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An agent-based simulation of retailers' ecological behavior in central urban areas. The case study of Turin

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Abstract
The paper provides an empirical analysis of urban freight transport in the city center of Turin through the use of Agent-based Modelling. The aim is to explore to what extent the policies fostered by Turin's municipality within the European project NOVELOG (New Cooperative Business Models and Guidance for Sustainable City Logistics) could trigger more ecological behaviors in retailers during the provision's process. The model is based on the idea that ecological behavior depends both on economic and social features, such as imitative component and service's quality perceived and individual environmental sensitivity. The agents are informed through real data provided by the City of Turin. Different kinds of scenarios are provided, in order to simulate the provision's process in current situation, without policies and in presence of alternative policies. Price-based policy simulates the effect of an hypothetical NOVELOG monetary incentive, while motivation policy would exploit the strong network effect in order to spread across all the agents. The results show that the policies improve the timing of the diffusion of virtuous behaviors, reducing the total production of pollutant emissions. The effects of high monetary incentives or the combination of price and motivation policy are strong.

Keywords: City Logistics, Agent Based Model, Retailers Behavior.

JEL codes: O18, R15, R49

1 Introduction

The paper presents an empirical Agent-Based Model (ABM) of urban goods' provision of retailers located in the Turin central Limited Traffic Zone (LTZ).

Being one of the most polluted cities in Europe (Legambiente 2018), the City of Turin is one of the partners of the European funded project NOVELOG (New Cooperative Business Models and Guidance for Sustainable City Logistics – H2020), whose aim is designing a more efficient and less pollutant freight provision system within many European cities.

The model presented in this paper has the aim to provide support to policy design by the City of Turin within the NOVELOG framework. In the context of NOVELOG the City developed an innovative governance model based on a proactive and effective stakeholders' cooperation for achieving a resilient urban development. This governance model has been also reported by the Italian Ministry of Economy and Finance in the document on Strategies for the transport and logistics infrastructures (NOVELOG WP 5). The main aim of the municipality of Turin is the reduction of the freight-related congestion and polluting emissions without penalizing social and economic activities within the city center. The city addressed so far the rules on logistics service providers' access to LTZ through a dedicated permit. The permit scheme for logistics service providers, in place since June 2016, is a so-called "pull measure" dedicated to incentivize the replacement of highly polluting vehicles with more ecological ones. The permit is given to the operators which comply with the following requirements: use of clean vehicles for the LTZ deliveries (Euro 5 standard or CNG or Electric), of maximum 5 tons of mass and equipped with GPS systems. The permit allows a free entry in the LTZ from 6.00 to 24.00, the use of dedicated bus lanes and of loading/unloading areas within pedestrian zones. The reaction of the logistics operators to this measure was positive. The beneficiaries report that more flexibility in the delivery and pick up trips planning allows to save time, to reduce the number of fees, to improve the driver's quality of life (by reducing stress), and to decrease the number of stops and of returns to the depot.

Since the measure seems effective in encouraging ecological behavior, the city is evaluating the possibility of extending the permit also to retailers which often use own-account transport. For this reason the

ABM presented in this paper is focused on retailers of Turin LTZ. It is empirically based since agents are informed through real data provided by the city of Turin on traffic flows and vehicle types in the LTZ and type of commercial activities. Different scenarios of the city logistics process in absence of policies and in presence of alternative policies, are presented. The output variables are, firstly, the time needed to obtain a certain percentage of agents shifting from non-ecological to ecological behavior due to policy implementation and, secondly the change in pollutant emissions due to shift of agents' behavior[1]. The research questions that the simulation model addresses are the following. First, which mechanisms have stronger influence on the retailers' decision-making process about ecological or non-ecological behavior for goods supply? Second, to what extent NOVELOG-based policies implemented by the city of Turin may foster more ecological behaviors of retailers during the process of freight provision?

The paper is structured as follows: next section presents data and methodology, while section 3 describes the model simulation and section 4 discussed the results.

