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Lessons learned from the ex-post evaluation of light rail users in an Italian city

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Abstract
In the last decade, Italian municipalities implemented urban light rail lines, yet forecasting passenger numbers often overlooks heterogeneity in individuals' characteristics and travel habits. For this reason, in the current paper, we investigate which factors influence the frequency of using a new light rail service. The data employed for the study come from a survey conducted in the city of Cagliari (Italy) among a sample of light rail users who started to use this means of transport after its introduction. The analysis reveals a preference for light rail due to factors like travel time and traffic stress over cost considerations. The construction of an ordered probit model highlights the significance of performance characteristics, prior modal choices, and socio-demographic variables in determining light rail usage frequency. The paper concludes with actionable recommendations: acknowledging individual heterogeneity in promoting light rail use, envisioning scenarios beyond infrastructure, and emphasizing monitoring to assess the new line's impact and formulate effective behavioural measures.

Keywords: light rail, public transport, discrete choice model, past behaviour, travel behaviour change

1. Introduction

The development of light rail (LR) lines in urban environments is one of the most popular transport policies implemented to reduce the use of private cars (Petkov, 2020; Fageda, 2021). LR projects are capable of improving the quality of existing public transport systems, promoting urban development, and supporting city strategies for sustainable economic growth (Ferbrache and Knowles, 2017; Olsen, 2020). Following the example of European cities, over the last decade, Italian central and local governments have started funding the planning and construction of new LR lines. *Cura del ferro* (iron treatment) has become a popular expression among transport planners in Italy, referring to the strategy of encouraging urban rail transport to alleviate congestion and reduce greenhouse gas concentrations in the atmosphere.

However, the planning of LR networks in Italian cities, in most cases, does not encompass a deeply analysis of the potential characteristics of the system's users, despite the high level of heterogeneity of individuals targeted by the intervention and their

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decision-making processes. Indeed, prior research (Quin *et al.*, 2016; Fowri and Seyedabrishami, 2020) has shown that differences among urban travellers in the influence of level of service variables (such as time, cost, transfer, comfort), as well as other factors, such as socio-demographic characteristics, personal traits, attitudes, and perceptions, are commonly observed.

The other aspect often not taken into consideration concerns individuals' past behaviour. Usually, people tend to stick to their travel habits unless internal or external factors come into play and push them to reconsider their mode of transport (Eriksson *et al.*, 2008). Hence, it is possible that individuals who already adopt a sustainable travel behaviour are more willing to use a new LR service, leading to a transfer from the bus system to the LR system (Termida *et al.*, 2016; Piras *et al.*, 2018). Regarding car drivers, their lack of trust in the quality of public transit services may make them less interested in switching from the private vehicle to the light rail (Piras *et al.*, 2022), even though the new means of transport offers a higher level of comfort than the bus and is faster than using a car.

Given the above considerations, there is a need to better understand the different profiles of people who changed their travel behaviour following the introduction of a new LR line in Italy. Compared to the bus system, LR transit is more expensive and difficult to modify (Sun *et al.*, 2020). Thus, the analysis of current and potential users of the service should be conducted extensively. This knowledge can provide useful insights for planning and designing various elements of a light rail network, such as the location of stops, stop quality, service frequency, and possibilities for interchanging with other means of transport, ultimately leading to increased operating efficiency and service quality. Additionally, understanding the individual factors that lead to the use of LR would help implement supportive strategies for promoting this new travel alternative.

Therefore, the current research aims to unveil the factors that may influence the choice to use a new light rail service in the Italian context. Specifically, we intend to explore the individual and trip characteristics, as well as the motivations, of people who started using this travel alternative after its introduction and use this knowledge to formulate policy implications. To achieve this objective, we conduct an in-depth descriptive analysis and construct an ordered probit model that simulates the probability of using the new light rail line with a certain frequency. The data used in this study were drawn from a survey conducted by the authors in the metropolitan area of Cagliari, a mid-sized city in Italy, two years after the implementation of the new light rail line.

The remainder of the paper is organized as follows: in Section 2, we provide a brief overview of past research investigating the use of light rail. Section 3 is concerned with the methodology of the study. In Section 4, we report the results of descriptive statistics and present the findings of the model specification and estimation process. In Section 5, we discuss the policy implications of the current study and the lesson learned from the ex-post evaluation of light rail users. In the last section we draw some final remarks and conclusions.

2. Literature review

Most of the existing research on the impacts of the implementation of a light rail/tram line in an urban environment consists of aggregate studies that focus on the new modal share or the increase in transit usage after the introduction of the new means of transport. Some studies have reported a general increase in transit usage (Dueker and Bianco, 1999; Senior, 2009; Piras *et al.*, 2018; Brands *et al.*, 2020). Others have found a lower level of car ownership and use (Bhattacharjee *et al.*, 2012; Huang *et al.*, 2017) and a reduction in greenhouse gas emissions (Boarnet *et al.*, 2016; Fageda, 2021). A couple of works have pointed out that there could be differences between the short-term and long-term effects of LR, with impacts changing depending on the context of the analysis. While Dueker and Bianco (1999) detected a reduction of transit share and LR use in the long-term period, Senior (2009) observed that the more frequent use of transit remained stable over time, though only for work journeys.

