio, C.I., Gómez-Gardeñes, J., Romance, M., Sendiña-Nadal, I., Wang, Z., Zanin, M., 2014. The structure and dynamics of multilayer networks. Phys. Rep. 544, 1–122.

Cascetta, E., Carteni, A., Pagliara, F., Montanino, M., 2015. A new look at planning and designing transportation systems: a decision-making model based on cognitive rationality, stakeholder engagement and quantitative methods. Transp. Policy 38, 27–39.

Castellano, C., Fortunato, S., Loreto, V., 2009. Statistical physics of social dynamics. Rev. Mod. Phys. 81 (2), 591–646.

CITYLAB, 2015. Lessons and experiences with living laboratories. Deliverable 3.3, Horizon 2020 Programme.

Davidsson, P., Henesey, L., Ramstedt, L., Tornquist, J., Wernstedt, F., 2005. An analysis of agent-based approaches to transport logistics. Transp. Res. Part C 13, 255–271.

DfT – Department for Transport, 2003. Freight Quality Partnerships – Case Studies. Good practice case study 410.

Eriksson, M., Niitamo, V.P., Kulkki, S., 2005. State-of-the-Art in Utilizing Living Labs Approach to User-Centric ICT Innovation. CDT, Luleå University of Technology, Sweden.

Galam, S., 2002. Minority opinion spreading in random geometry. Eur. Phys. J. B 25 (4), 403–406.

Gatta, V., Marcucci, E., 2014. Urban freight transport policy changes: improving decision makers' awareness via an agent-specific approach. Transp. Policy 36, 248–252.

Gatta, V., Marcucci, E., 2016a. Stakeholder-specific data acquisition and urban freight policy evaluation: evidence, implications and new suggestions. Transp. Rev. 36 (5), 585–609.

Gatta, V., Marcucci, E., 2016b. Behavioural implications of non-linear effects on urban freight transport policies: the case of retailers and transport providers in Rome. Case Stud. Transp. Pol. 4 (1), 22–28.

Gatta, V., Marcucci, E., Scaccia, L., 2015. On finite sample performance of confidence intervals methods for willingness to pay measures. Transp. Res. Part A 82, 169–192.

Hensher, D.A., Puckett, S.M., 2005. Refocusing the modelling of freight distribution: development of an economic-based framework to evaluate supply chain behaviour in response to congestion charging. Transportation 32, 573–602.

Holguín-Veras, J., 2008. Necessary conditions for off-hour deliveries and the effectiveness of urban freight road pricing and alternative financial policies in competitive markets. Transp. Res. Part A 42, 392–413.

Holguín-Veras, J., Aros-Vera, F., Browne, M., 2015. Agent interactions and the response of supply chains to pricing and incentives. Econ. Transport. 4 (3), 147–155.

Holmgren, J., Davidsson, P., Persson, J.A., Ramstedt, L., 2012. TAPAS: a multi-agent-based model for simulation of transport chains. Simul. Model. Pract. Theory 23, 1–18.

Jones, E., Chatterjee, A., Marsili, R.L., 2009. A collaborative plan for curbside freight delivery in Washington, DC, USA. ITE J. 79 (5), 22–25.

Le Pira, M., Inturri, G., Ignaccolo, M., Pluchino, A., Rapisarda, A., 2015. Simulating opinion dynamics on stakeholders' networks through agent-based modeling for collective transport decisions. Procedia Comput. Sci. 52, 884–889.

Le Pira, M., Ignaccolo, M., Inturri, G., Pluchino, A., Rapisarda, A., 2016. Modelling stakeholder participation in transport planning. Case Stud. Transp. Pol. 4 (3), 230–238.

Le Pira, M., Ignaccolo, M., Inturri, G., Pluchino, A., Rapisarda, A., 2017. Finding shared decisions in stakeholder networks: an agent-based approach. Physica A 466, 277–287.

Liedtke, G., 2009. Principles of micro-behavior commodity transport modeling. Transp. Res. Part E 45, 795–809.

Lindholm, M., 2014. Successes and failings of an urban freight quality partnership – the story of the gothenburg local freight network. Procedia – Soc. Behav. Sci. 125, 125–135.

Macal, C.M., North, M.J., 2010. Tutorial on agent-based modelling and simulation. J. Simul. 4, 151–162.

Marcucci, E., Gatta, V., 2012. Dissecting preference heterogeneity in consumer stated choices. Transp. Res. Part E 48, 331–339.

Marcucci, E., Gatta, V., 2013. Intra-agent heterogeneity in urban freight distribution: the case of own-account operators. Int. J. Transp. Econ. XL/2, 267–286.

Marcucci, E., Gatta, V., 2014. Behavioral modeling of urban freight transport. Testing non-linear policy effects for retailers. In: Gonzalez-Feliu, J. et al. (Eds.), Sustainable Urban Logistics: Concepts, Methods and Information Systems. Springer, pp. 227–243.

Marcucci, E., Gatta, V., 2017. Investigating the potential for off-hour deliveries in the city of Rome: Retailers' perceptions and stated reactions. Transp. Res. Part A: Pol. Pract. http://dx.doi.org/10.1016/j.tra.2017.02.001 (in press).

Marcucci, E., Marini, M.A., Ticchi, D., 2005. Road pricing as a citizen-candidate game. Eur. Transp./Trasporti Europei 31, 28–45.

