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Sustainable urban freight transport adopting public transport-based crowdshipping for B2C deliveries

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Abstract

Cities crave innovative logistics solutions dealing with the requirements of the 'on demand economy'. The paper estimates the willingness to act as a crowdshipper (supply) and to buy a crowdshipping service (demand) to get goods delivered/picked-up in the last mile B2C e-commerce situation. Specifically, it innovates by considering an environmental-friendly crowdshipping based on the use of the mass transit network of the city where parcels customers/crowdshippers pick-up/drop-off goods in automated parcel lockers located either inside the transit stations or in the surroundings. This issue is very important since "standard" crowdshipping is usually not able to reduce congestion and polluting emissions due to the dedicated trips performed using private motorized vehicles. The paper rests on an extensive stated preference survey. The hypothetical scenarios used to acquire both demand (customers') and supply (crowdshippers') preferences make use of the most relevant attributes emerging from a preliminary investigation performed in the study context. The investigation is performed in the city of Rome and the metro is the transit system considered. The results are useful in understanding and quantifying the potential of this freight transport strategy for e-commerce in an urban context and in providing local policy makers with a good knowledge base for its future development.

Keywords: Crowdshipping, On demand economy, Urban freight transport, City logistics, Discrete choice models, Stated preference

1 Introduction

Cities are experiencing a fast-rising demand for mobility linked both to urban and logistics sprawl. Furthermore, e-commerce, and especially B2C, generates a strong demand for home delivery services provoking, in turn, both social and environmental costs increase [48]. Proposing solutions that might contribute to improving the environmental sustainability of "last mile" delivery is fundamental especially due to the e-commerce-related trips, which, together with urbanization, is increasing substantially [1].

Crowdshipping, an innovative delivery model could, at least in principle, stimulate a better use of currently unexploited transport capacity thus reducing transport costs and emissions [9]. Crowdshipping is a sharing mobility service and implies delivering goods using the crowd [35]. Paloheimo et al. [40] question its ability to reduce congestion and polluting emissions since most of these initiatives rely on dedicated trips performed using private motorized vehicles. Paradoxically the greater the success the higher its social and environmental impact due to a rebound effect that might produce an increase in travel times and fuel consumption. Therefore, when proposing crowdshipping as a possible solution one should test its environmental and social friendliness rather than assume it.

This paper investigates a crowdshipping service implementation that circumvents all these considerations on environmental issues, together with other relevant externalities (e.g. fewer traffic accidents, less land use, etc.), by relying on the use of non-dedicated public transport trips. In fact, the least polluting trip is the one that does not take place. In our case, the service environmental friendliness is ensured *ex-ante* since it does not imply

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performing any additional trip and those that are taking place make use one of the least polluting modes. The paper focuses on commuters using the metro rather than the bus since the former is typically more frequent and reliable than the second thus making an additional stop/detour more easily acceptable also for low compensations which are typical for last mile deliveries.

The paper aims at testing under which conditions crowdshippers will produce the service and the customers buy it. The configuration of the delivery service, that can be produced/bought assuming crowdshippers use the metro during their regular home-to-work trips, is crucial to detect the feasibility of this form of crowdshipping. The paper sheds light on the necessary conditions to involve commuters, already using public transport and thus not producing additional trips, in delivering freight within the city in a timely and efficient manner. It is important to note that the type of goods to be transported is a critical issue, especially for green crowdshipping. In fact, size and weight can reduce people availability of acting as crowdshippers, while it is plausible that consumers would be less inclined to receive valuables or personal goods through the crowd using public transportation. However, this is not necessarily an overwhelming obstacle. In fact, one can still expect a large number of deliveries where parcels are compatible with green crowdshipping and, moreover, it is not intended to be *the* solution, but it should help the logistics system to deal with the requirements of the 'on demand economy'.

European urban freight transport initiatives and actions have been promoted in the last years to promote research to identify innovative and effective solutions [25]. Policy interventions may produce unintended results also depending on the decision-making process adopted [33]. Participatory planning based on a living lab approach [16] or collaborative governance models [31] can help obtaining the desired results. As a first step, it is fundamental to perform ex-ante behavioral analyses focusing on policy/solution acceptability, taking into account stakeholders' preferences, in order to provide policy-makers with an efficient and effective decision-support system [17, 23, 24].

The innovative crowdshipping concept is analyzed using the city of Rome as a case study where: i) almost 3 million people live, ii) citizens perform around 700,000 thousand trips during the morning peak, iii) congestion causes about 135 million hours lost, iv) operators employ in the city center approximately 32,700 vehicles daily to perform more than 35,000 loading and unloading operations [11].

2 Literature review

Crowdshipping, also referred to as crowd logistics, crowdsourced delivery, cargo hitching or collaborative logistics, uses free capacity available in various transport modes to perform deliveries [10]. Most of the literature on this subject has focused on the various business models developed [43] while little is known about the behavior and perception of crowdshipping users and buyers.

Savelsbergh and Van Woensel [44] discuss the case of Walmart which contemplate the involvement of its in-store customers (occasional drivers) to deliver items that online customers order. It aims at guaranteeing same-day delivery to online customers and uses company drivers only in addition to perform occasional unforeseen deliveries. From a city logistics perspective, offering such a service is likely to increase the number of freight movements further, making coordination and consolidation of direct-to-consumer deliveries even more challenging. Furthermore, Mak [26] studies a novel crowdshipping service strategy foreseeing the use of in-store customers to deliver orders to online customers, looking at its potential impact on retailers' operational and marketing strategies. However, this study focuses on economic aspects without delving on its environmental consequences.

Slabinac [46] illustrates the DHL case, where the German logistics service provider developed a crowdshipping service in Sweden. DHL involved, through monetary incentives, individuals going home to provide last mile delivery services from a retailer to a shopper's home. The participation was organized via the use of an ad hoc-developed mobile application. Amazon also explored similar settings to those used by Walmart and DHL for the provision of crowdshipping services [6].

The recent increase in the number crowdshipping initiatives around the world has attracted the attention also of academic researchers [32] that started to investigate this subject focusing on both the service characteristics as well as on the related optimization problems. For example, Archetti et al. [2] formulated the Vehicle Routing Problem with Occasional Drivers representing Walmart's vision of the vehicle routing problem. In fact, Walmart uses a fleet of capacitated vehicles and drivers to perform deliveries, as well as occasional drivers. The company seeks to minimize the costs of satisfying its customers' demand (i.e., perform all deliveries). The paper addresses the problem using a multi-start heuristic procedure. The results indicate that employing occasional drivers may produce significant benefits especially if coupled with an appropriate compensation scheme.