Alongside aggregate studies, different works have attempted to identify which factors, from a disaggregate standpoint, can influence the choice of using light rail over other travel alternatives. Most of the prior research suggests that travel costs and in-vehicle travel times are among the most important factors that convince people to use light rail (Cherchi and Ortúzar, 2002; Creemers *et al.*, 2012; Termida *et al.*, 2016; González *et al.*, 2017; Sottile *et al.*, 2019). Moreover, several studies indicate that, beyond travel time and costs, individual and household characteristics also influence the decision to use light rail. It has been shown that car ownership negatively influences the propensity to use light rail (Senior, 2009; Creemers *et al.*, 2012; Sottile *et al.*, 2019; Piras *et al.*, 2022). Concerning age, some authors found that younger individuals are more likely to start using a new light rail service (Creemers *et al.*, 2012; Termida *et al*., 2016), while others did not detect a significant importance for this variable (Senior, 2009; Sottile *et al.*, 2019; Piras *et al.*, 2022). Similarly, it seems that there is no significant difference between males and females in terms of light rail usage (Senior, 2009; Creemers *et al.*, 2012; Termida *et al.*, 2016; Piras *et al.*, 2022).

One of the variables that strongly influence the use of a new LR system is past behaviour. At an aggregate level, several studies have observed that the share of LR users who were former bus and rail passengers ranges from 50% to 80% (Golias, 2002; Vuk, 2005; Lee and Senior, 2013; Piras *et al.*, 2018; Brands *et al.*, 2020). Interestingly, Senior (2009), in his case study, reported that many LR passengers used to travel by car, but they used the new service with less frequency compared to former bus users. Other works have tried to model the impact of past behaviour on the utility of using LR through the construction of discrete choice models, employing Stated Preference Data (Creemers *et al.*, 2012), panel data (Termida *et al.*, 2016), or both (González *et al.*, 2017). All of them found a lower propensity for car drivers to use the light rail.

In terms of methodology, some studies relied on descriptive statistics (Dueker and Bianco, 1999; Lee and Senior, 2013; Piras *et al.*, 2018; Sun *et al.*, 2020), while others explored the relationship between the use of LR and explanatory variables through discrete choice models. Most works used specifications based on logit formulations: MNL logit (Sottile *et al.*, 2019; Piras *et al.*, 2022), nested logit (Cherchi and Ortúzar, 2002), and mixed logit (Creemers *et al.*, 2012; Termida *et al.*, 2016; González *et al.*, 2017).

Nevertheless, the majority of the above papers analysed only the choice between using *vs.* not using the LR or the choice of using the LR over other means of transport, while only a small number of papers investigated the factors influencing the frequency of using the LR and the differences among current users of the service. Senior (2009), through the construction of an ordered regression, showed that a more frequent use of the LR depends on some individual and household characteristics (age, employment status, car availability). Termida *et al.* (2016) observed that certain categories of people (younger individuals, commuters, individuals with no children at home) are more likely to use a new tram extension as part of their regular mode choice than others.

Compared to previous literature, the contribution of the current article is twofold. First, unlike most prior research, we conduct an in-depth analysis solely focusing on those users who changed their means of transport after the introduction of an LR line in the urban context of the study. This approach allows us to understand which individual, trip, and Level of Service attributes impact the choice to use the new service more or less frequently. Second, while previous studies have investigated the role of different variables on the choice of using a new LR through discrete choice models, the majority of them only examined the direction and statistical significance of the variable, without commenting on its magnitude. In contrast, we compute pseudo-elasticity effects to understand the weight of explanatory variables, including past behaviour, which is an attribute often not considered in previous research. Third, from these two analyses, we derive lessons learned to inform policy-making on how to plan the implementation of a new LR service.

3. Methodology

3.1 Data collection

Cagliari's first light rail line, called MetroCagliari, opened in 2009. It connects the city centre of Cagliari, characterized by the presence of different services and commercial activities, to the municipality of Monserrato, situated in the suburbs. The line spans a length of 6.3 km and features seven stops and two terminals along its route. There are five park and ride sites along the MetroCagliari line, providing a total of 700 parking spots. During weekdays, the light rail service operates from 6:20 am, with the last trip departing at 10:20 pm. Trains mostly run at intervals of approximately 10 minutes. One of its terminals, 'Piazza Repubblica,' is situated in an area of the city characterized by a dense population of 56,000 residents and a high concentration of workplaces, with 21,000 workers located within a 500-meter radius. Car users in this area face significant time wasted on finding parking spots, up to 15 minutes, and expensive parking fees ranging from $1.00 to $1.20 per hour.