2 Data and methodology

Agent-Based Modelling has been chosen to reproduce retailers' behaviors because it is particularly appropriate to represent very complex, dynamic and non-linear social systems, such as the urban transport system is (Gilbert, 2008; López-Paredes *et al.*, 2012; Maggi and Vallino, 2016 and 2017). In particular, ABM permits to take in consideration stakeholders heterogeneity, monetary and non monetary incentives and social networks dynamics, implementing a generative approach (Natalini & Bravo, 2014) and considering spatial, temporal and behavioural complexity (Parker *et al.* 2003).

In the model presented in this paper, called "ABM-TO", high importance is given to the concept that ecological behavior does not depend only on economic incentives, but also on psychological and social dynamics. While prices and economic determinants continue to be very influential variables on the decision-making process, often behavioral change is also triggered by imitation-based behaviors and choices driven by subjective perception of the received service.

[1] Literature reviews on retailers behaviours and needs are to be found in Danielis et a. 2013, Maggi 2007, Paglione 2006, Stathopoulos et al 2012, Taniguchi and Tamagawa 2005.

In this phase the focus of the paper lies on the behavioural dimension of the agents linked to monetary and social variables, while it is planned to include an explicit spatial dimension that influences the decision making process. This will be possible through the integration of the Geographical Information System (GIS) in the Netlogo Platform in the subsequent research steps.

ABM-TO reproduces the process of goods' provision conducted by retailers. The main hypothesis is that the policies, in order to be effective and provide incentives for a more ecological behavior, should contain features that are perceived as a benefit and an improvement of the initial conditions by the retailers. The tool utilized is NetLogo. Using data provided by Turin Municipality, a non-spatial network has been built, which represents retailers network within the LTZ of Turin. The decisions of 762 agents (30% of the 2,542 retailers in Turin LTZ) are simulated. Every agent symbolizes a retailer and represents one of the network hubs. The network structure acts a proxy of the relational and social relations whithin the domain of the working context. The structure and the dynamics of the network are based on the approach developed by Bass (1969). Each retailer may use either own-account or third-party solutions for freight transport. An "ecological behavior" is defined as the use of own-account with low pollutant vehicle or the use of third-party transport, following the hypothesis, based on economies of scale and density, that the efficiency of transport providers is higher than in the case of the own-account transport. On the other hand, "non-ecological behavior" is defined as the use of own-account high pollutant vehicle. Agents' behavioral rule is based on three elements:

- The "payoff", or final satisfaction level, which is composed by the price of freight transport and the perceived quality of the service.
- A personal propensity to innovation, sensibility to environmental issues (personal motivation).
- The influence of the professional social network. The neighborhood of the working context generates imitative processes for ecological behaviors.

In the baseline model, without policy implementation, a slow process of behavioral improvement is simulated, producing a shift from non-ecological to ecological behaviors. The simulation of the policies will improve the timing of the diffusion of virtuous behaviors.

The incentive for behavioral change of the agents derives from three different kinds of mechanisms:

– A low random probability that the agent will change his/her behaviour for personal reasons, which are out of the influence of both payoff and social pressure of the working context. We assume that this probability is independent from the professional social network, but it is linked to other factors out of the model control, such as personal value change or influence of social networks different than the professional one. This probability is low because we assume that the choice about the freight transportation method is mainly dependent on economic reasoning and on influence of the professional network. Agents with non-ecological behaviour compare service quality and the price that they have to pay. The price levels in the model are informed with actual data on vehicles types. If the final satisfaction level (payoff) is lower than the price, the agent has an incentive to change behaviour from non-ecological to ecological.
– In case that the payoff is higher than the price, the agent observes his professional network members and is subject to their influence.