Behrend and Meisel [4] analyze a platform combining shipping requests with community members' planned trips through the development of mathematical and heuristic models with the aim of maximizing profits. The results quantify the benefit of integrating item-sharing (i.e. sharing of tools or leisure equipment

between community's members) and crowdshipping as a function of crowdshippers' detour flexibility and compensations. The opportunity to combine limited flexibilities in a neighborhood delivery turns out to be additionally beneficial, as it provides consumers with access to items that are not reachable through the other modes. Due to these findings, the authors conclude that an integration of item-sharing and crowdshipping has the potential to push collaborative consumption by delivering through the crowd.

Yildiz and Savelsbergh [50] deal with crowd-sourced transportation for on-demand meal delivery. They investigate the interaction between courier satisfaction (i.e., couriers' willingness-to-wait), courier compliance (i.e., couriers' offer acceptance-probability) and profit.

Marcucci et al. [30] investigate the necessary pre-requisites a crowdshipping service needs to satisfy so to be attractive within the highly competitive urban freight delivery market. The exploratory investigation focuses on 200 university students in the city of Rome. While 87% of the students stated their willingness to operate as crowdshippers, the percentage decreases with the increase of the delivery box dimensions and with the decrease of the remuneration. As it is for the demand side, 93% would accept to receive goods via a crowdshipping service. However, the percentage drastically falls if: i) the customers cannot contact the crowdshipping company, ii) there is no direct contact with the crowdshipper or no package tracking is possible/available. The investigation also discovered that the maximum possible deviation from the usual path followed ranges from 1.5 km, in case the crowdshipper is using a non-motorized mode of transport, to 3.1 km for private transport.

Punel and Stathopoulos [42], using stated choice experiments, investigate the factors influencing the acceptability and preferences for crowdshipping. They provide some insights into the attributes affecting preferences for goods delivery performed via occasional drivers. The paper investigates delivery scenarios performed by non-professional shippers, compares them to traditional shipping options and evaluates them assuming a service user's point of view (i.e. demand side). In a recent study Punel et al. [41] analyze how and to what extent attitudes, preferences, and characteristics of crowdshipping users differ from non-users. The main results show that crowdshipping is more prevalent among young people, men, and full-time employed individuals and that urban areas are preferential for the development of crowdshipping service. The green attitude is also relevant in the choice process, in fact, the individuals who have a strong sense of community and environmental concern are more likely to use crowdshipping services.

Buldeo Rai et al. [10] systematically analyze a set of 42 papers and interview 11 logistics practitioners in order to reconstruct the state of practice of crowdshipping. The study suggests that three characteristics substantially affect the sustainability of such an initiative: third-party involvement (i.e. the involvement of professional third parties in case of insufficient or underperforming crowd), crowd motivation (i.e. financial stimulus or sustainability and community matters) and its modal choice. Specifically, the modal choice is important from an environmental perspective, especially when favoring soft modes, public transportation, and clean vehicles.

The present paper innovates with respect to the literature since it jointly investigates crowdshipping demand and supply, focusing on people preferences, while also considering a "green" service based on the use of public transportation.

3 Methodology

The paper uses stated preference (SP) exercises to identify the most important features associated with the choice of acting as a crowdshipper (i.e. service supply side) and with the willingness to use the crowdshipping service (i.e. service demand side). The study investigates agent's behavior using discrete choice models.

The SP scenarios are tailored to the city of Rome, used as a case study, and its metro network for B2C deliveries. The paper studies a hypothetical scenario where small packages can be picked-up/dropped-off in Automated Parcel Lockers (APLs) located either inside metro stations or in their surroundings.

The following section describes the data acquired via the survey.

3.1 Survey and data description

The administration of two specific surveys during October 2017 – one to 240 inhabitants of the city of Rome (demand-side survey) and the other one to 240 of its metro users (supply-side survey) – produced the data used in this study (for more detail, see also [45]). A convenient sampling strategy was adopted and approximately two-thirds of the interviews were performed via social media and e-mail, while one third "face-to-face".[1]

Four sections compose the questionnaire:

1. *Socio-demographic*: collects gender, age, level of education, employment and behavioral variables useful to detect a green attitude (GA).
2. *Travel reconstruction*: investigates the characteristics of the main home-based trip. Origin/destination points and travel times are common information collected in both the surveys. The supply-side survey collects data about the metro stations used, access/egress mode to/from metro stations, as well as public transport subscription.

3. *Hypothetical crowdshipping configurations evaluated through stated preferences scenarios*:

- The supply-side survey investigates the role APLs location, remuneration, delivery booking, and alternative bank crediting modes (Table 1) play in stimulating people to act as crowdshippers. Remuneration was set considering current shipping costs in the B2C market and the rates applied by existing national crowdshipping companies; the "delivery booking" feature is representative of the high or low crowdshipper's flexibility to react to an online delivery request.
- The demand-side survey explores the role of service time and cost, parcel tracking availability, delivery schedule date/time flexibility (Table 1) in stimulating potential e-commerce users to choose a crowdshipping service for delivering the goods they bought. Shipping fees and time refer to current national shipping companies operating in Italy.

4. *Additional behavioral statements*: this section aims at discovering further service characteristics/perceptions as well as specific issues (e.g. willingness to deviate from the usual path) for the potential crowdshipper (leave the usual metro stations or moving outside them), or the most preferred time slot to pick-up the parcel for the potential crowdshipping buyer.

Following Gatta and Marcucci [15], who suggest using advanced experimental design techniques when performing SP exercises in the urban freight transport field, we use a Bayesian D-Optimality efficient design to define the choice tasks in both surveys. The results of a pilot survey (i.e. utility-neutral design, see [51]) were used as an input to develop the final choice tasks. D-optimality aims at minimizing the determinant of the covariance matrix of the model coefficients and maximize the expected value of the chosen alternatives [21].