Our research group conducted a survey in 2011, titled "Who uses MetroCagliari?" with the aim of understanding who chose to use the light rail, their motivations for choosing this travel alternative, their socio-demographic characteristics, as well as their attitudes and perceptions toward the new means of transport. To gather data, we distributed postcards to LR users at the LR stops and on board, inviting them to visit the project's website and complete an online questionnaire. The questionnaire consisted of four different sections:

- trip description (origin, destination, departure time, mode used from the origin to the LR stop, mode used from the LR stop to the destination, ticket, main purpose of the trip, frequency of the trip);
- information on behavioural change (means of transport used before the light rail went into service, availability of different travel alternatives);
- socio-economic and family information (age, gender, education, occupation, income, household structure, car ownership, car characteristics, *etc.*);
- opinion about Metrocagliari and subjective factors that influenced the decision to use the light rail.

Concerning the description of the trip, we asked for the frequency of the use of the LR only for the purpose of the last trip the respondents made with the LR. Note that the frequency of using the light rail was assessed using the following scale: “1) rarely, 2) few times per year, 3) few times per month, 4) more than once a week, 5) daily”.

A total of 546 questionnaires were fully completed, representing 10% of the total daily LR users at the time of the survey. For the purpose of this paper, we considered only individuals who declared to use the light rail more than rarely, and we excluded high school and middle school students. The decision to exclude individuals who use the LR only occasionally was necessary because the number of individuals belonging to this category was quite small (30 individuals). Additionally, we chose not to include students who go to high school or middle school as their travel behaviour and characteristics differ significantly from the rest of the adult population. Consequently, the final sample used in the present study consists of 461 observations.

3.2 Model framework

The model reproducing the light rail use frequency has the form of an ordered probit model:

$$y_q^* = \boldsymbol{\beta}_{LOS}\boldsymbol{LOS}_q + \boldsymbol{\beta}_{SE}\boldsymbol{SE}_q + \sum_k \beta_{k,PB} PB_{k,q} + \xi_q\,,\;\; y_q = n \text{ if } \psi_{n-1} < y_q^* < \psi_n \quad (1)$$

where y_q^* is the latent propensity associated with the frequency of using the light rail of individual q. The latent propensity y_q^* is linked to the observed frequency of using the light rail y_q by the ψ thresholds ($\psi_0 = -\infty$ e $\psi_N = +\infty$). Four different categories of frequency - 1) a few times per year; 2) a few times per month; 3) more than once a week, 4) daily - were considered in the current study. $\boldsymbol{LOS}_q$ is a vector of Level of Service and trip characteristics variables, $\boldsymbol{SE}_q$ is a vector of socio-demographic variables, $PB_{k,q}$ is a lagged variable representing the effect of past travel behaviour on the choice to use the light rail with frequency n. ξ_q is normal distributed error term.

To interpret the estimated parameters of the ordered probit model and understand the magnitude of the effects of the exogenous factors on the LR usage frequency, we computed “pseudo-elasticity” effect for each variable. The pseudo-elasticity is calculated using the following formula:

$$\Delta P = (y = n|\boldsymbol{x}, \widetilde{\boldsymbol{x}}) = \sum_{q=1}^{Q} \frac{1}{Q} \left[P\left(y_q = n|\widetilde{\boldsymbol{x}}_q\right) - P\left(y_q = n|\boldsymbol{x}_q\right)\right] \quad (2)$$

where Q represents the number of individuals in the sample, $P\left(y_q = n|\boldsymbol{x}_q\right)$ is the choice probability of choosing the LR with a frequency equal to *k*. $P\left(y_q = n|\widetilde{\boldsymbol{x}}_q\right)$ is the choice probability after a modification of the variable $\boldsymbol{x}_q$. All the models were estimated using Pandas Biogeme software (Bierlaire, 2020).

4. Results

4.1 Analysis of participants

Table 1 displays an overview of the socio-economic characteristics of our sample. Most of the sample comprises females (59.65%). In terms of age distribution, 30.15% fall within the 18 to 30 age group, 27.33% are aged between 31 and 40, 34.92% are between 41 and 60, and 7.59% are 61 years of age or older. Regarding employment status, 61.38% of the respondents are workers, 16.92% are students, while the remaining 21.70% are housewives, retired, or unemployed. A minority of participants (30.8%) declared having at least one child in the household, and the average number of household members is 3.24. The percentage of interviewees who possess a personal car is 57.92%, which is lower than the average in the city of Cagliari at the time of the survey (67.1% in 2011).

