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Exploration of the impact of on-street parking pricing on the shift to public transport

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ABSTRACT

On-street parking pricing is a widely applied traffic management measure, which aims to maximise the use of the limited parking resources, and to discourage private cars usage especially in dense urban areas. The present study examines the case of Thessaloniki, Greece, where a controlled parking system operates since 2017. Although the existing system operates satisfactory, it does not efficiently utilise parking resources during periods of fluctuating demand. There is currently a dilemma to shift from a fixed hourly pricing to a dynamic pricing policy for discouraging private cars usage especially during peak hours, and triggering a modal shift to alternative modes and mainly public transport. For the provision of sound scientific evidence to policy makers, a stated preference survey is conducted and collected data are analysed by using a mixed-logit approach that is capable of handling population's heterogeneity. The results show that the users' choice behaviour is highly dependent on the existing mobility preferences and is significantly guided by parking and travel costs; yet, great heterogeneity is identified among individuals regarding the two cost-related parameters. The outcomes of the analysis provide data-driven evidence to local authorities for defining lower and upper parking pricing limits that are affordable for users and have the intended impact.

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KEYWORDS On-street parking pricing; dynamic parking pricing; parking scheme; public transport; mixed logit model

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1. Introduction

Parking in urban areas is connected to multiple challenges and impacts on traffic flow and urban dynamics. Studies have shown that up to 30% of traffic congestion in urban areas is caused by drivers searching for parking spaces (Shoup, 2006). In terms of economic impact, the cost of searching for parking and the productivity loss associated to it, account to billions of dollars annually in the US (Shoup, 2017). Additionally, research indicates that unnecessary driving can significantly contribute to air pollution and greenhouse gas emissions, further exacerbating urban environmental challenges (Cats et al., 2016). Furthermore, the allocation of land for parking lots and structures reduces valuable urban space that could otherwise be used for green spaces, affordable housing, or commercial development (Cervero & Kockelman, 1997).

To address these issues, cities increasingly implement innovative solutions such as smart parking systems and vehicle access regulations including urban tolls, while they promote alternative modes of transport like public transport, cycling, and walking to lessen the stress on urban infrastructure. Parking pricing strategies have been implemented worldwide to manage urban parking demand, alleviate congestion, and optimise the use of limited parking resources. According to Parmar et al. (2020) parking price is one of the most critical factors for parking demand. Various schemes have been applied, including flat rate pricing, time-of-day pricing, dynamic pricing, residential parking permits, pay-by-plate systems and occupancy-responsive parking pricing.

One of the main aspects of parking is pricing and economics, since mispricing may affect the results of parking policies. Several studies have focused on pricing to determine elasticity of demand for the parking market (Kelly & Clinch, 2009), and optimal parking quantity and price (Inci, 2015). In the literature, empirical (Litman, 2023) or modelling (Jakob et al., 2020) approaches are used to study the effects of parking pricing. A common framework for studying impacts does not exist and the majority of relative studies rely on either manual parking counts, revealed preference surveys (Kelly & Clinch, 2009) or stated preference surveys (Cats et al., 2016). Parking related impacts from empirical studies may be related to parking occupancy including temporal variations (Cats et al., 2016), effectiveness of pricing schemes in terms of user behaviour changes (Piccioni et al., 2019) and changes in modal share (Feeney, 1989; Hensher & King, 2001). In terms of modelling, existing studies assess microscopically or macroscopically (Jakob et al., 2020) the topic, which determines the data requirements on demand and supply.

Focusing on dynamic parking policies and modal share, there is a gap in literature addressing such effects and specifically shifts from private vehicles to public transport. While prior research has examined parking pricing strategies more broadly, there is limited empirical evidence on how dynamic parking pricing affects modal shift towards public transport. This study advances the

literature and directly examines how dynamic parking prices affect travellers' decisions to shift from private vehicles to public transport. Effects on public transport focus on influencing ridership levels, modal choices and user satisfaction. For example, dynamic parking policies may incentivise travellers to consider alternative modes of transport, including public transport. When the cost and availability of parking in urban areas become less favourable due to dynamic pricing, individuals may opt for public transport options as a more convenient and cost-effective alternative, potentially leading to increased ridership levels (Litman, 2023). Dynamic parking policies may complement public transport systems by encouraging drivers to use bus and rail for longer trips or during peak travel times, optimise the use of existing transit infrastructure and support investments (Shoup, 2017), and improve first- and last-mile connectivity to public transit hubs by encouraging the use of park-and-ride facilities, bike-sharing programs, and alternative transport modes. Based on the timeframe that each study uses, it may be concluded that studied effects may be grouped into two categories: the decision-making phase and the after-implementation phase.

This study aims to explore the effects of fluctuating parking prices to support the decision-making phase for upgrading an existing controlled parking system from fixed to dynamic pricing. To achieve this goal, we explore changes in modal share and specifically shifts to public transport by collecting data through a stated-preference survey and developing a mixed-logit model, for the city of Thessaloniki in Greece. The model incorporates variables related to travel time and cost, parking cost and existing user mobility preferences. The outcomes of the model provide data-driven evidence to the authorities for defining lower and upper parking pricing limits that are affordable for users and may lead to the intended impact.

2. Literature review

Parking pricing has great potential to affect users' travel behaviour and parking characteristics (e.g. parking duration) since drivers tend to adjust their travel patterns to minimise travel costs (Nourinejad & Roorda, 2017). User response to parking charging depends on gender, income, travel time and other travel costs (Feng & Ye, 2008). In this context, travellers can react to parking management in various ways, such as by changing their parking habits, their mode of travel, their destination, their schedule and their activities (Yan et al., 2019). Changes in modal share highly depend on local conditions such as availability and convenience of public transport and other available transport modes (Yan et al., 2019).

Utilizing data from automated parking collection systems, Cain et al. (2001) and Syed et al. (2009) explored how parking pricing variations affect demand and how this information may be used to manage supply. Studies on parking pricing may present diverse results when different strategies are implemented.

An increase in parking price during peak hours did not result to a noticeable effect on the distribution of traffic peaks and decrease in parking demand (Wang et al., 2020). On the contrary, Nourinejad and Roorda (2017) investigated the impact of hourly parking pricing on travel demand and concluded that parking pricing, when implemented imprudently, may increase demand. In this context, they emphasised the dwell time elasticity as an important factor to obtain optimal results out of parking pricing schemes. In another study, an increase of the parking price was found to significantly reduce parking demand (–20%) while also reducing parking duration (–10%) (Mo et al., 2021). Consequently, price elasticity of expected perceived parking cost may be used to evaluate the users' response to parking charging and to optimise parking prices (Li et al., 2021).