The optimal design produced four different questionnaire blocks in both surveys, each including three choice's exercises with three alternatives: two unlabeled linked to a crowdshipping service (i.e. option A and B) and a "no choice" option. The "no choice" alternative represents the *status quo* implying not using the crowdshipping service (for the demand-side) or acting as a crowdshipper (for the supply-side). Notwithstanding the use of the "no choice" option could also lead to a serious reduction in the information gathered [12], we prefer to include it so to increase both the realism of choice tasks and the robustness of respondents' estimated preferences [3]. However, less than 10% of the sample selected the "no choice" option in both surveys.

Table 2 reports a summary of respondents' socio-demographic characteristics. Although the sample does not perfectly reflect census data distribution for the entire population of Rome, the high number of young respondents moving for study/work represents an added value given the specific purpose of the study. In fact, young people are typically keener to use crowdshipping platforms (Briffaz and Darvey, [8]). Indeed, some studies suggest that web surveys have high rates of technologically advanced respondents [22].

The supply-side respondents state that the home-based trips involving the use of the metro are mainly taking place in the morning peak (79%). A similar frequency for the work-to-home trips in the afternoon (84%) is linked to the survey taking place during regular weekdays. Access/egress to/from metro stations usually takes place by walking (52.9%) and 50 min is the average travel time associated to the entire origin-destination trip. Interestingly, 75% of the demand-side respondents pass close to, at least, one metro station during his/her home-based trip.

Table 1 Description of features and levels for the SP scenarios

Demand-side survey		Supply-side survey	
Features	Levels	Features	Levels
Shipping fee (with respect to current national shipping companies)	• Lower (+ 1)	Location of APL	• Inside metro stations (+ 1)
	• Typical (− 1)		• Outside metro stations/adjacent buildings (− 1)
Shipping time (with respect to current national shipping companies)	• Lower (+ 1)	Remuneration	• 3 €/delivery (+ 1)
	• Typical (− 1)		• 1 €/delivery (− 1)
Parcel tracking	• Available (+ 1)	Delivery booking	• Real-time booking (+ 1)
	• Not available (−1)		• Off-line booking (− 1)
Delivery date and Time schedule flexibility	• Yes (+ 1)	Bank crediting modes	• Single delivery (+ 1)
	• No (−1)		• Every 5 deliveries (− 1)

Table 2 Socio-demographic characteristics of the sample

	Demand-side survey		Supply-side survey		*Entire Pop [%]*
	Sample size	*Sample [%]*	*Sample size*	*Sample [%]*	
Gender[a]					
Man	112	48.9	105	46.7	46.7
Woman	117	51.1	120	53.3	53.3
Age[a]					
16–30	102	44.5	95	42.2	16.5
31–44	49	21.4	67	29.8	23.0
45–58	50	21.8	40	17.8	26.5
> 58	28	12.2	23	10.2	34.0
Level of education[b]					
Primary school diploma	4	1.7	2	0.9	16.9
Middle School diploma	15	6.6	12	5.3	28.0
High school diploma	113	49.3	146	64.9	36.5
University degree (any level)	82	35.8	55	24.4	15.1
Post university degree	15	6.6	10	4.4	3.6
Professional status[b]					
Employed	88	38.4	104	46.2	47.9
Student	66	28.8	70	31.1	7.7
Retired	14	6.1	12	5.3	22.4
Working student	14	6.1	5	2.2	–
Housewife (no male)	24	10.5	21	9.3	10.5
jobless	23	10.0	13	5.8	11.5
Income					
< 5.000 €	66	32.7	73	35.3	
€ 5000 - € 10,000	36	17.8	27	13.0	
€ 10,000 - € 20,000	53	26.2	66	31.9	
€ 20,000 - € 30,000	29	14.4	28	13.5	
€ 30,000 - € 40,000	11	5.4	11	5.3	
€ 50,000 - € 80,000	6	3.0	1	0.5	
> 80.000 €	1	0.5	1	0.5	

[a]Resident population 1st January 2017, age group 16–99 (ISTAT data – http://demo.istat.it/)
[b]2011 Census, age group 16–99 (ISTAT data - http://datiopen.istat.it/)

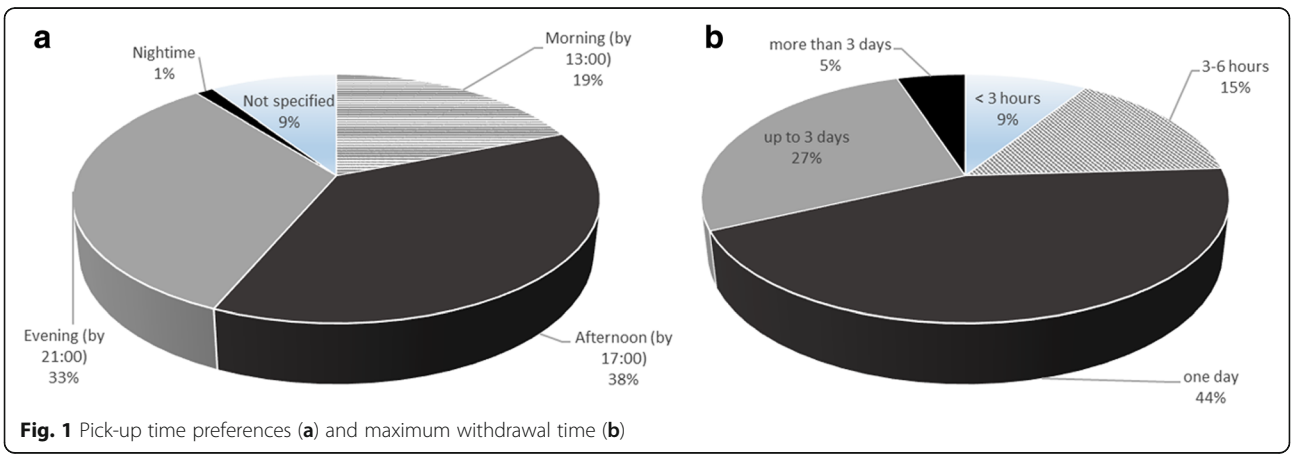

Fig. 1 Pick-up time preferences (**a**) and maximum withdrawal time (**b**)

Most of the potential users of the crowdshipping service (Fig. 1) declared to prefer to pick-up the parcel during the afternoon (38%) or evening (33%) and to have the withdrawal option available at least for 24 h (44%). Only 9% of the respondents declared to prefer having a short withdrawal time (less than 3 h), mainly for safety reasons.