Table 1: Socio-economic characteristics of the sample

Variables	**N**	**%**
Total	461	100.00%
Gender		
Male	186	40.35%
Female	275	59.65%
Age		
Age 18 - 30	139	30.15%
Age 31 - 40	126	27.33%
Age 41 - 60	161	34.92%
Over 60	35	7.59%
Employment status		
Student	78	16.92%
Worker	283	61.38%
Other	100	21.70%
Number of household members (AVG)	3.24	
Presence of children	142	30.80%
Presence of children <13y	71	15.40%
Own car	267	57.92%
Number of cars per household (AVG)	1.73	
Level of education: graduate	163	35.36%
Personal income per month		
€ 0-1,000	210	45.55%
€ 1,001-2,000	169	36.66%
€ 2,001-4,000	40	8.68%
> € 4,000	23	4.99%
Unknown	19	4.12%

4.2 Analysis of trip characteristics

Regarding the frequency of using the light rail (Table 2), 11.28% of the respondents stated using it a few times per year, 22.13% a few times per month, 26.68% more than once a week, and 39.91% use it every day. In terms of the purpose of travel, 52.28% of the sample declared using the LR for work/study. This result is corroborated by the analysis of the departure time, where 42.3% of the respondents started their trip between 6.00 am and 10.00 am, a time frame that is more likely to be used for commuting purposes.

The analysis of travel habits before the introduction of the LR revealed that 41.21% of the sample used to travel by public transport (bus), 47.07% by car, while 11.71% of the participants declared to have never made the trip (hereinafter referred to as new travellers). The Sankey diagram in Figure 1 displays the interplay between past behaviour and the frequency of using the light rail. The percentage of those who use the LRT every day is slightly greater for new travellers and former users of the bus (40.6%) compared to those who used to travel by car (39.2%). Conversely, the share of those who use the LR only a few times is larger among car drivers (13.82%) than new travellers (9.26%) and bus users (8.95%). The reader should note that the percentage of car users (47.07%) is much higher than those reported in the literature (Knowels, 1996; Golias, 2002; Vuk,

2005) because, in our final sample, we did not include high school and middle school students, who are the category of people more likely to use public transport.

Table 2: Trip characteristics for different levels of use of the LR

Variables	**Total**		**Frequency of use of LR**							
			A few times per year		**A few times per month**		**More than once a week**		**Every day**	
	N	[%]	N	[%]	N	[%]	N	[%]	N	[%]
Total	461	100.00%	52	11.28%	102	22.13%	123	26.68%	184	39.91%
Purpose of the trip										
Work/study	241	52.28%	14	5.81%	18	7.47%	50	20.75%	159	65.98%
Other	220	47.72%	38	17.27%	84	38.18%	73	33.18%	25	11.36%
Departure time										
6.00 am – 8.00 am	43	9.33%	1	2.33%	5	11.63%	5	11.63%	32	74.42%
8.01 am – 10.00 am	152	32.97%	13	8.55%	15	9.87%	35	23.03%	89	58.55%
10.01 am - 1.00 pm	73	15.84%	12	16.44%	22	30.14%	25	34.25%	14	19.18%
1.01 pm – 4.00 pm	67	14.53%	6	8.96%	16	23.88%	16	23.88%	29	43.28%
4.01 pm – 7.00 pm	103	22.34%	18	17.48%	40	38.83%	27	26.21%	18	17.48%
7.01 pm – 10.00 pm	23	4.99%	2	8.70%	4	17.39%	15	65.22%	2	8.70%