Changes in parking pricing were also found to affect duration of on-street parking (Wang et al., 2020). Drivers that park occasionally in an area are less sensitive to parking charges than drivers who park in a specific area frequently or even in a daily basis (Kelly & Clinch, 2006). In a similar context, drivers that park for longer time, such as commuters, are more sensitive to parking price changes (Li et al., 2021; Vidovic & Simicevic, 2023). Mingardo et al. (2022) studied the effects of three commonly implemented parking policies in the EU on parking duration. They considered "pricing only", "pricing and time restrictions" and "daily tickets", and concluded that time restrictions are more efficient than pricing only.

Evans and Pratt (2005) observed that parking price increases lead to shifts in location or alterations in behaviours, rather than changes in demand or travel mode. Similarly, according to Yan et al. (2019), travellers are more probable to relocate to a different parking area than changing travel mode. However, they found that the elasticity of parking demand concerning egress time (the time required to reach one's destination from a parking spot), surpassed that of parking price.

While some studies emphasise that travellers may initially relocate to different parking areas rather than immediately changing their travel mode (Hunt & Teply, 1993; Parmar et al., 2021; Yan et al., 2019), a growing body of literature directly investigates the potential for parking pricing to induce a shift towards public transport. For instance, in Nanjing, research has shown that higher parking charges are effective in encouraging commuters to switch to public transport options like buses or metros (Ding & Yang, 2020). Similarly, analyses in Seattle indicate that increased parking fees in areas with good access to public transport encourage the use of public transport and other alternative modes, with potential revenues even funding these alternatives (Kirschner & Lanzendorf, 2020). A study using Seattle data found that increasing parking fees from \$0.28 to \$1.19 per hour reduced car-driving distance by 11.5% (Næss et al., 2020). Furthermore, Seattle has reduced parking requirements for new developments, especially near frequent transit stops, influencing a shift towards walking and

away from driving due to parking challenges and expense (McAslan, 2018). The broader role of parking policies in influencing travel demand and behaviour, and consequently mode choice, is also a critical area of study (Ng, 2014). The effectiveness of parking pricing policies is highly dependent on local conditions and the specific urban context (Yan et al., 2019).

In order to investigate the effectiveness of parking pricing policies it is also important to consider the users' perception. Through an empirical study in four different zones in Rome, Piccioni et al. (2019) investigated the effectiveness of parking pricing schemes. It was revealed that many drivers perceive pricing policies only as a way for the authorities to earn money. Such perceptions may lead drivers to systematically engage in undesirable behaviours such as illegal parking. The on-street parking price adjustment in Nanning, China, resulted in higher perceived parking costs, closer proximity of parking spaces to destinations, and fewer parked cars (Mo et al., 2021). Despite these apparent improvements, concerns about equity arose as individuals with lower incomes faced challenges in accessing parking or had to alter their travel mode choices, while high-income individuals were less affected. User response to parking charging is not solely an economic calculation but also a matter of perception, intertwined with the attractiveness and availability of alternative modes. For example, in Malang City, Indonesia, findings suggest that changes in parking rates could encourage a shift to public transportation, contingent on the public transport meeting community demand and criteria (Utomo et al., 2020). This implies that the perceived quality and convenience of public transport heavily influence the effectiveness of parking pricing in promoting its adoption. Understanding public acceptance for transport taxes, including parking fees, is thus critical for the successful implementation of policies aimed at encouraging sustainable transport choices (Kallbekken et al., 2013).

The abovementioned findings of the literature indicate that the impacts of parking pricing policies depend on multiple factors and for this reason studies may lead to diverse results. Users' sociodemographic characteristics can significantly affect perceptions and behaviour, while the same applies for the existing mobility preferences/habits of the users. As such, the present study builds upon a mixed-logit model that considers population's heterogeneity and incorporates variables related with the current mobility preferences. Also, based on the literature, the impact of parking pricing policies is mainly focused on travel destination changes rather than on transport mode shift. Yet, in the case of implementing parking pricing policies in a city centre, the shift of the destination is in many cases unattainable, especially for cities like Thessaloniki where activities, services and points of interest are concentrated within the city centre. In such contexts, the potential for parking pricing to drive a mode shift towards public transport becomes paramount. A notable study conducted in Thessaloniki itself demonstrated that even a moderate increase in hourly parking charges could significantly reduce private car use and notably increase public transport

ridership, provided systematic law enforcement is in place (Morfoulaki et al., 2017). Similar considerations for integrated management systems in concentrated Central Business Districts have been explored in cities like Palermo, Italy (Migliore et al., 2014). These local examples highlight that the interaction between parking policy and public transport ridership in densely concentrated urban areas warrants dedicated investigation.

3. Methodology

3.1. Case study

The study area is the city of Thessaloniki, located in Northern Greece. Thessaloniki is home to around one million residents and covers an area of approximately 1,285 square kilometres. The city experiences challenges related to traffic congestion, primarily due to a heavy reliance on private transport to meet mobility needs and the inability of public transport services to provide a competing service. According to Thessaloniki's Sustainable Urban Mobility Plan (SUMP) (2019), private cars are used for 36% of city trips (aiming to reach 24–28% by 2030), while public transport accounts for 32% of the modal share (aiming to reach 38–40% by 2030).

At the time of data collection (December 2023), public transport services in the city were provided solely by buses, as the metro system was under construction. Buses often operated beyond capacity during peak hours and exhibited notable reliability issues. Although the metro system is now operational, the results of this study are based on the transport conditions existing during the survey period. The cost of using public buses in Thessaloniki is relatively low compared to other European cities (Statista, 2020). A single regular ticket is priced at €0.60, with a discounted fare of €0.30 for students and other eligible groups. Daily tickets are available for €2.50, and monthly passes cost €16, providing more flexible options for frequent users. By comparison, in cities such as Berlin, Paris, and Madrid, single bus or metro tickets typically range between €1.90 and €2.50, while monthly passes can exceed €80, highlighting the affordability of public transport in Thessaloniki.

In 2017, aiming to manage parking and traffic in specific areas of the city, a controlled parking system was implemented in the city of Thessaloniki. The system includes four parking space categories:

- for residents: Anyone living at an address in the implementation areas is entitled to free parking at certain locations. To secure this right, residents apply for resident card to the municipal community to which they belong.
- for visitors: Anyone who does not own a resident card is entitled to a parking cost of 1.70 €/hour from 08:00am to 21:00pm during weekdays and from 09:00am until 16:00pm on Saturday. Apart from the aforementioned hours,

parking is free, including Sundays and public holidays. Parking on these spaces is allowed for a maximum of 4 hours.