With respect to the maximum deviation from the usual path, it is interesting to note that about half of the potential crowdshippers (43.1%) is not willing to modify the path if the APL is outside the metro stations while 39.2% would accept to deviate the path for a maximum of 300 m. Only 15.3% is willing to travel an additional distance of 600 m, while the percentage of those willing to travel more than 600 m is negligible.

The measure of GA relies on four qualitative levels (no GA, low, medium, high), eliciting a self-stated weight of individual-specific pro-environmental behavioral attitudes. These attitudes are considered a proxy for the interest in/concern about environmental problems. This, in fact, should also correlate to the adoption of sustainable transport modes or the consumption of organic products. Each attitude has been assessed through a Likert scale during the survey: 68% of the respondents self-stated a medium level of green attitude (Fig. 2, a).

Finally, respondents were asked to express a judgment on the chances of success of the crowdshipping service both in urban and suburban areas, under the hypothesis of expanding it using APLs located in the main metro and urban rail network city stations. In the urban case, a substantial part of the sample (46%) foresees a successful service while 41% are not sure. As for the suburban area, the percentage of respondents confident in the success of the service decreases to 25% (Fig. 2, b).

4 Results and discussion

4.1 Econometric results

Two multinomial logit models were used to estimate the willingness to adopt the crowdshipping service (1) and to act as a crowdshipper (2), where maximum likelihood is the standard estimation process [19].

The final utility specifications are reported below where the two unlabeled options are defined on the basis of the four attributes and the "no choice" option depends on the alternative-specific constant (ASC) and the variable "Age". In fact, out of the socio-demographic and attitudinal variables, only age, treated as continuous, was statistically significant.

MNL1 demand-side model:

$$\begin{aligned} V_A &= \beta_1 * \text{Shipping Fees}_A + \beta_2 * \text{Shipping Times}_A \\ &+\beta_3 * \text{Parcel Tracking}_A + \beta_4 * \text{Delivery Planning}_A V_B \\ &= \beta_1 * \text{Shipping Fees}_B + \beta_2 * \text{Shipping Times}_B \\ &+\beta_3 * \text{Parcel Tracking}_B + \beta_4 * \text{Delivery Planning}_B V_{\text{no choice}} \\ &= \beta_5{}^* \text{Age} \quad + \text{ASC} \end{aligned} \tag{1}$$

MNL2 supply-side model:

$$\begin{aligned} V_A &= \beta_1 * \text{Location of APL}_A + \beta_2 * \text{Remuneration}_A \\ &+\beta_3 * \text{Delivery booking}_A + \beta_4 * \text{Bank Credit Mode}_A V_B \\ &= \beta_1 * \text{Location of APL}_B + \beta_2 * \text{Remuneration}_B \\ &+\beta_3 * \text{Delivery booking}_B + \beta_4 * \text{Bank Credit Mode}_B V_{\text{no choice}} \\ &= \beta_5{}^* \text{Age} \quad + \text{ASC} \end{aligned} \tag{2}$$

Tables 3 and 4 report the results of the two models estimated with Biogeme [7]. Both models fit well the data (Rho-square around 0.3). Moreover, the sample

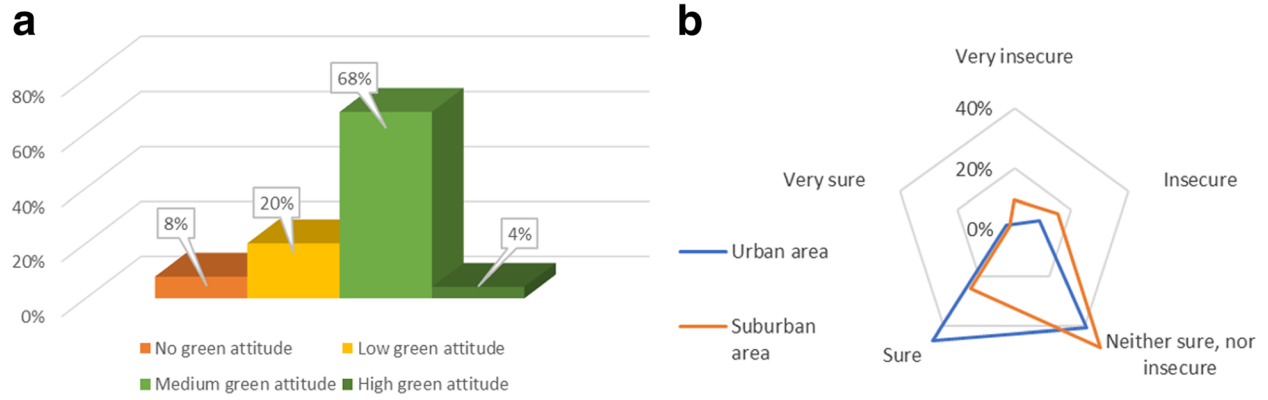

Fig. 2 Green Attitude levels (**a**) and level of trust on the success of the service (**b**)

Table 3 MNL1, demand-side model: parameter estimates, fit statistics and validation

	MNL			
	Coeff. (β)	Stand. Error	T-test	*P*-value
Attributes				
Age	0.0905	0.0118	7.65	0.00
Shipping fees* [a]				
Lower	0.6750	0.0998	6.76	0.00
Shipping time** [a]				
Lower	0.5870	0.0882	6.65	0.00
Parcel tracking***				
Present	0.6980	0.0946	7.38	0.00
Delivery date and Time schedule flexibility ****				
Yes	0.7860	0.0886	8.87	0.00
"no choice" [ASC]	−5.2300	0.5880	−8.90	0.00
Model Fit Statistics				
N. of observations (individuals)	618 (206)			
Null log-likelihood	− 678.942			
Final log-likelihood	− 469.842			
Likelihood ratio test	418.201			
Rho-square	0.308			
Adjusted rho-square	0.299			
Simulation test				
Sample reconstitution	59.9%			

*base level: "Typical"; **base level: "Typical"; ***base level: "Not available"; ****base level: "No"
[a] with respect to current national shipping companies

reconstitution, i.e. the number of times the model is able to reproduce the right choice of the users, is equal to approximately 60% for the demand-side model and 62% for the supply-side one.