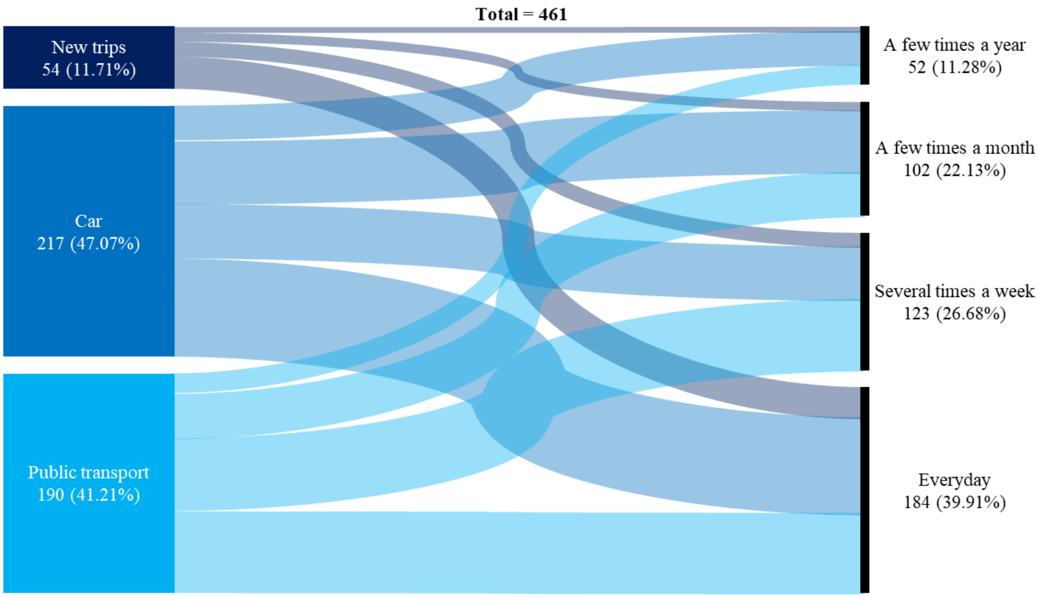

Figure 1: Sankey diagram showing the frequency of LR usage depending on the previous means of transport.

The different relationship between the frequency of LR usage and past behaviour can be explained by the different performances registered by the private car and the public transport. Indeed, it is interesting to compare the distribution of travel times by LR with the travel time by car and bus. Travel times were computed through an algorithm employing Google Directions API and included both in-vehicle and out-of-vehicle times (walking time, waiting time). The average travel time for those who used the car was way lower (13.3 min) than the travel time by LR (26.3 min). Conversely, the average travel time for the former users of the bus was higher (37.8 min) than the average travel time by LR (32.9 min). It is important to note that the travel time by car did not include the out-of-vehicle time and the time spent looking for an empty parking space, which, for the considered corridor, ranges between 5 and 40 minutes.

One of the aims of the survey was to understand whether the light rail was used alone or in conjunction with other means of transport (private car or public transport). Table 3 shows that 53.58% of the sample use the light rail alone, 21.69% are park and riders/kiss and riders, while 24.73% combine the bus/train service with the LR. This distribution is confirmed by the analysis of the distance from the origin to the LR stop: 61.61% of the sample have a distance lower than 1 km, 18.44% ranged from 1.01 km to 3 km, while the remaining 19.96% have a distance larger than 3 km.

Table 3: Frequency of LR usage and inter-modality

Variables	**Total**		**Frequency of use of LR**							
			A few times a year		**A few times a month**		**Several times a week**		**Every day**	
	[N]	[%]	[N]	[%]	[N]	[%]	[N]	[%]	[N]	[%]
LR used with/without other means of transport										
With other modes (bus)	100	21.69	8	8.00	17	17.00	31	31.00	44	44.00
With other modes (car)	114	24.73	16	14.04	22	19.30	18	15.79	58	50.88
LR alone	247	53.58	28	11.34	63	25.51	74	29.96	82	33.20
Distance from origin to LR stop										
< 1 km	284	61.61	31	10.92	67	23.59	89	31.34	97	34.15
1 – 3 km	85	18.44	13	15.29	20	23.53	13	15.29	39	45.88
≥ 3 km	92	19.96	8	8.70	15	16.30	21	22.83	48	52.17

4.3 Analysis of opinions about MetroCagliari

Table 4 presents the survey results regarding factors that influenced the decision to use the light rail and opinions about the light rail service for the different frequency levels of use of the LR. Respondents were asked to rate each statement on a 5-point Likert scale from 1 (completely disagree) to 5 (completely agree). Overall, we observed that the main motivations for choosing the new travel alternative were the reduction of traffic stress (AVG 4.377) and travel time (AVG 4.241), followed by the reduction of environmental pollution (AVG 4.000). Travel cost was not considered a significant factor in the process of changing travel behaviour (AVG 3.972). Regarding the perception of the LR service quality, only the average values of the two items concerning “the level of safety at stops and interchange parking areas” and “the possibility of interchange with other public transport means”, received ratings above three. The sample generally believes that the LR does not bring any disadvantages to the city. Additionally, respondents feel that the LR can bring benefits to the environment.

We identified some statistical differences in the average values of the items based on the category of LR usage frequency. Concerning the quality of the LR service, **Errore. L'origine riferimento non è stata trovata.** shows that those who used the LR a few times a year perceived significantly less security at interchange areas (parking and stops) compared to the other groups. On the other hand, those who use the LR more frequently perceived that there is an adequate description of the service and availability of tickets more than the other categories.