- loading/unloading: These areas are used to supply stores and are subject to the regulatory decisions of the Municipality of Thessaloniki.
- persons with disabilities: free parking near the entrance of the house is provided for those who they have a disability or they are the trustee of a disabled person.

One of the areas that the controlled parking system operates is the city centre, where 1,610 parking spaces for visitors and 3,435 parking spaces for residents are available. The controlled parking system had 300,000 unique users in 2022 and served roughly 1,500,000 parking transactions. The average parking duration for visitors in the city centre is two hours. The city is currently engaged in discussions regarding the potential implications of transitioning from a fixed hourly parking cost in the city centre to a dynamic pricing policy.

3.2. Data collection

For the purpose of this research, an online stated preference experiment was designed. The web questionnaire was disseminated through local websites to ensure broad participation. A total of 208 responses were collected in December 2023. While we acknowledge that this sample size may raise concerns regarding statistical precision, the stated preference design resulted in multiple observations per respondent, yielding a total of 1,248 observations for model estimation. For a confidence level of 95%, the corresponding margin of error of the survey is 6.79% (Daniel, 1999), which is considered acceptable for exploratory behavioural analysis. The distribution of the sample per area of residence is presented in Figure 1. The distribution of responses covers many parts of the city, but the majority of participants lives in the eastern part of Thessaloniki.

The questionnaire was divided into three sections in order to collect information from the participants:

- Respondents' existing mobility preferences: The aim of this section was to understand the frequency travelling, and usage of car and public transport for trips that have the city centre as a destination, as well as the frequency of using the controlled parking system.
- Respondents' stated preferences: First, participants were asked to evaluate different hypothetical prices for the controlled parking system in Thessaloniki. The prices ranged from 0.5 €/hour to 3 €/hour, with a step of 0.25 €/hour, and the respondents had to select among "very cheap", "cheap", "normal", "expensive", "very expensive". Following, six stated preference scenarios were addressed to the respondents, where participants had to choose between

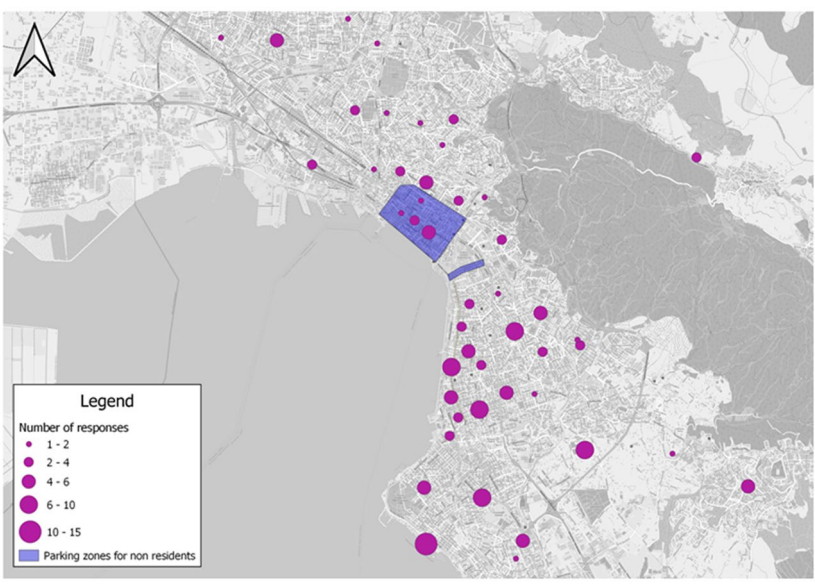


Figure 1. Spatial distribution of responses.

	<u>Car</u>	<u>Bus</u>
	Travel cost: The cost of fuel required in the current situation to move from your home to the center. Travel time: The time it takes in the current situation to move from your home to the center by car. Cost of parking in a visitor space in the controlled parking system: 5,5 € (2,75 €/hour) Time to find a parking space: 2'	Travel cost: The cost of a reduced city bus ticket in the current situation (€0,45). Travel time: The time it takes in the current situation to move from your home to the center by city bus. Cost of parking in a visitor space in the controlled parking system: Not applicable. Time to find a parking space: Not applicable.
		
Select the means of transport you would choose	☐	☐

Figure 2. Example of stated preference choice tasks (a) private car, (b) bus.

travelling by car or by bus from their place of residence to the centre of Thessaloniki, taking into consideration different travel attributes (an example is presented in Figure 2). The stated preference experiment was designed following a context-specific, attribute-based approach, aiming to balance behavioural realism with cognitive simplicity for respondents. In more detail, the travel attributes that were included in the scenarios are: travel cost with

private car and bus, travel time with private car and bus, parking cost for private car, time to find a parking space for private car. To enhance realism, the travel cost by private car, as well as travel time by private car and bus, were kept fixed for each respondent and tailored to their individual place of residence. These values were obtained by first asking respondents to report their current travel time to the city centre by car and public transport and by combining this information with their area of residence; routing tools were then used to calculate consistent and realistic travel time and cost values for each individual scenario. This individualised fixing of time and cost attributes was intentionally adopted to reflect respondents' real-life travel conditions and to place greater analytical emphasis on parking-related attributes, which constitute the core policy lever examined in this study. Maintaining realism in stated preference experiments is widely acknowledged as a key factor for improving response validity and behavioural consistency (Cherchi & Hensher, 2015). The travel cost with public transport attribute had two levels, €0.45 and €0.90 similarly to the prices of the discounted and regular tickets at the time of the survey. The parking cost had four levels, ranging from 0 to €5.50 (2.75 €/hour), while the time to find a parking space had also four levels, ranging between 2 and 15 minutes. The specific attribute levels and their combinations, were defined based on the existing controlled parking pricing scheme and observed parking search times in the city centre, ensuring that all scenarios remained within realistic and policy-relevant bounds. To further define a clear and consistent choice context, respondents were instructed to assume that (a) the trip takes place on the afternoon of a typical weekday when shops are open, and (b) the duration of stay in the city centre is approximately two hours. Fixing the time spent in the city centre allowed the experiment to focus on visitor-type trips (e.g. shopping, personal appointments, leisure), which represent the primary target group of the controlled parking system, while also reducing cognitive burden and avoiding excessive scenario complexity.

- Participants' demographic and socioeconomic characteristics: In this section, participants were asked to state their gender, age, employment status, monthly household income and place of residence. The latter was used to estimate the travel cost and duration, with private car and public transport, to the city centre which is the destination considered in the analysis.

3.3. Data analysis and modelling

The responses were initially subjected to a descriptive analysis, involving the computation of absolute and relative frequencies. This approach aimed to offer a comprehensive overview of participants' characteristics, attitudes, and preferences.