All the coefficients have the expected signs and are statistically significant. Age coefficient is positive showing that older people are less interested in working as crowdshippers or in using a crowdshipping service. Moreover, the negative sign of the ASCs implies, ceteris paribus, a positive attitude towards crowdshipping. Since attributes are qualitative and expressed in effects coding (see Table 1), one can compare the magnitude of the various coefficients. As it is for MNL1, the possibility to plan the delivery date and its time schedule is the most relevant feature, while having a lower shipping time with respect to the current situation has the lowest impact on utility. This reflects the fact that the actual delivery system is, in general, efficient in terms of shipping time (e.g. same-day delivery) while time windows are usually large, and people have to wait at home their goods, producing either dissatisfaction or missing deliveries. Looking at MNL2, one can note that APLs location is the most impacting attribute while delivery booking the least. Having APLs inside the metro stations instead of outside is more important than the remuneration (considering the range used in the survey: 1–3€/delivery). Real-time booking is preferred over the off-line, but this characteristic is less required than the others testifying that people need to organize themselves to produce the crowdshipping service using public transport.

Naïve preference heterogeneity investigations, focusing on sub-samples,[2] did not produce robust results due to the small number of respondents. However, this issue should be further investigated through more advanced models, such as latent class [27]. Furthermore, some of the attributes can be quantitatively treated (e.g. remuneration) so to calculate robust willingness to pay/accept measures that might be useful to characterize this innovative delivery service [18].

4.2 Policy implications

The paper estimates the probability of acting as a crowdshipper as well as of adopting the crowdshipping service depending on different service configurations. All possible attribute levels combinations are investigated, for

Table 4 MNL2, supply-side model: parameter estimates, fit statistics and validation

	MNL			
	Coeff. (β)	Stand. Error	T-test	*P*-value
Attributes				
Age	0.0473	0.0111	4.25	0.00
Location of APL[a]				
Inside metro stations	0.5940	0.0706	8.42	0.00
Remuneration[b]				
3 €/delivery	0.4890	0.061	8.02	0.00
Delivery booking[c]				
Real-time booking	0.3350	0.0683	4.90	0.00
Bank credit mode[d]				
Single delivery	0.5330	0.0698	7.64	0.00
"no choice" [ASC]	−3.390	0.483	−7.03	0.00
Model Fit Statistics				
N. of observations (individuals)	627 (209)			
Null log-likelihood	− 688.83			
Final log-likelihood	−489.293			
Likelihood ratio test	399.074			
Rho-square	0.290			
Adjusted rho-square	0.281			
Simulation test				
Sample reconstitution	62%			

[a]base level: "Outside metro stations/adjacent buildings"; [b]base level: "1 €/delivery"; [c]base level: "Off-line booking"; [d]base level: "Every 5 deliveries"

both demand and supply, assuming three types of users characterized by different ages:

- Profile 1: average population in Rome with an average age of 50 (Pop. Roma);
- Profile 2: young population with an average age of 25 (Young people);
- Profile 3: elderly population with an average age of 65 (Old people).

Figure 3 and Fig. 4 show, respectively, that the probability of both acting as a crowdshipper and adopting the crowdshipping service can range from very low to very high values. Most important changes are attributable to the proposed service conditions (level of service). It is also interesting to observe a substantial variability linked to age, especially for the potential consumer's case. In what follows, we focus on profile 1, representing the average age of the population in Rome (excluding people younger than 16 years old). This is in line with the average age of e-consumers in Italy, where a higher propensity in the e-commerce is detected in the ranges 35–44 and 45–54 years old, especially for intensive e-buyers [20].

Crowdshipping initiatives in Rome are still few and mostly linked to the food sector by dedicated trips. Analyzing the existing crowdshipping companies and other national/international experiences, one discovers that: i) all the operating platforms actually require an off-line booking of the service; ii) parcel tracking is usually available and iii) a remuneration is provided for each individual delivery. By fixing these features of the service, while assuming delivery times similar to those offered by traditional operators, one can simulate several scenarios for both the demand- and the supply-side, as reported in Table 5.

The paper provides a preliminary estimate of the number of orders performed per day by a crowdshipping service using the metro in Rome based on the following assumptions: i) the potential crowdshipping demand is mainly generated by the same users of the metro network, as well as by inhabitants located in the surrounding area of the metro stations (the latter computed adopting a catchment area of 800 m radius for each stop and reducing the number by the modal share of the metro service in Rome, Table 6); ii) the e-shopping rate for B2C delivery of small packages, not directly available in the literature, has been computed according to (3); iii) the simulated probabilities of Table 6 are adopted as derived by the estimated discrete choice models.