The data which are utilized are contained in two different databases, both provided by the city of Turin. The first database contains data on vehicles crossing the entry points of the LTZ of Turin within 10 days in 2013, indicating the type of vehicle and transport (own-account or third-party). The second dataset contains information about commodity sectors, location and size of commercial activities within the LTZ in Turin. According to the scientific literature (among others, Danielis *et al.,* 2013; Maggi, 2007), the behavioral trends of the retailers belonging to the different commodity sectors are observed, in terms of choice for either own-account or third-party transport, and in terms of frequency of freight provision. We exploit the information included in both databases to inform the agents' model and assign to each of them an initial behavior regarding frequency of goods provision and choice for own account or third party transport. Knowing on the one hand the percentage distribution of vehicles by feature through the data on entry points of the LTZ, and on the other hand the trend of frequency of freight provision by commercial categories through the scientific literature we assigned to each agent the correspondent probabilities of restock frequency, of use of own-account or third-party an of vehicle features (Euro class). Table 1 shows the distribution of retailers among the different delivery frequency classes and the tendency of each frequency class to use either own-account or third-party solutions for freight transport. Regarding environmental pollution, the PM_{10} emissions generated by vehicles of the different Euro classes have been taken into account, as they are considered to be among the most dangerous for human health (European Environment Agency, 2016). Table 2 shows the values for the average PM_{10} emissions of every Euro class and the percentage of vehicles crossing the LTZ entry points belonging to every Euro class. These data have been utilized to statistically infer the distribution of simulated agents' vehicles across the Euro classes.

Table 1. Retailers features (Sources: Danielis *et al*., 2013, Maggi, 2007, city of Turin data)

Frequency of goods delivery	**Distribution of retailers**	**Percentage of use of own-account transport**
Many times a day	1.2%	0%
Daily	51.0%	70%
Many times a week	5.1%	65%
Weekly	19.5%	50%
Many times a month	3.4%	28%
Seasonal	19.8%	12.5%

Table 2. Euro Class of freight vehicles LTZ of Turin

Euro class	**PM10 (g/km)**	**Percentage of use in the Turin LTZ**
Euro 0	0.2	0.65%
Euro 1	0.18	0.6%
Euro 2	0.11	5.4%
Euro 3	0.07	25.45%
Euro 4	0.04	50.4%
Euro 5	0.005	17.5%

From the real data provided by the city of Turin, it emerges a relatively virtuous situation, with the majority of vehicles recorded (50.4%)

being of Euro 4 polluting class. From the data of the city of Turin, it is possible to observe that for each frequency class, the probability of using a Euro 5 vehicle, with least emissions, is of 17.5%. In the framework of this work, Euro 5 is considered to be the threshold between ecological and non- ecological vehicle, since this threshold has been utilized by policy makers for designing the NOVELOG permit.

3 The simulation scenarios

Different scenarios, which are constructed according to the level of intensity of different policies or their combination and hypothetical different reactions of the stakeholders, are compared.

In the simulation, agents tend to improve their behavior according to the three processes presented above. Consequently, simulated policies apply to the starting scenario. Every agent starts choosing either the own-account or third-party option given its restock needs, which are based on the size of the business, the type of operations, the sector where it belongs. The hypothetical application by Turin Municipality of the NOVELOG policy directly to the retailers is simulated. A so-called price based policy implies the possibility of giving an indirect incentive to retailers for the purchase of a less pollutant vehicle or to shift to third-party transport services, promoting a more environmental behavior. The indirect incentive would not be a direct monetary transfer, but it would consist of a set of requirements that the retailer should comply with, in order to obtain a permit similar to the one that NOVELOG designed for the logistics operators, as explained in section 1. This permit would produce a decrease of the total costs that the retailers should pay for freight supply. While designing the simulated policies, the so-called "pull" approach is followed, which already characterizes the NOVELOG policy, seeking for providing incentives for proactive attitudes by the beneficiaries, instead of concentrating on punishing beneficiaries' behaviors that violate the rules.

Three types of price policies are simulated:

- *Soft own-account policy*: focus on light decrease of the price of own-account with low pollutant vehicle (Euro 5).
- *Strong own-account policy:* focus on strong decrease of the price of own-account with low pollutant vehicle (Euro 5).
- *Third-party policy*: focus on strong decrease of the price of use of third party transport option.