In this study, for the stated preference experiment we use a mixed-logit model framework. Standard logit models assume that individuals in the population share the same preferences for the attributes of alternatives. Yet, in reality, preferences may vary significantly among individuals, and the standard logit model fails to capture this heterogeneity. On the other hand, in a mixed logit model (or random parameters logit model) the parameters are assumed to vary from one individual to another. Therefore, mixed-logit models are capable of handling population's heterogeneity (inter-individual heterogeneity) and capturing the variability in preferences across different decision-makers (Hensher & Greene, 2003).

As in a typical random utility model, each individual is assumed to choose the alternative that provides the highest utility; the utility for an individual n , for an alternative i and a choice situation t is specified as:

$$U_{nit} = V_{nit} + \varepsilon_{nit} \quad (1)$$

where V_{nit} is the systematic part of utility and ε_{nit} is the stochastic disturbance which is independently and identically distributed according to Gumbel type I distribution across individuals, alternatives and choice situations. The systematic part of the utility, for the purposes of this study, is specified as following for the private car and the public transport options accordingly:

$$V_{car,it} = \delta_{car} + [\exp(\mu_{DTT} + \sigma_{DTT} \cdot \varepsilon_{DTT,i})] \cdot DTT_{it} + [\exp(\mu_{DTC} + \sigma_{DTC} \cdot \varepsilon_{DTC,i})] \cdot DTC_{it} - [\exp(\mu_{cp} + \sigma_{cp} \cdot \varepsilon_{cp,i})] \cdot cost_park_{it} + \sigma_{panel} \cdot v_{car,it} \quad (2)$$

$$V_{PT,it} = \delta_{PT} - [\exp(\mu_{DTT} + \sigma_{DTT} \cdot \varepsilon_{DTT,i})] \cdot DTT_{it} - [\exp(\mu_{DTC} + \sigma_{DTC} \cdot \varepsilon_{DTC,i})] \cdot DTC_{it} + \beta_{cmu} \cdot car_monthly_usage_i + \beta_{PTmu} \cdot PT_monthly_usage_i + \beta_{pmu} \cdot park_monthly_usage_i + \sigma_{panel} \cdot v_{PT,it} \quad (3)$$

where:

- δ : the alternative specific constant (ASC). Considering that the number of estimable ASC parameters is $t-1$ (t is the total number of alternatives), the ASC parameter associated with public transport was fixed to zero.
- μ : the mean of the underlying normal distribution used to construct log-normal random coefficients
- σ : the standard deviation of the underlying normal distribution used to construct log-normal random coefficients
- ε : an individual-specific draw from a standard normal distribution (used to generate the random coefficients)
- β : a fixed coefficient

- σ_{panel} : the standard deviation of the error component added to each alternative's utility
- $v_{*,it}$: an independent and identically distributed (i.i.d.) standard normal draw across individuals, alternatives, and time, used for the error components.

In the present specification, the panel effect was implemented through alternative-specific individual-level error components. More specifically, separate normal draws were assigned to the private car and public transport utilities, and these draws remain constant across the repeated choice situations of the same respondent. This specification allows the model to capture serial correlation in the utilities across observations for the same individual without imposing a common error component across alternatives.

As previously noted, the model accounts for inter-individual heterogeneity by specifying random parameters for selected variables. Specifically, as shown in Equations (2) and (3), random coefficients were assumed for the three travel-related variables: DTT, DTC, and cost_park. These were modelled using negative log-normal distributions, reflecting the expectation that their effects on utility should be negative. Initial values for the means of these distributions were based on a preliminary multinomial logit model, using the estimated coefficients of the respective variables. In the present specification, the random parameters were assumed to be independent across attributes (i.e. no correlation structure was imposed among the random coefficients). While correlated random parameter specifications can provide additional behavioural insights, estimating such models would require the estimation of additional covariance terms and typically larger samples to ensure stable estimation; therefore, an independent specification was adopted in this study. While the inclusion of intra-individual heterogeneity (error components) was also tested, it did not improve model fit and substantially increased computational time. As a result, only inter-individual heterogeneity was retained in the final specification. Similar findings regarding the estimation with both inter- and intra-individual heterogeneity are also identified by Krueger et al. (2021).

The explanatory variables of the mixed-logit model are specified in Table 1. It is noted that travel time and cost were initially examined as alternative specific parameters, but after several trial and error tests it was considered more suitable to proceed with generic parameters. Considering that DTT and DTC were computed as travel time/cost with public transport minus travel time/cost with car, both parameters were added with a positive sign in the utility of car and with a negative sign in the utility of the public transport alternative. The cost of parking is included only in the car alternative, since parking cost does not exist for the public transport alternative. Moreover, parameters related to individuals' existing mobility preferences were only included in the utility of the public transport alternative. Finally, the panel effect term was added in the utilities of both alternatives.

Table 1. Description of model's explanatory variables.

Variable	Description
DTT	Travel time with public transport minus travel time with car
DTC	Cost with public transport minus cost with car
cost_park	Cost for parking
car_monthly_usage	Use of private car at least once per month (0: No, 1: Yes)
PT_monthly_usage	Use of public transport at least once per month (0: No, 1: Yes)
park_monthly_usage	Use of controlled parking system at least once per month (0: No, 1: Yes)

The probability that an individual n will choose an alternative i , for a given value of β_n is:

$$P_{ni} | \beta_n = \frac{e^{(V_{ni})}}{\sum_c e^{(V_{nc})}} \quad (4)$$

and the unconditional probability is specified as following:

$$P_{ni} = \int_{\beta_1} \int_{\beta_2} \int_{\beta_3} (P_{ni} | \beta) f(\beta | \theta) d\beta_1 d\beta_2 d\beta_3 \quad (5)$$

For estimating the mixed-logit model, the Simulated Maximum Likelihood approach was used, with 1,500 Halton draws (Halton, 1960). The analysis was conducted in the Apollo package (Hess & Palma, 2019), which is implemented in the R programming language (R Core Team, 2017). Within Apollo, the panel component was implemented through alternative-specific inter-individual error components, using separate draws for the car and public transport utilities that remain constant across repeated choice observations for each respondent.

4. Results

4.1. Descriptive statistics

The descriptive statistics offer a summary of the demographic and socioeconomic characteristics, existing preferences, and stated choices of the participants. Table 2 illustrates the demographic and socioeconomic characteristics of those engaged in the survey. A predominant portion of the participants comprises males (61.5%), with a full-time job (89.9%). Most of the respondents (54.3%) are aged between 25 and 39, while there is also a high share (34.1%) of respondents that are aged between 40 and 55. Regarding the monthly household income, all classes, except the first one, represent a sufficient sample.