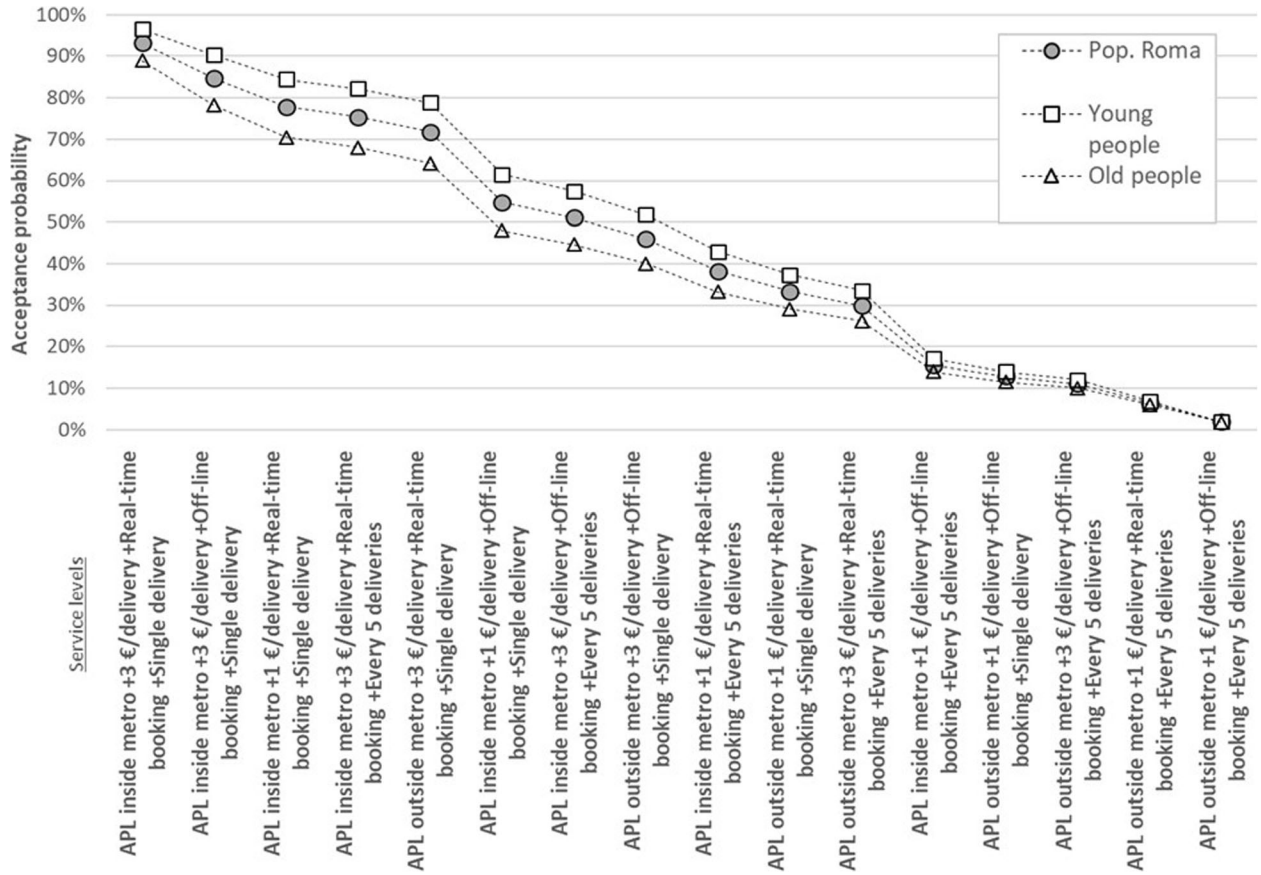

Fig. 3 Probability of acting as a crowdshipper with respect to the characteristics of the service (level of service) and the characteristics of the potential crowdshipper (Age)

$$E\text{–}shopping\ rate\left[\frac{orders}{day\ inhab}\right] = \frac{\left(Web\ Shopper[\%] * Physical\ shipment[\%] * E\text{–}commerce\ frequency\left[\frac{orders}{year\ inhab}\right]\right)}{250} \quad (3)$$

where:

- Web Shopper is the percentage of the population making at least one online purchase;
- Physical shipment is the percentage of orders requiring a physical shipment;
- E-commerce frequency is the annual average frequency of online purchase;
- 250 is the number of days in one year, excluding weekend days and public holidays.

Information required in (3) was derived by elaboration of data from different sources [5, 36, 37], finally obtaining an e-shopping rate of 0.0262 orders/day per inhabitant.

At the same time, it is possible to estimate the number of potential crowdshippers per day as a function of the probabilities simulated for the supply-side in the different scenarios and the commuters using the metro lines in Rome (Table 6). Since the frequency of acting as a crowdshipper is not investigated by the SP, we have assumed[3] a frequency of two times for each week in order to quantify the number of available crowdshippers per day.

One observes by comparing demand with available supply in different service scenarios that in the status quo that only in one case (i.e. low remuneration for crowdshippers and location of APL outside the metro stations - Supply Scenarios, Scenario 4, Table 6), the demand can be higher than the available supply (about 5′800 crowdshippers per day versus up to 14′100 orders/day).

Table 7 reports the supply and demand comparison results in a 2025-time horizon that accounts both for the