Marcucci, E., Stathopoulos, A., Gatta, V., Valeri, E., 2012. A stated ranking experiment to study policy acceptance: the case of freight operators in Rome's LTZ. Ital. J. Reg. Sci. 11 (3), 11–30.

Marcucci, E., Gatta, V., Valeri, E., Stathopoulos, A., 2013. Urban Freight Transport Modelling: An Agent-Specific Approach. Franco Angeli, Milano, Italy.

Marcucci, E., Gatta, V., Scaccia, L., 2015. Urban freight, parking and pricing policies: an evaluation from a transport providers' perspective. Transp. Res. Part A 74, 239–249.

MDS Transmodal, 2012. DG MOVE European Commission: Study on Urban Freight Transport. Final Report. Chester, UK: MDS Transmodal Limited.

Nuzzolo, A., Comi, A., 2014. Urban freight demand forecasting: a mixed quantity/delivery/vehicle-based model. Transp. Res. Part E: Log. Transp. Rev. 65, 84–98. http://dx.doi.org/10.1016/j.tre.2013.12.014. Elsevier Ltd.

Nuzzolo, A., Comi, A., 2015. Urban freight transport policies in Rome: lessons learned and the road ahead. J. Urbanism: Int. Res. Placemaking and Urban Sustainability 8 (2), 133–147.

Nuzzolo, A., Comi, A., Ibeas, A., Moura, J.L., 2016. Urban Freight Transport and City Logistics Policies: Indications from Rome, Barcelona and Santander. Int. J. Sustainable Transp. 10 (6), 552–566. http://dx.doi.org/10.1080/15568318.2015.1014778. Francis & Taylor.

Quak, H., 2008. Sustainability of Urban Freight Transport: Retail Distribution and Local Regulations in Cities PhD thesis. Erasmus University, Rotterdam, The Netherlands.

Quak, H., Lindholm, M., Tavasszy, L., Browne, M., 2016. From freight partnerships to city logistics living labs – giving meaning to the elusive concept of living labs. Transport. Res. Procedia 12, 461–473.

Quick, K.S., 2014. Public Participation in Transportation Planning. In: Garrett, Mark. (Ed.), Encyclopedia of Transportation: Social Science and Policy. Sage Publications, Thousand Oaks, CA, pp. 1132–1137.

Quick, K.S., Narváez, G.E., Saunoi-Sandgren, E., 2015. Changing Minds Through Deliberation: Citizens' Accounts of Their Changing Local Transportation Policy Preferences. In: Transportation Research Board 94th Annual Meeting (No. 15–1286).

Roorda, M.J., Cavalcante, R., McCabe, S., Kwan, H., 2010. A conceptual framework for agent-based modelling of logistics services. Transp. Res. Part E 46, 18–31.

Stathopoulos, A., Valeri, E., Marcucci, E., 2012. Stakeholder reactions to urban freight policy innovation. J. Transp. Geogr. 22, 34–45.

Stathopoulos, A., Valeri, E., Marcucci, E., Gatta, V., Nuzzolo, A., Comi, A., 2011. Urban freight policy innovation for Rome's LTZ: a stakeholder prospective. In: Macharis, C., Melo, S. (Eds.), City Distribution and Urban Freight Transport: Multiple Perspectives. Edward Elgar Publishing Limited, Cheltenham, pp. 75–100.

Tamagawa, D., Taniguchi, E., Yamada, T., 2010. Evaluating city logistics measures using a multi-agent model. Procedia – Soc. Behav. Sci. 2 (3), 6002–6012.

Taniguchi, E., Thompson, R.G., Yamada, T., 2012. Emerging techniques for enhancing the practical application of city logistics models. Procedia-Soc. Behav. Sci. 39, 3–18.

Taniguchi, E., Tamagawa, D., 2005. Evaluating city logistics measures considering the behavior of several stakeholders. J. Eastern Asia Soc. Transport. Stud. 6, 3062–3076.

Taniguchi, E., Thompson, R.G., 2015. City Logistics – Mapping The Future. CRC Press, Taylor and Francis Group, Boca Raton, FL, USA.

Valeri, E., Gatta, V., Teobaldelli, D., Polidori, P., Barratt, B., Fuzzi, S., Kazepov, Y., Sergi, V., Williams, M., Maione, M., 2016. Modelling individual preferences for environmental policy drivers: empirical evidence of Italian lifestyle changes using a latent class approach. Environ. Sci. Policy 65, 65–74.

van Duin, J.H.R., van Kolcka, A., Anand, N., Tavasszy, L.A., 2012. Towards an agent-based modelling approach for the evaluation of dynamic usage of urban distribution centres. Procedia – Soc. Behav. Sci. 39, 333–348.

Voinov, A., Bousquet, F., 2010. Modelling with stakeholders. Environ. Model. Softw. 25, 1268–1281.

Watts, D.J., Strogatz, S.H., 1998. Collective dynamics of 'small-world' networks. Nature 393, 440–442.

Wefering, F., Rupprecht, S., Bührmann, S., Böhler-Baedeker, S., 2014. Guidelines. Developing and Implementing a Sustainable Urban Mobility Plan. Rupprecht Consult – Forschung und Beratung GmbH.

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

Zhang, M., Janic, M., Tavasszy, L.A., 2015. A freight transport optimization model for integrated network, service, and policy design. Transp. Res. Part E 77, 61–76.