Table 3 outlines the existing mobility preferences of the participants, emphasising the frequency of using private car, public transport, and the controlled parking system. The data reveal that respondents mainly rely on private cars for their trips to the city centre. There is only a small percentage (22.6%) that uses private car less frequently than once per month, while a significant 51.9%

Table 2. Participants' demographic and socioeconomic characteristics.

Variable	Categories	Frequency (%)
Gender	0: male	0: 128 (61.5%)
	1: female	1: 77 (37.0%)
	2: prefer not to answer	2: 3 (1.4%)
Age	0: 18–24	0: 8 (3.8%)
	1: 25–39	1: 113 (54.3%)
	2: 40–55	2: 71 (34.1%)
	3: 55–64	3: 11 (5.3%)
	4: >64	4: 5 (2.4%)
Occupation	0: full time employee	0: 187 (89.9%)
	1: part time employee	1: 5 (2.4%)
	2: unemployed	2: 4 (1.9%)
	3: university student	3: 8 (3.8%)
	4: retired	4: 4 (1.9%)
Monthly household income (in €)	0: 0–500	0: 2 (1.0%)
	1: 501–1000	1: 18 (8.7%)
	2: 1001–1500	2: 56 (26.9%)
	3: 1501–2000	3: 39 (18.8%)
	4: 2001–2500	4: 25 (12.0%)
	5: 2501–3000	5: 20 (9.6%)
	6: >3000	6: 35 (16.8%)
	7: prefer not to answer	7: 13 (6.3%)

of respondents use a private car on a weekly basis. On the other hand, public transport is being used by only 17.7% on a weekly basis. Moreover, it seems that the respondents have substantial experience of the controlled parking system, since only 14.9% has never used it and 53.8% uses it at least once per month.

Figure 3 summarises the responses about the perception of the respondents with regards to several hypothetical hourly prices, for on-street parking in the city centre. The results indicate that an hourly price of €1.50 is considered normal, prices between €1.75 and €2.00 are considered expensive, and prices equal or greater than €2 are considered very expensive. According to this distribution of responses, the existing parking price of 1.70 €/hour for the Thessaloniki's controlled parking system is considered expensive.

Table 4 presents the response frequencies for the stated preference scenarios and specifically how respondents' choices vary depending on changes in parking costs and time looking for a parking space. The results suggest that respondents' decisions are mainly driven by cost rather than time spent looking for a parking space; more specifically, private car seems to be the preferred choice, except in cases where parking costs are higher than 2 €/hour.

The choices in the stated preference scenarios are further analysed to explore whether respondents' existing mobility preferences have an impact on the choices in the stated preference context. The results indicate that there is a strong link between the existing preferences and the stated choices (Table 5). As the car usage frequency increases, and mainly as the controlled parking usage increases, the possibility of selecting a private car in the stated preferences scenarios increases significantly. On the other hand, those that currently use

Table 3. Existing mobility preferences.

Variable	Categories	Frequency (%)
Car usage frequency (general, not destination-specific)	0: never	0: 9 (4.3%)
	1: less than 1 time per 6 months	1: 10 (4.8%)
	2: 1–5 times per 6 months	2: 28 (13.5%)
	3: 1–3 times per month	3: 53 (25.5%)
	4: 1–2 times per week	4: 48 (23.1%)
	5: 3–5 times per week	5: 33 (15.9%)
	6: 6–7 times per week	6: 27 (13.0%)
Public transport usage frequency (general, not destination-specific)	0: never	0: 70 (33.7%)
	1: less than 1 time per 6 months	1: 39 (18.8%)
	2: 1–5 times per 6 months	2: 35 (16.8%)
	3: 1–3 times per month	3: 27 (13.0%)
	4: 1–2 times per week	4: 19 (9.1%)
	5: 3–5 times per week	5: 10 (4.8%)
	6: 6–7 times per week	6: 8 (3.8%)
Controlled parking usage frequency (general, not destination-specific)	0: never	0: 31 (14.9%)
	1: less than 1 time per 6 months	1: 26 (12.5%)
	2: 1–5 times per 6 months	2: 39 (18.8%)
	3: 1–3 times per month	3: 60 (28.8%)
	4: 1–2 times per week	4: 38 (18.3%)
	5: 3–5 times per week	5: 9 (4.3%)
	6: 6–7 times per week	6: 5 (2.4%)

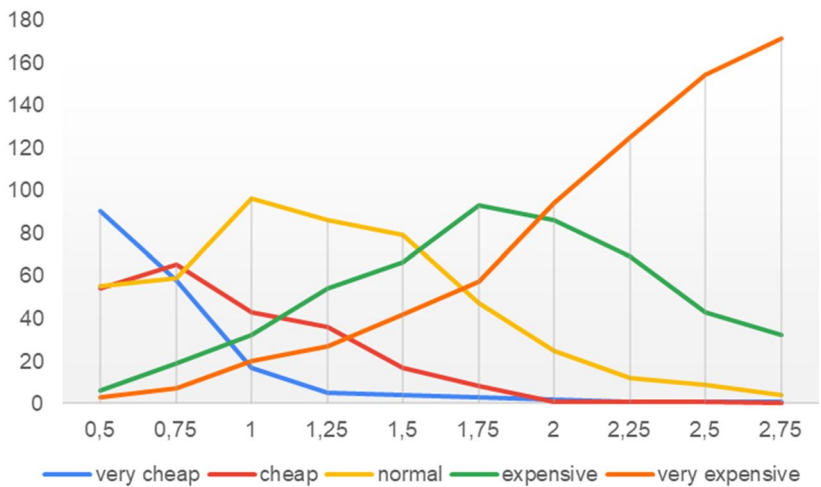


Figure 3. Perceptions regarding controlled parking pricing (absolute frequencies of responses).

public transport more frequently are much more possible to select public transport in the stated preference scenarios.

4.2. Mixed-logit model results

The results of the mixed-logit model are presented in Table 6. The δ_{car} value shows that there is an a-priori preference for the private car over the public

Table 4. Choices in stated preference scenarios.

Scenario	Parking cost for two hours	Time seeking for parking	Selected private car	Selected PT
1	2.0€ (1€/hour)	5 mins	161 (77.4%)	47 (22.6%)
2	5.5€ (2.75€/hour)	2 mins	84 (40.4%)	124 (59.6%)
3	0	15 mins	143 (68.8%)	65 (31.3%)
4	4.0€ (2€/hour)	5 mins	119 (57.2%)	89 (42.8%)
5	5.5€ (2.75€/hour)	10 mins	71 (34.1%)	137 (65.9%)
6	2.0€ (1€/hour)	15 mins	124 (59.6%)	84 (40.4%)

Table 5. Choices in stated preference scenarios in relation with existing mobility preferences.