Table 4: Average opinion for different frequency categories about attributes and qualities of the LR and significance tests between differences among the four frequency groups

Variables	Total	A few times a year (1)	A few times a month (2)	Several times a week (3)	Every day (4)	t-stat 2 vs 1	t-stat 3 vs 2	t-stat 4 vs 3
Factors influencing the choice of using the LR								
Reduced travel costs	2.581	2.442	2.402	2.537	2.750	0.190	-0.917	-1.451
Reduced traffic stress	4.377	4.231	4.539	4.293	4.386	-1.574	1.885*	-0.732
Reduced travel time	4.241	4.308	4.314	4.203	4.207	-0.034	0.774	-0.025
Reduced environmental pollution	3.972	3.731	4.088	4.065	3.913	-1.722*	0.152	1.081
Level of LR Service quality								
The level of safety at interchange areas and LR stops is high	3.696	3.423	3.765	3.805	3.663	-2.071**	-0.343	1.365
It is possible to interchange with other PT means	3.087	2.865	2.843	3.130	3.255	0.117	-1.886	-0.955
The description of the service and availability of tickets is adequate	2.900	2.692	2.745	3.130	2.891	-0.285	-2.614	1.845*
Fares are low	2.811	2.635	2.618	2.854	2.940	0.101	-1.771*	-0.757
Opinion about the disadvantages of the light rail								
The LR disturbs road traffic	1.295	1.288	1.304	1.333	1.266	-0.183	-0.398	0.989
The LR is noisy	1.436	1.365	1.480	1.496	1.391	-1.077	-0.167	1.248
The LR is dangerous	1.421	1.481	1.441	1.415	1.397	0.336	0.340	0.248
The LR spoils the aesthetic of the city	1.278	1.212	1.265	1.333	1.266	-0.730	-0.974	1.011
Environmental sustainability of the light rail								
The LR contributes to increase sustainable mobility	4.069	4.115	4.118	4.016	4.065	-0.016	0.826	-0.441
The LR contributes to increase the level of walkability	4.004	3.904	4.078	4.033	3.973	-1.191	0.388	0.560
The LR contributes to increase the public health	3.948	3.885	4.059	3.943	3.908	-1.074	0.883	0.305
The LR contributes to increase the environmental quality	4.171	4.154	4.206	4.187	4.147	-0.373	0.167	0.403

(**) Significant at 95%; (*) Significant at 90%

4.4 Modelling results

The results of the model estimation are presented in Table 5. Regarding the Level of Service variables, we found that longer trips are associated with a lower propensity y_q^* to use the LR, indicating that the new mode of transport is utilized more frequently for shorter distances. Additionally, as the number of bus stops within 250m of the trip origin increases, the probability of using the LR frequently reduces. This suggests that users who have better access to their destination via the bus network may prefer that service over the LR.

Two trip characteristics, the purpose of the trip, and the departure time, significantly influence the propensity to use the LR. Individuals traveling for work or study are more likely to use the LR. Moreover, trips taken between 6 a.m. to 8 a.m. and 8 a.m. to 10 a.m. are associated with a higher likelihood of frequent LR use. This makes sense, as most commuting trips start in that timeframe.

Regarding socio-demographic characteristics, the model indicates that females are more likely to use the light rail more frequently than males. The model also indicates that individuals older than 60 years are more likely to use the LR more frequently, followed by those aged 40 to 60 years. This finding partially contradicts Senior's (2009) observation of higher LR usage frequency among those aged 18 to 44 years. Additionally, income levels also influence the latent propensity y_q^* to use the LR. Individuals with a monthly revenue between 2,000 € and 4,000 € are more likely to use the LR occasionally, while those with a revenue exceeding 4,000 € are more apt to use it frequently. This might be due to the LR corridor being situated in one of the wealthier areas of Cagliari.

Lastly, the impact of past behaviour on the latent propensity to use the LR is analysed. Consistent with previous research (Senior, 2009; Piras *et al.*, 2018), individuals who used to travel by car are less likely to frequently use the LR. Note that we attempted to incorporate parameters that measure the difference between past and current travel costs and times in our model to assess their statistical significance. However, it turned out that these variables did not contribute significantly to the overall analysis.

Table 1 Model estimation results

Variable	Value	Rob. t-test
Thresholds		
τ_1	-1.53	-5.92
τ_2	-0.595	-2.38
τ_3	0.323	1.28
Level of Service variables		
Travel time [1/min]	-0.007	-2.05
Number of bus stops within 250 m from the origin	-0.028	-1.94
Trip characteristics		
Departure time: 6:00am-08:00 am	0.508	2.04
Departure time: 8:00am-10:00 am	0.372	2.89
Purpose of the trip: work/study	1.228	8.94
Socioeconomic characteristics		
Gender	-0.151	-1.40
Age (ref. cat. Age > 60 years old)		
Age 18 – 30 years old	-0.282	-1.38
Age 31 – 40 years old	-0.390	-1.78
Age 41 – 60 years old	-0.232	-1.16
Income (ref. cat. Income < € 2,000 or unknown)		
Income € 2,001 - € 4,000	-0.466	-2.19
Income > 4,000 €	0.387	1.45
Past behaviour		
Private vehicle as previous mode	-0.214	-1.85
Goodness-of-fit measures		
Sample size	461	
Constant log likelihood	-598.838	
Final log likelihood	-508.702	
ρ^2	0.1505	

Errore. L'origine riferimento non è stata trovata. 6 displays the pseudo-elasticity effect for each variable included in the specification of the ordered logit model. The largest effect is associated with the trip purpose: if all participants travelled for work or study reasons, the probability of using the LR every day would increase by approximately 19.5%. Regarding the level of service attributes, if all individuals had an additional bus stop within 250m of their origin, the probability of using the LR every day would decrease by 0.84%. Similarly, if the total travel time increased by 20%, the probability of using the light rail daily would drop by 1.20%. Furthermore, if every individual were a former car user, the probability of using the LR every day would decrease by 3.4%. This result highlights that the habit of using a certain travel mode does have an effect on the LR usage frequency, although it is smaller than the effects exerted by other variables, such as trip purpose or level of income.