Moreover, these three policies have been combined with a motivation policy (see last two columns of Table 3). This last policy is represented by a parameter that increases the preference for less polluting means of transportation, i.e. the above called “personal motivation”, of 10% independently from their price. In other terms, the policy positively affects the agent intrinsic motivation for ecological behavior and on the desire to increase its reputation within the network (Fowler and Christakis, 2010). Examples of motivational instruments are educational campaign or eco-labeling.

The “no policy” scenario (the starting situation; first row) and the three scenarios of price policies application are summarized in Table 3. The prices of the different transport solutions vary in the range 0-5 (second column). The same range is utilized in the model code in order to quantify the level of subjective satisfaction about the service, and this last variable is randomly evolving over time and heterogeneous among the agents. In absence of particular incentives in place the own-account option with ecological vehicle (OAE) is the most expensive one (5 level), followed by the own-account with a non-ecological vehicle (OANE: 3.5 level). The third-party transportation solution is the cheapest, when compared with the others two (TP: 2.5 level). The third column indicates the initial share of agents having an ecological behavior calculated by the model, after the calibration with the data described in section 2. It indicates the initial shock given by the policy (only by the motivation policy in the scenario 1 and by price policies and their combination with motivation policy in scenario 2, 3 and 4).

The model calculates for each scenario the unit of time needed in order to increase of 20% the number of “adopters”, i.e. agents that shifted from non-ecological to ecological behavior. One unit of time corresponds to one tick in NetLogo software (minimum value is 1). The unit of time to reach the threshold in case of price policy application is indicated in column 4, while the corresponding value in the case of combination of price policy with motivation policy can be found in the last column.

In the no-price policy scenario (first row) agents tend to become “adopters”. In that scenario motivation policy is used alone, obtaining a strong improvement, since the unit time to increase the adapter of 20% decreased from 1.83 to 1.54. The application of price policies improves the timing of adoption.

In scenario two (second row), the soft own-account policy is applied, which means that the main focus is placed on the shift from OANE to OAE , with “light” incentives in this direction. The price of OAEmoves from level 5 to level 3 while the price of the third-party (TP) option goes only from level 2.5 to 2.3. This price policy generates a reduction of 7.1% of the time needed to reach the desired threshold of adopters. Moreover, if these price policies are combined also with the motivation one, the time reduction improves (-9%).

In scenario three (third row) a more intense, but similar kind of policy, called “strong” own-account policy, is applied. The imaginary monetary incentives for retailers would produce a decrease of the OAE from level 5 to level 2, while the price of the TP solution would change again only from 2.5 to 2.3 level. This policy mix generates a decrease of 14% of the time needed to reach the desired threshold. The addition of the motivation policy produces the same results of scenario two (a time reduction of 9%).

Finally, in the last scenario (fourth row), the third-party policy application is simulated. The TP price strongly shift in this case from the initial 2.5 to 1.5 level, while the OAE would decrease by a small proportion, changing from 5 to 4.5 level. In this scenario the combination of price policies with motivation policy gives better results (-14.28% of time reduction) than the price policies alone (-8.19%).

Table 3. Results of policies’ implementation

Scenario	**Price levels**	**Initial share of adopters of ecological behavior (PM10 g/km)**	**Unit of time to reach +20% adopters (price policies)**	**Time reduction (price policies)**	**Unit of time needed to reach +20% adopters (motivation policy)**	**Time reduc duction (motivation policy)**
1. No-price policy	TP: 2.5 OAE: 5 OANE: 3.5	57% (22)	1.83	-	1.54	-

2. Soft own-account policy	TP: 2.3 OAE: 3 OANE: 3.5	55% (23.43)	1.7	-7.1%	1.41	-9%
3. Strong own-account policy	TP: 2.3 OAE: 2 OANE: 3.5	59% (21)	1.56	-14%	1.4	-9%
4.Third-party policy	TP: 1.5 OAE: 4.5 OANE: 3.5	60% (20.18)	1.68	-8.19%	1,32	-14.28%

Note: “Adopters” means agents that shifted from non-ecological to ecological behavior TP=third-party transport. OAE=own-account with ecological vehicle. OANE=own-account with non-ecological vehicle. Prices of freight transportation are expressed into levels within a 0-5 range.