		% selected car	% selected PT	Mann-Whitney U test	
				Z-value	P-value
Car usage frequency	Never	27.8	72.2	-5.186	<0.001
	Less than 1 time per 6 months	35.0	65.0		
	1–5 times per 6 months	44.6	55.4		
	1–3 times per month	62.6	37.4		
	1–2 times per week	58.0	42.0		
	3–5 times per week	60.1	39.9		
PT usage frequency	6–7 times per week	65.4	34.6	-12.340	<0.001
	Never	78.8	21.2		
	Less than 1 time per 6 months	55.6	44.4		
	1–5 times per 6 months	48.6	51.4		
	1–3 times per month	39.5	60.5		
	1–2 times per week	32.5	67.5		
Controlled parking usage frequency	3–5 times per week	50.0	50.0	-8.665	<0.001
	6–7 times per week	16.7	83.3		
	Never	33.3	66.7		
	Less than 1 time per 6 months	44.2	55.8		
	1–5 times per 6 months	56.0	44.0		
	1–3 times per month	60.6	39.4		
	1–2 times per week	71.1	28.9		
	3–5 times per week	61.1	38.9		
	6–7 times per week	90.0	10.0		

Table 6. Model results – parameter estimate.

Parameter	Estimate	95% CI	Std. error	Rob. t-ratio	p-value
δ_{car}	2.1209	[0.553, 3.689]	0.7999	2.360	0.0183**
δ_{PT}	0.0000	NA	NA	NA	NA
β_{cmu}	-1.2481	[-2.808, 0.312]	0.7959	-1.544	0.1226
β_{PTmu}	3.1542	[1.735, 4.573]	0.7239	4.198	<0.001***
β_{pmu}	-1.6617	[-3.047, -0.276]	0.7072	-2.167	0.0302**
μ_{cp}	-0.3692	[-0.616, -0.123]	0.1258	-2.457	0.0140**
σ_{cp}	0.7016	[0.490, 0.914]	0.1082	7.910	<0.001***
μ_{DTT}	-3.4377	[-4.615, -2.261]	0.6005	-4.804	<0.001***
σ_{DTT}	0.3435	[-0.416, 1.103]	0.3875	1.547	0.1218
μ_{DTC}	-0.5926	[-1.349, 0.164]	0.3863	-1.664	0.0960*
σ_{DTC}	1.1535	[0.725, 1.582]	0.2185	6.559	<0.001***
σ_{panel}	2.3851	[1.741, 3.029]	0.3288	6.649	<0.001***

 $n_{indiv} = 208$; $n_{obs} = 1248$

LL(start) = -1192.87; LL(final) = -563.88

AIC = 1149.76; BIC = 1206.18

Adj. $R^2 = 34.82\%$ *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

transport alternative. This preference is somewhat expected considering that the respondents already rely more on private cars for their trips to the city centre. The impact of the respondents' existing mobility preferences on their choices in the stated preference context is also reflected in the estimates of the model parameters, which are related to the frequency of using a private car, public transport and the controlled parking system. As it was observed in the descriptive statistics, these three variables influence the choice of the respondents, and as the model's results show, there is a much higher likelihood to choose the public transport alternative if the individual already uses public transport at least once per month. While the parameter associated with public transport monthly usage is statistically significant, the coefficient for car monthly usage does not reach conventional significance levels. Nevertheless, its sign is behaviourally consistent, indicating a lower propensity to shift away from the private car among habitual car users. Given the exploratory nature of the analysis and the role of this variable in capturing long-term mobility habits, it was retained in the model to preserve behavioural completeness and avoid potential omitted-variable bias. On the contrary, individuals who frequently use the controlled parking system are more inclined towards choosing the private car alternative.

Regarding the travel time and cost-related parameters both the signs and the magnitudes are reasonable. Although not all standard deviations of the random parameters are statistically significant, their inclusion allows for a flexible representation of inter-individual heterogeneity, which is particularly relevant in the context of parking pricing responses. Additional model estimations in which the standard deviation of the travel time difference parameter was

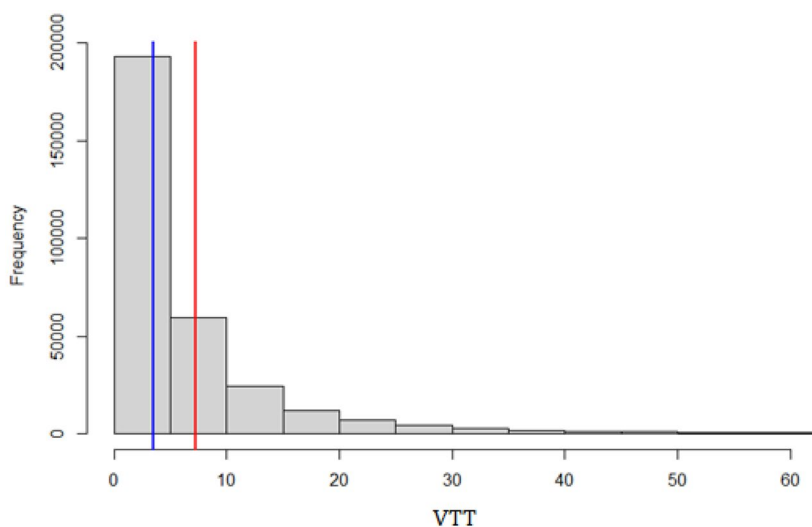


Figure 4. Value of travel time distribution (mean in red line and median in blue line).

constrained to zero resulted in slightly worse model fit, while the remaining parameter estimates remained stable. Based on the t-ratio values of the standard deviations, substantial heterogeneity is identified across individuals, specifically with respect to the cost-related parameters. The presented evaluation metrics of the model significantly outperform the metrics of a respective standard logit model that was initially developed, indicating that the consideration of the inter-individual heterogeneity is essential for more robust estimations.

Based on the travel time and cost parameter estimates, the value of travel time (VTT) and its distribution is being computed (Figure 4). The mean VTT is equal to 7.20 €/hour (red line in Figure 4), while the median VTT is equal to 3.49 €/hour (blue line in Figure 4). There is a right-skewed distribution, with most individuals having a VTT lower than 5.00 €/hour.

4.3. Modal share estimations

For examining the impact of different on-street parking prices on the shift to public transport, a synthetic dataset was generated and used for out-of-sample predictions. This dataset included the same variables that were used in the estimated mixed-logit model and each variable was generated based on the following rules:

- `car_monthly_usage`: for 77.5% of the cases the value is 1 (yes) and for the rest of the cases 0 (no)
- `PT_monthly_usage`: for 30.8% of the cases the value is 1 (yes) and for the rest of the cases 0 (no)
- `park_monthly_usage`: for 53.8% of the cases the value is 1 (yes) and for the rest of the cases 0 (no)
- `DTT`: continuous values with mean equal to 14 and standard deviation equal to 15
- `DTC`: continuous values with mean equal to -0.31 and standard deviation equal to 0.86
- `cost_park`: four different scenarios were examined (1.0, 1.7, 2.0, 2.5 €/h).