Table 6 Pseudo-elasticity effects

Variable	Change	A few times a year	A few times a month	Several times a week	Every day
Travel time	+ 20%	0.63%	0.47%	0.11%	-1.20%
Departure time: 6:00am-08:00 am	Everybody	-5.58%	-4.69%	-0.10%	10.37%
Departure time: 8:00am-10:00 am	Everybody	-4.06%	-2.73%	0.87%	5.92%
Departure time: 10:00 am – 22:00 am	Everybody	1.49%	2.44%	1.98%	-5.90%
Purpose of the trip: work/study	Everybody	-9.30%	-9.83%	-0.37%	19.51%
	Nobody	8.46%	10.91%	2.87%	-22.24%
# Bus stops within 250 m from the origin	+ 1	0.45%	0.33%	0.05%	-0.84%
Private vehicle as previous mode	Everybody	1.83%	1.40%	0.18%	-3.41%
	Nobody	-1.61%	-1.15%	-0.21%	2.97%
Male	Everybody	1.44%	1.06%	0.17%	-2.68%
Female	Everybody	-0.98%	-0.72%	-0.10%	1.81%
Age 18-30	Everybody	0.40%	0.13%	-0.37%	-0.16%
Age 31-40	Everybody	2.23%	1.32%	-0.26%	-3.29%
Age 41-60	Everybody	-0.38%	-0.44%	-0.47%	1.29%
Age > 60	Everybody	-3.61%	-3.28%	-1.34%	8.23%
Income < € 2000	Everybody	-0.71%	-0.17%	0.40%	0.48%
Income € 2000 - € 4000	Everybody	8.09%	4.85%	-0.02%	-12.92%
Income > € 4000	Everybody	-5.62%	-5.25%	-1.59%	12.46%

5. Policy implications and lessons learned

Italy, with the recent introduction of European guidelines and national legislation on Sustainable European Mobility Plans (SUMPs), cities are increasingly adopting this planning tool. These plans are instrumental in identifying transport strategies aimed at reducing car usage, encouraging a shift to public transport, and achieving a 90% reduction in emissions by 2050 in the transport sector. As mentioned in the introduction, the implementation of new light rail lines is one of the most popular measures to achieve these objectives. However, it is concerning that the long-range planning of light rail services often relies solely on the results of four-step demand models, without complementing them with cognitive analyses. These four-step models are typically aggregate models based on time and cost average relations at the zone level, which do not account for individuals' heterogeneity in the process of travel behaviour change. As our study highlights, considering the heterogeneity in travel behaviour, including socio-demographic characteristics and travel habits, is critical for effective light rail planning. This information should be investigated and incorporated when developing SUMPs. Furthermore, understanding the characteristics of potential new users of a light rail service can provide valuable insights for designing future scenarios in SUMPs. In the Italian context, future scenarios involving the implementation of new light rail lines are primarily constructed as a package of measures, which predict modal split for alternative transit line geometries. However, they often do not consider future changes in mobility demand attributes. Descriptive scenarios, , as suggested by researchers (Amer *et al.*, 2013; Lyons *et al.*, 2021), should be run by planners to explore how transit travel volumes might change based on the evolution of the population's characteristics. For instance, in the specific context of our study, where we observed that commuters are more likely to use the new light rail line, running a descriptive scenario that considers an increase in the popularity of working from home and a reduction in the number of commuting trips could provide valuable insights. This would help determine whether the introduction of a new light rail service is still capable of achieving the required target of reducing car use.

The second crucial aspect of the study highlights the significance of monitoring and conducting ex-post evaluations to assess the impacts of the implemented light rail measure. By analysing the characteristics of LR users after its introduction, we identified factors that may hinder the new travel alternative from reaching its full operational capacity. The most remarkable example of this concerns the existence, along the corridor served by the light rail, of different lines of the bus. As revealed by model results, for those individuals whose origin is located in areas well-covered by the local bus service the probability of using the light rail frequently is lower. This outcome aligns with previous research (Yen *et al*., 2018) and emphasizes the need for transport planners to re-design bus service lines in conjunction with the introduction of a new light rail line. Ensuring that both public transport services complement each other rather than compete is crucial for maximizing the potential of the light rail system. Therefore, when planning the implementation of a new light rail line, forecasting the impacts on the entire modal share and integrating it with other means of transport, particularly the bus service, becomes essential. Another significant factor that influenced the use of the light rail was the total travel time, with a negative coefficient in the model. This finding holds valuable implications for policy-making, as it indicates that the light rail route should be designed to minimize walking distances to stops and reduce the need for interchanging with other means of transport.