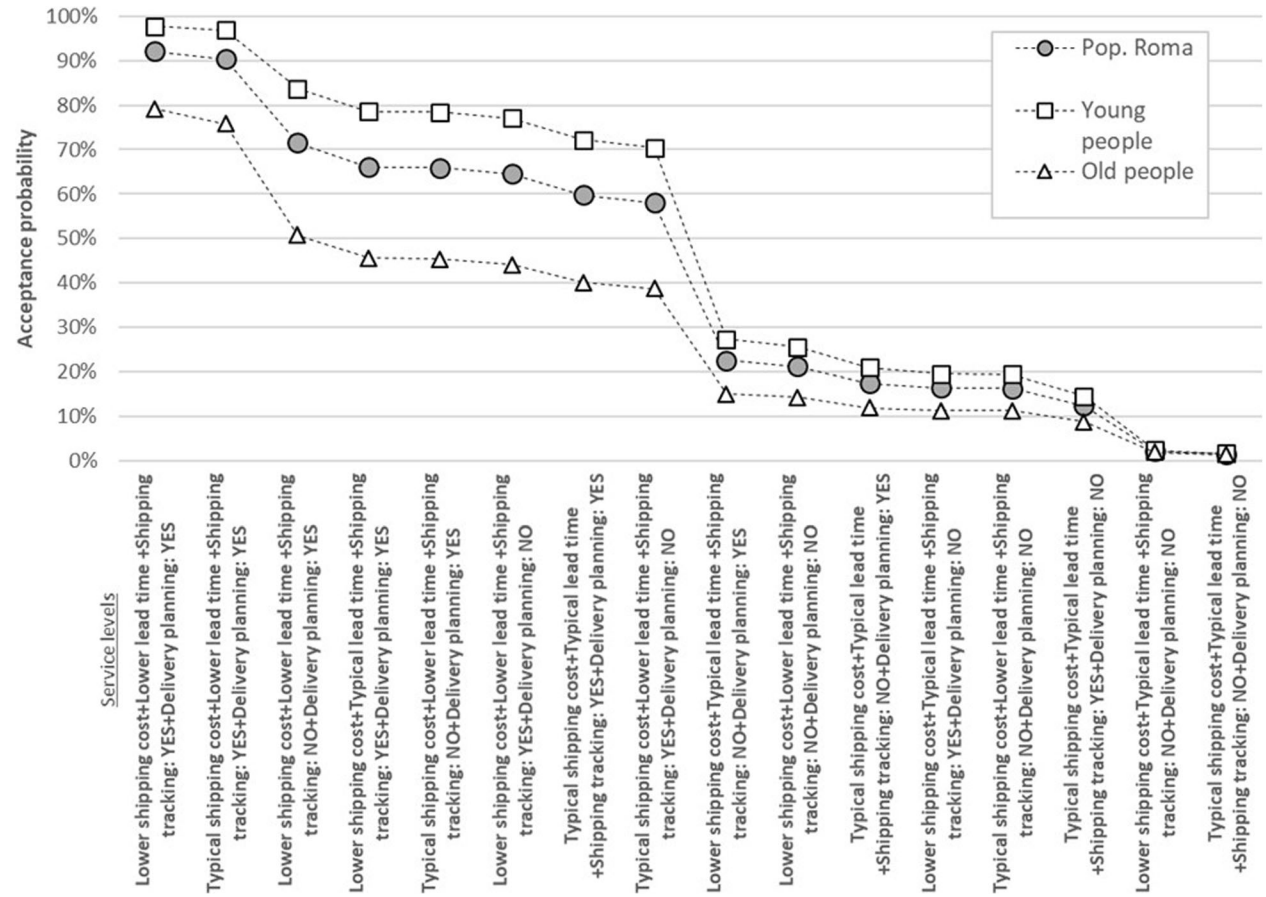

Fig. 4 Probability of adopting the crowd-shipping with respect to the characteristics of the service (level of service) and the characteristics of the potential user (Age)

Table 5 Possible scenarios for supply and demand with respect to the actual crowdshipping platform conditions

	Scenario 1	*Scenario 2*	*Scenario 3*	*Scenario 4*
Demand-side simulation				
Shipping fees (with respect to current national shipping companies)	Lower	Typical	Lower	Typical
Shipping times (with respect to current national shipping companies)	Typical	Typical	Typical	Typical
Parcel tracking	Available	Available	Available	Available
Delivery date and Time schedule flexibility	Yes	Yes	No	No
Probability of adopting a crowdshipping service	*66.1%*	*59.7%*	*16.4%*	*12.4%*
Supply-side simulation				
Location of APL	Inside metro stations	Inside metro stations	Outside metro stations/adjacent buildings	Outside metro stations/adjacent buildings
Remuneration	3 €/delivery	1 €/delivery	3 €/delivery	1 €/delivery
Delivery booking	Off-line booking	Off-line booking	Off-line booking	Off-line booking
Bank crediting modes	Single delivery	Single delivery	Single delivery	Single delivery
Probability to act as a crowdshipper	*84.6%*	*54.8%*	*46.0%*	*12.8%*

Table 6 Estimation of potential demand for crowdshipping by public transport and potential crowdshippers in Rome (current state)

Demand SCENARIOS	Metro users[a] [users/peak hour]	Inhabitants[b]	Probability to adopt crowdshipping service	Potential demand [orders/day]
SCENARIO 1	113′347	647′154	66.10%	14′100
SCENARIO 2			59.70%	12′730
SCENARIO 3			16.40%	3′500
SCENARIO 4			12.40%	2′640
Supply SCENARIOS	Metro users[a] [users/peak hour]		Probability to act as a crowdshippers	Potential crowdshippers [crowdshippers/day]
SCENARIO 1	113′347		84.6%	38′350
SCENARIO 2			54.8%	24′840
SCENARIO 3			46.0%	20′850
SCENARIO 4			12.8%	5′800

[a]Users of the Rome's metro lines during the peak hour (Roma Mobilità, [47])
[b]Inhabitants in the 800'meters catchment area (elaboration from census data ISTAT 2011, https://www.istat.it/it/archivio/104317)

forecasted metro network developments in the city (Fig. 5, b) and the likely e-commerce evolution with an e-shopping rate of up to 12.4 orders/year per inhabitants (Fig. 6).

The number of potential crowdshippers follows the evolution of the metro network. Since the increment of metro users is quite limited, in the worst case (Supply scenarios, scenario 4, Table 7) we obtain 7′090 potential crowdshippers/day with an increment of 22% with respect to the present. Instead, the potential demand might double, possibly rising to more than 29′000 orders/day (Demand scenarios, scenario 1, Table 7). Only moving to supply-side scenario 3 one finds that the number of potential crowdshippers does not satisfy the maximum potential demand. However, this figure might vary by considering the possible lifestyle changes due to either environmental policy interventions [49] or incentives such as gamification [29] and parking cash-out [13]. These results underline a potential market for the new service and the importance of paying attention to service design especially with respect to the supply side. Improving public transport network reliability, as planned by the city of Rome to improve citizens' acceptability of a new road pricing scheme [34], would also increase the feasibility of this type of crowdshipping. Service quality in local public transport and its proper evaluation is fundamental for a modal shift (e.g. Felici and Gatta, [14,38, 39]). In addition, the investigated solution can be fruitfully combined with an innovative off-hour delivery scheme that has been recently proposed in Rome [28].

There are several obstacles hindering the development of crowdshipping systems: the legal issue related to workers is one of the most relevant. It is worth noting that remuneration can play a fundamental role. In fact, a very low compensation (even not monetary, such as a public transport ticket), as in the green crowdshipping system investigated, can push people to provide the delivery service without "being workers". Moreover, since e-commerce is increasing

Table 7 Estimation of potential demand for crowdshipping by public transport and potential crowdshippers in Rome (year 2025)

Demand SCENARIOS	Metro users[a] [users/peak hour]	Inhabitants[b]	Probability to adoptcrowdshipping service	Potential demand [orders/day]
SCENARIO 1	138′421	709′579	66.10%	29′540
SCENARIO 2			59.70%	26′680
SCENARIO 3			16.40%	7′330
SCENARIO 4			12.40%	5′540
Supply SCENARIOS	Metro users[a] [users/peak hour]		Probability to actas a crowdshippers	Potential crowdshippers[crowdshippers/day]
SCENARIO 1	138′421		84.6%	46′840
SCENARIO 2			54.8%	30′340
SCENARIO 3			46.0%	25′470
SCENARIO 4			12.8%	7′090

[a]Users of the Rome's metro lines during the peak hour (Roma Mobilità, [47])
[b]Inhabitants in the 800'meters catchment area (elaboration from census data ISTAT 2011, https://www.istat.it/it/archivio/104317)