The abovementioned frequencies, mean values and standard deviations were defined based on the respective values of the original dataset. Since random sampling was followed during the data collection process, it can be reasonably assumed that these values are representative of Thessaloniki's population.

Using the abovementioned synthetic dataset, and based on the estimated mixed-logit model, the shares of private car and public transport were estimated for each one of the four pricing scenarios that were examined. The modal share estimations are presented in Table 7 and Figure 5. It is noted that the 1.7 €/hour was used as a baseline, since it consists the current pricing of the controlled

Table 7. Modal share per pricing scenario (relative values).

Parking duration	Pricing	Private car share	PT share	PT difference (comparing to baseline)
Short-term (30 mins)	Baseline (0.85)	71%	29%	–
	Low (0.50)	73%	27%	–6.9%
	Mid (1.00)	70%	30%	+3.4%
	High (1.25)	69%	31%	+6.9%
Mid-term (1 hour)	Baseline (1.70)	66%	34%	–
	Low (1.00)	70%	30%	–11.8%
	Mid (2.00)	64%	36%	+5.9%
	High (2.50)	60%	40%	+17.6%
Long-term (2 hours)	Baseline (3.4)	55%	45%	–
	Low (2.00)	64%	36%	–20%
	Mid (4.00)	51%	49%	+8.9%
	High (5.00)	45%	55%	+22.2%

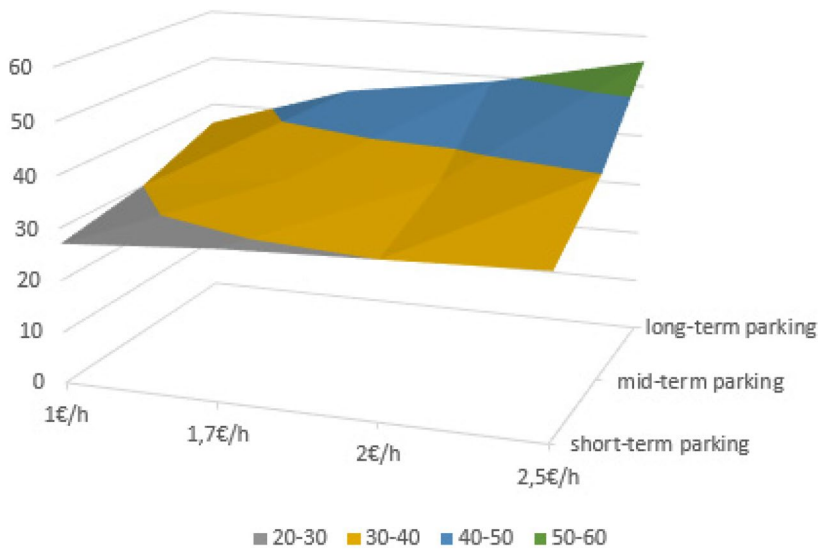


Figure 5. Public transport modal share (relative values) in relation with parking pricing and duration.

parking system. The results show that for the most of the examined cases, public transport modal share is almost half of the private car modal share (30–40% vs 60–70%). However, this difference is being bridged to a large extent in the case of long-term parking; especially for prices of 2 €/hour, public transport becomes equally attractive with private car.

Going the analysis one step further, an attempt to estimate absolute (and not relative) values of the modal share of the two modes is being made. For doing so, modal share values from the Thessaloniki’s strategic traffic model (i.e. the one used for city’s SUMP) are being extracted and especially for trips that have the city centre as a destination and are being conducted for purpose other

Table 8. Modal share per pricing scenario (absolute values).

Pricing scenario	Private car share	PT share
Baseline (1.70 €/hour)	37.0%	31.0%
Low (1.00 €/hour)	43.2%	24.8%
Mid (2.00 €/hour)	34.2%	33.8%
High (2.50 €/hour)	30.1%	37.9%

than going to work or education (since the purpose of the visitors parking spaces of the controlled parking system is not to serve these types of trips). According to Thessaloniki's strategic traffic model, the absolute modal share of private car for this group of trips is 37% and the one of public transport is 31%. These absolute modal share values are proportional with the relative modal share values that were presented in [Table 7](#) for the baseline scenario in the case of long-term parking (as mentioned in [Section 3.1](#) the average parking duration is approximately 2 hours, which expresses the long-term parking case). Thus, using the percentage differences for the public transport modal share, that were presented in [Table 7](#) for the long-term case, absolute modal shares for the two modes can be estimated for each pricing scenario, for trips that are destined to the city centre and have purpose other than going to work or education ([Table 8](#)). This calculation assumes that the relative modal share changes estimated from the stated preference model can be proportionally transferred to the baseline modal shares derived from the strategic traffic model. As a result, the values reported in [Table 8](#) should be interpreted as indicative scenario estimates rather than precise forecasts of future modal shares.

5. Discussion and conclusions

This study illustrated the status quo of the citizens of Thessaloniki, which are largely constrained by the transport options available to them due to the lack of alternatives and a strong reliance on private car usage. Over recent years, there has been a gradual shift in two key aspects: the evolving preferences of residents and the implementation of infrastructure and policies aimed at promoting sustainable mobility. This shift is facilitated by the introduction of new shared mobility services, as well as by policies and interventions like expanded bike lanes, revised parking policies, and stricter enforcement measures in the city centre (Thessaloniki's Sustainable Urban Mobility Plan, 2019). The metro system, which became operational in the end of 2024, is already reshaping the city's urban mobility landscape. Accordingly, there is a continuing need to guide these changes towards more sustainable mobility by defining appropriate transport policies, including strong public space regulation, to integrate traditional and innovative transport modes while incentivising citizens to adopt more sustainable options.

In this study, we utilised survey data from Thessaloniki in 2023 to explore the impact of fluctuating parking fees on mode choice, specifically focusing on

public transport. Results indicate that an essential parameter that has the potential to incentivise or discourage the use of private vehicles is the direct cost of the trip. The parking cost stands out as the sole out-of-pocket expense directly associated with the trip itself and unlike other travel costs that may be more indirect or obscured, such as fuel or maintenance, parking fees are immediately visible and tangible to travellers. This means that an important share of the citizens in Thessaloniki do not weight with the same importance different factors such as time, fixed and operation costs when selecting a transport mode, which favours the selection of private cars and not public transport.