Figure 1 illustrates the NetLogo interface that shows on the left the starting scenario of the model and on the right the end of a simulation run, in the case of third-party policy. The network of retailers is represented: green hubs indicate retailers that started with ecological behavior, while red ones are the retailers with non-ecological behavior. Thanks to the diffusion process due to imitation mechanisms within the social network agents shift from non-ecological to ecological behaviors: yellow hubs that became the majority in the interface represent the retailers that adopted ecological behavior during the simulation run.

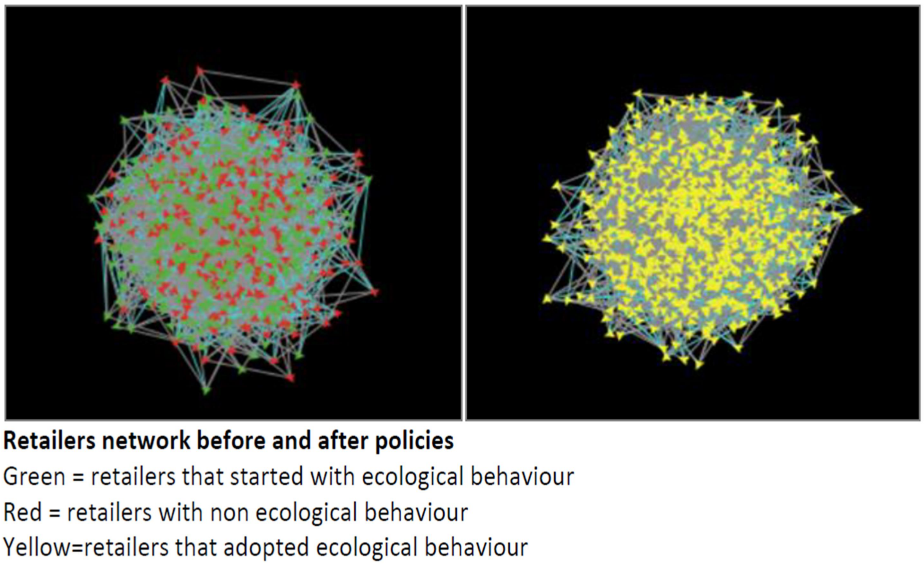

Fig. 1. Retailers network and adopters at the beginning and at the end of the simulation

4 Results discussion and conclusions

The results show that even just the initial shock given by the policies increases the share of adopters, because of the agents' decisional rules supposed in the model. The best scenario is n. 4 that shows an increase of adopters from 57% to 60% and a corresponding decrease of emissions from 22 to 20.18 PM10 g/km.

Looking at the percentage of time reduction, it becomes clear that the most effec-tive policies are the strong own-account policy which significantly reduces the price of low pollutant vehicles (scenario 3) and the third-party transport policy, but only if coupled with an intervention on the motivational level (scenario 4). In both cases, indeed, the time needed to increase of 20% the adopters of an ecological behavior is reduced by 14%.

The addition of the motivation policy to price policies tends to amplify all effects with the exception of scenario 3, while the use of motivation policy alone (first row) shows a strong improvement (time unit decreased from 1.83 to 1.54). Soft incentives for more ecological vehicles in own-account transport (scenario 2) are more effective overtime than as initial shock.

In all the scenarios the environmental emissions always decrease by about 34% when the percentage of adopters increases (from about 20-22 to 14.52 PM10 g/km).

Concluding, results suggest that a policy oriented at providing incentives for a shift from own-account to third party freight transportation seems more effective with respect to an alternative policy giving a low monetary incentive for the purchase of an ecological vehicle in the own-account option, but only if this policy is coupled with an intervention at the motivational level. In case it would not be possible to implement this last kind of intervention, then a strong own-account policy with incentives for purchasing ecological vehicles would be most effective. Results are the product of a balance between the effect produced by the price based policy and the effect pro-duced by the network influence which influences and are influenced by the personal motivation. The strong role played by this last dimension in the simulation confirms the findings of the scientific literature on reputation effects (Milinski *et al.*, 2002; Fowler and Christakis 2010).

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