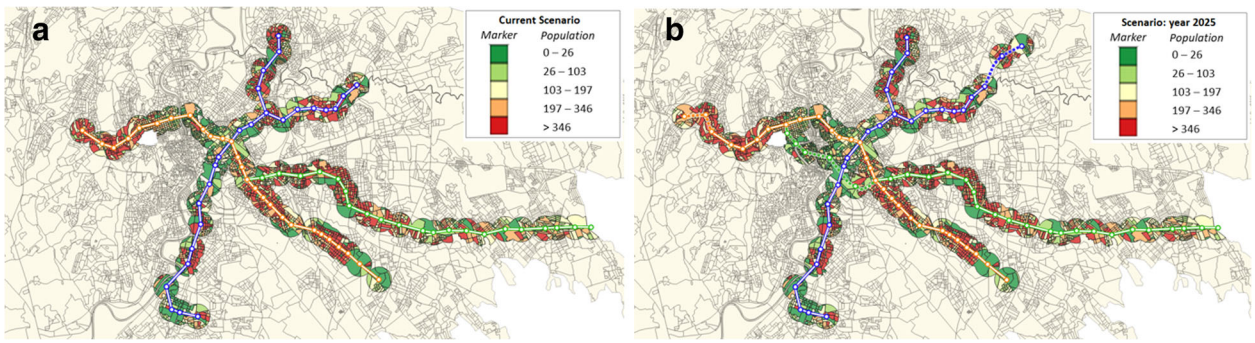

Fig. 5 Metro lines in Rome for the current scenario (**a**) and the future scenario (**b**) with their respective catchment area

and crowdshipping is not intended to replace traditional logistics providers (rather, it is a complementary system), potential social implications on wages and labor force employed are less critical.

5 Summary and conclusions

Crowdshipping provides a good delivery service in the last mile. It is particularly suitable for e-commerce and it is progressively developed and adopted worldwide. Crowdshipping is both innovative and with a great growth potential, both economic and environmental. Its success much depends on organizational and performance issues. Standard crowdshipping, using dedicated motorized trips, might squander most of the potential economic/environmental benefits, also considering the strong rebound effects that might arise from the success of the initiative.

The paper proposes two SP surveys, in the city of Rome, and studies "green" crowdshipping potential demand and supply. In particular, it explores under which conditions commuters, moving from home to work and vice-versa, would possibly act as crowdshippers, investigating specific population segments that are using the metro for their systematic trips. The underlying belief is that the most efficient crowdshipping service is the one based on non-dedicated trips.

Model results show that APLs location is the most relevant feature even more important than remuneration. Additionally, the paper analyses the demand side by investigating how potential e-commerce users can be stimulated in choosing a crowdshipping service for delivering the goods they bought. Results show that the possibility to plan the delivery date and its time schedule has the highest impact on consumers' utility.

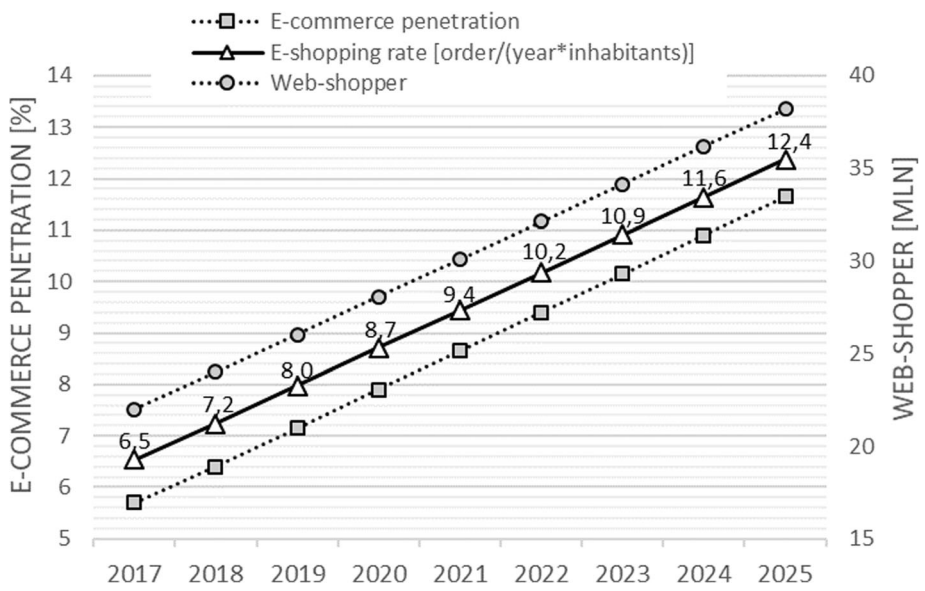

Fig. 6 Trend of e-shopping rate based on e-commerce penetration rate and web shoppers increase up to 2025(Elaboration of the authors based on historical data)

Moreover, comparing demand and supply results, a scenario analysis is performed given different service configurations. Preliminary results are comforting since the estimated number of potential crowdshippers in Rome is higher than those that would satisfy the potential demand.

The main strength is the identification of the most important instruments needed to develop a crowdshipping service capable of relying on a sufficiently large base of crowdshippers so to provide a reliable and low-cost solution for last-mile deliveries. The results will be made available to Rome Mobility Agency who is interested in this topic and willing to explore/test alternative service configurations in a real-life pilot study should financial resources be procured.

The likely increase of small-volume/ low-weight/ parcel market in the near future, due to the diffusion of e-commerce, and the recent opening of the C-metro line in Rome suggest investigating this crowdshipping configuration further.

Future research will focus on: i) increasing the sample size, ii) acquiring additional preference information (e.g. frequency with which agents are available to work as crowdshippers, freight type impact on agents' choice, etc.), iii) adopting more advanced estimation models (e.g. latent classes) and calculating willingness to pay/ accept measures to possibly develop a pre-business pilot study; iv) quantifying the environmental effects obtainable from the development of crowdshipping services based on public transport use (e.g. environmental pollutants, noise abatement), v) testing financial viability, vi) linking regular logistics chains with the crowdshipping service envisioned, vii) defining necessary pre-requisites for crowdshipping service integration, viii) evaluating the potential effects of associating green-label recognition to public transport crowdshipping, ix) designing logistics networks to optimize network structure and nodes location, x) investigating further social implications on wages and labor force employed in the logistics sector.

6 Endnotes

[1]The effect of the media used to collect the data is not tested since the face-to-face sample is too small. However, no substantial differences emerged considering the two survey administration types. As an example, notwithstanding face-to-face respondents are less technologically advanced, the percentage of people who did not select the crowdshipping service in any of the proposed configurations was just slightly lower than the percentage obtained by on-line interviews.

[2]Respondents were classified according to a qualitative data analysis exploring what attributes they have focused on during choice tasks.

[3]This assumption was made after discussions with some crowdshipping companies.

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