Based on findings in this study, dynamic pricing may shift more travellers into PT when local conditions and travel behaviour are considered into transport planning. When local conditions and individual travel behaviours are integrated into transport planning strategies, dynamic pricing emerges as a potent tool. It can effectively incentivise travellers to opt for PT options by adjusting fares based on real-time demand, congestion levels and time of day. This adaptive pricing approach encourages more efficient use of public transit and also contributes towards alleviating traffic congestion and reducing carbon emissions.

More generally, the developed model can support parking policy making by providing the city administration with actionable insights on how to apply dynamic or static pricing to the existing parking facilities in the city centre, which can significantly reduce the number of vehicles circulating for parking a space (Mackowski et al., 2015). Moreover, the model results can feed local transport models with realistic mode choice parameters to better analyse the scenarios defined in the SUMP, especially the ones involving multimodal hubs or park and ride facilities and support the governance of the local eco-system illustrating educated guests with data-driven insights and quantitative results. It allows to define the maximum and minimum thresholds of parking fares and determines whether they should be dynamic or static, providing a tool to enhance the usage of public transport.

It also allows to improve public transport attractiveness and transport justice by alleviating social inequalities with regards to the affordability of the cost of transport and improving equity. This is especially important for the future transport landscape, where mobility-as-a-service business models will change the cost for using different mobility means. Focusing on the social perspective of parking pricing, the results suggest that: a) there is high heterogeneity for cost parameters, which indicates that a proportion of travellers are affected more towards shifting to public transport, and b) although the average travellers' value of travel time (VTT) equals 7.20 euro per hour, the distribution shows that the majority of values (median) approximates 3.5 euros per hour, thus the impact from parking pricing differs among different traveller groups. For comparison, previous studies have reported higher values of travel time for car drivers, with estimates of around €9.25 per hour for commuting trips in the Netherlands (Kouwenhoven et al., 2014) and approximately €14.32 per hour for car drivers

in Austria (Hartwig et al., 2024). This finding may infer both positive and negative impacts related to social perspective, however, early identification of negative effects may be alleviated by developing suitable transport policies.

Low-income travellers are disproportionately affected by increases in parking fees due to their limited financial resources, are more sensitive to changes in parking fees, and they might be compelled to shift to public transport options, which are generally more affordable. As mentioned such a shift may be seen as positive from a social perspective by providing more equitable access to transport for all income groups; it can also reduce congestion and environmental pollution, benefiting the overall community. However, a group of travellers with high VTT are willing to pay more for the convenience and efficiency of parking in certain locations or at specific times. While higher-income travellers may not be as deterred by increased parking fees, lower-income individuals may face greater challenges in accommodating these changes. Measures should be taken to mitigate the potential adverse effects on low-income travellers, while leveraging dynamic pricing to incentivise mode shifts towards public transport. Subsidies or discount-fare programs can be targeted at low-income individuals, and a share of revenue generated from dynamic pricing schemes may be used to fund such strategies or/and expand public transport service to underserved communities.

From a policy perspective, the results provide quantitative guidance on parking pricing levels capable of inducing meaningful, yet socially acceptable, modal shifts. The findings indicate that a moderate increase in parking prices to approximately €2.00 per hour can lead to an increase of around 3 percentage points in public transport mode share compared to baseline conditions. While this shift alone does not fully achieve the targets set in Thessaloniki's SUMP, which aims to increase public transport share from approximately 32% to 38–40% by 2030, it represents a significant and realistic step in that direction. The results further suggest that differentiated pricing by parking duration can reinforce this effect, particularly by discouraging longer stays in the city centre. When combined with complementary measures that improve the attractiveness of public transport, moderate parking pricing policies can contribute meaningfully to achieving the SUMP objectives in a socially acceptable manner.

The primary policy-based insight of this study is that parking pricing, particularly when applied dynamically and in relation to parking duration, may be a powerful actionable lever for influencing travel behaviour in dense urban areas. When parking prices exceed locally affordable levels, a noticeable shift from private car use to public transport is observed, even in cities with limited public transport alternatives. This indicates that well-calibrated parking pricing policies can serve as parking management tools as well as effective demand-management instruments that support broader sustainable mobility objectives.

With regards to the limitations of the model, it does not allow the users to change destination, which for no home-work trips can have a significant impact since the parking cost is an important factor to select destination, more than

mode; however, this flexibility in changing destination only applies to a small portion of the trips so the overall impact of this limitation is reduced. Additionally, the model does not include the reduced time looking for a parking due to the less demand for parking places and the unique alternative to the private vehicle in the model is the mass public transport, while nowadays other modes like micro-mobility or active mobility are serious alternatives in city centres, even car sharing services can be an interesting alternative to analyse, since in many of these systems parking is free; however, these limitations are overpassed when applying the whole four steps transportation model. Furthermore, the relatively modest sample size limits the precision of the estimated random parameter distributions, and future studies with larger samples could improve the robustness of the results, particularly with respect to inter-individual heterogeneity. It is also noted that the margin-of-error calculation reported in the paper reflects survey sampling precision rather than the stability of random parameter distributions in the mixed logit model, and therefore the estimated standard deviations of the random parameters should be interpreted with appropriate caution. In addition, larger samples would allow a more detailed investigation of how heterogeneity in cost sensitivity correlates with socioeconomic characteristics, enabling a more data-driven assessment of the equity implications of parking pricing policies.

Finally, future research directions could include more modes in the analysis, such as active or micromobility modes or apply game theory and/or system dynamics methods to assess “negotiation” capabilities of the relevant actors and allow iterations to converge to more robust results. For the latter, the tool could be used to identify the first- and second-best solutions for parking pricing in the city, weighting social welfare of citizens and private earnings of parking operators (Magsino et al., 2022). Time restrictions have been also found to be a significant factor when incorporated into strategies for managing parking behaviour (Mingardo et al., 2022); maximum parking time rather than using only dynamic pricing should be further explored to estimate joint impacts towards modal shift.

Additionally, focus groups and co-creation techniques could be applied to involve all the relevant actors in the decision-making process, and not only having the view of the end users, or the synergies of dynamic parking pricing with other similar strategies such as urban tolling system or even Low Emissions Zones as well as in the overall Mobility as a Service business model could be analysed.

Author contributions

CRedit: **Andreas Nikiforiadis**: Conceptualization, Data curation, Formal analysis, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing; **Lambros Mitropoulos**: Data curation, Writing – original draft, Writing – review & editing; **Annie Kortsari**: Data curation, Project administration; **Josep Maria Salanova Grau**: Conceptualization, Validation, Writing – original draft; **Georgia Ayfantopoulou**: Conceptualization, Supervision.

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