In addition to this, continuous monitoring and closer inspection of the behaviour of individuals who have chosen to use the new light rail service can provide valuable insights into the individual factors that influenced their decision. This knowledge can be instrumental for policy-makers and transport practitioners in designing and implementing effective behavioural measures that leverage these factors, which are often unknown. For example, one possible approach could be the launch of a communication campaign (Meloni *et al.*, 2017) aimed at informing motorists about the existence of a competitive alternative to the private car, such as the new light rail service. The campaign can highlight that many current users of the light rail are not only former bus users but also individuals who used to travel by car, as we observed in our case study. Emphasizing this social norm, where car drivers have already switched to the light rail, can be effective in persuading other motorists to adopt a more sustainable behaviour (Piras *et al.*, 2021). To implement such a campaign successfully, an ex-post survey would be necessary to provide the target audience with reliable information. This approach is essential when attempting to change people's habits, as it allows policy-makers to tailor their communication and intervention strategies effectively. Another example of behavioural measures could be the release of an advertising video where current users of the light rail talk about those elements of the new travel alternative that contributed to choose to switch from car to light rail. Because the duration of the video could be limited, the factors to talk about should be those that turned out to be crucial from the survey, namely the reduction of travel time and the reduction of the stress of the traffic.

6. Conclusions

Different research papers and technical reports have investigated how the implementation of a new light rail line impacts individuals' travel behaviour and the consequent change of the modal share following the introduction of the new alternative. Nevertheless, most of them are aggregate studies that did not consider individuals' heterogeneity in the decision process leading to switch means of transport. The present study was designed to explore, utilizing various methodologies, the factors that have a greater influence on encouraging people to use a new LR line service in the metropolitan area of Cagliari, Italy. The aim was to gain valuable insights that could be used to derive policy implications for promoting the use of the LR service.

From the descriptive analysis we found that the LR is mainly used for commuting purposes and those who use the LR service, in particular for high frequency, are the new travellers and former users of the bus. The different relationship between frequency and past behaviour could be due to the different performances registered by the private car and the public transport. Indeed, the car drivers have a lower average travel time than the travel time by LR contrary to the former users of the bus.

People are aware of the benefits associated with using the LR, and the primary motivations for its usage are the reduction of traffic stress, travel time, and environmental pollution, in order of importance. Interestingly, the perception of security increases with the frequency of LR usage, and those who are more familiar with the service perceive it to be adequately provided. The modelling results confirm that longer trips and an increasing number of bus stops within 250m decrease the propensity to travel by LR. However, commuters with a monthly income higher than 4,000 € and those traveling between 6 a.m. and 10 a.m. are more inclined to use the LR more frequently. On the other hand, former car drivers are less likely to use the LR more often.

The demand is elastic with respect to the trip purpose. For instance, if all individuals travelled for work or study reasons, the aggregate probability of using the LR daily would increase by approximately 20%. Conversely, the demand is inelastic regarding Level of Service attributes. If the travel time were increased by 20% for each participant, the probability of using the LR daily would decrease by only 1.2%. Similarly, the probability of using the LR every day would decrease by about 0.84% if all individuals lived in an area with an additional bus stop.

The main limitation of the paper is the limited dimension of the sample size. A larger sample would have permitted to know the opinion about the new LR service of a more representative portion of the population. The second limitation concerns the period of the data collection process (2011). Indeed, because of the recent spread of the COVID-19 pandemic and the diffusion, on a large scale, of smartphone applications that permit to purchase LR tickets or have real-time information on the public transport service, other factors contributing to individuals' willingness to use LR may have appeared. Despite its limitations, the study certainly adds to our understanding of the different factors that prompt individuals to take up using a new LR service in an Italian middle-size city. As Italian municipalities are expanding their efforts to improve the actual extension of LR systems in urban contexts, it becomes increasingly important to get insights about the effects that this modal alternative can generate at an individual level. In this sense, future research should investigate not only the behaviour of the LR users, but also examine more closely the reasons of those who decide to stick with their current travel habits and not change their travel behaviour. Additionally, the impacts of new LR lines may vary depending on the Italian context they are implemented (big cities *vs.* middle cities *vs.*

small cities, north Italy *vs.* south Italy). These differences should be explored more extensively, so that local policy-makers can easily identify which strategy would be a good fit for the specific context in which they are going to operate.

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