Framework and Model for Parking Decisions

Ofir Hilvert, Tomer Toledo, and Shlomo Bekhor

The search for available parking is one of the most challenging consequences of global urbanization and growth in motorization. This paper presents an overall framework for parking choice and search behavior, composed of three time–space phases: (*a*) pretrip static decision; (*b*) en route, passive search; and (*c*) in-area search strategy adaptation. The empirical part of the paper focuses on the first phase and describes a parking choice model that is based on pooled stated and revealed preference data sources. A special, web-based survey was designed to model the choice of parking type (on-street versus off-street parking). The model estimation results showed that the choice of parking location was affected by parking cost, search time, and walk time to the destination, facility type, and decision-maker characteristics. The model was applied to a case study to illustrate its capabilities to evaluate various policy measures. Specifically, the effect of a change in the demand for on- and off-street parking was evaluated with respect to the parking pricing policy and the value of search time for various parking durations.

To find a parking spot in urban centers is an increasingly difficult task. Substantial time is spent by drivers as they cruise for a vacant space. Shoup (*1*) reviewed several studies that, on average, estimated that vehicles in search of parking amounted to 30% of the total traffic in the areas assessed. Slow-moving vehicles in search of a vacant parking space affected other vehicles and added to the congestion already prevalent in many urban centers. This problem is likely to worsen with the continued growth in urbanization and motorization.

The significant disutility associated with the search for parking makes it a useful tool for urban transportation planners and managers (*2*). A wide range of technological and policy tools that address parking are used to control and manage both transportation demand (*3*) and supply (*4*). Parking-related measures include those taken to set the number of available parking spots and their spatial distribution, to set parking prices, limit parking duration, and develop free park-and-ride facilities around a city center. Implementation of such measures affects not only the mode of travel (*5*) but other travel decisions, too, such as destination, time of travel, and whether or not to change or cancel various activities (*4*). Successful design and implementation of such policies depend on the ability to understand and predict their implications for traveler behavior. Therefore, a wide range of studies have focused on the identification of the role of various parking attributes that affect driver choices. One method is to apply individual-level, disaggregate, travel behavior models.

The development of such models commonly includes administration of surveys to collect data on individual travel preferences. The data collected are then used to identify the influential variables that will be incorporated into the model.

Different parking choice models have been proposed in the literature. They can be classified with respect to the modeling approach, decision type, number of decisions modeled, and the data collection method [i.e., stated preference (SP) versus revealed preference (RP)]. Most parking models address mode-of-travel choices and parking characteristics (*6*–*8*) rather than the choice between parking alternatives. In addition, most research has considered parking choice as a stand-alone decision rather than as a component in a broader behavioral framework. The following paragraphs summarize selected parking type choice models that have been studied.

In 1982, Van der Goot (*9*) presented a multinomial logit (MNL) model for the choice among 22 parking alternatives that included illegal parking; off-street, multistory parking; and parking in on-street and off-street lots. The data set had its basis in an RP survey among drivers in the center of Haarlem, Netherlands. The results showed the importance of the walk time from the parking stall to the destination, and an inherent preference for off-street parking.

In 1988, Axhausen et al. (*10*) proposed an MNL model for the choice among three parking types: illegal parking, on-street parking, and off-street parking. The alternatives were described by their access time, search time, egress time, and parking cost. The data set for the model estimation consisted of a sample of 466 participants in an SP survey in Karlsruhe, Germany. The study emphasized how important it was to distinguish between different groups of individuals when a parking policy was set.

In 1997, Teknomo and Hokao (*6*) introduced an MNL model for the choice between an on-street parking space, off-street parking lot, and an off-street, multistory parking facility. The model had its basis in an RP survey among 528 drivers, who parked in the center of Surabaya, Indonesia. According to the model results, the choices made among parking types related to search and queue time, walk time, and parking cost.

In 2002, Golias et al. (*11*) presented a binary logit model for the choice between on-street and off-street parking. The model drew on 3,451 observations from 317 drivers, who participated in an SP survey administered in the center of Piraeus, Greece. A basic, although expected, finding of this research was that the cost of parking had the biggest impact on choice: the cheaper the parking alternative, the more attractive it became.

In 2004, Hess and Polak (*8*) presented a random coefficients logit model for the choice among five parking types: free on-street, charged on-street, charged off-street, multistory parking facility, and illegal parking. The model had its basis in 1,335 observations from a sample of 298 respondents in an SP survey conducted during 1989

in Birmingham, Sutton, Coldfield, and Coventry, United Kingdom. The model estimation results revealed differences in the coefficients of the explanatory variables by location and trip purpose and established the existence of random taste heterogeneity.

The aim of the present study reported in this paper was twofold: (*a*) to develop a general framework for a parking behavioral model that described the entire parking choice and search process and (*b*) to develop a model for the pretrip parking location choice component of the proposed framework. This model was formulated and estimated with the use of a combination of SP and RP data.

CONCEPTUAL FRAMEWORK

The proposed parking behavior framework is presented in Figure 1. It consists of several decisions that drivers make during their search for and selection of parking. These decisions are linked to spatial and temporal characteristics. More precisely, three distinct, travel-related phases in the parking search process were assumed.

Pretrip

The first phase includes driver parking decisions and considerations made before the actual trip. A driver's pretrip decisions establish his or her initial intentions. These decisions include the choice of parking type, parking facility, or on-street search area and route choice.

En Route

In the second phase, the driver is on the way to his or her destination and uses the route chosen pretrip. As the driver approaches the destination, he or she passes a search awareness point (*12*). This point, which may be defined by a walking distance to the destination, is where the search for parking begins. From this point on, the driver passively searches for parking until he or she reaches the search area or the parking facility chosen pretrip. The passive search is a general scan of the streets the driver passes through as he or she continues en route toward the destination. If during this scan the driver identifies
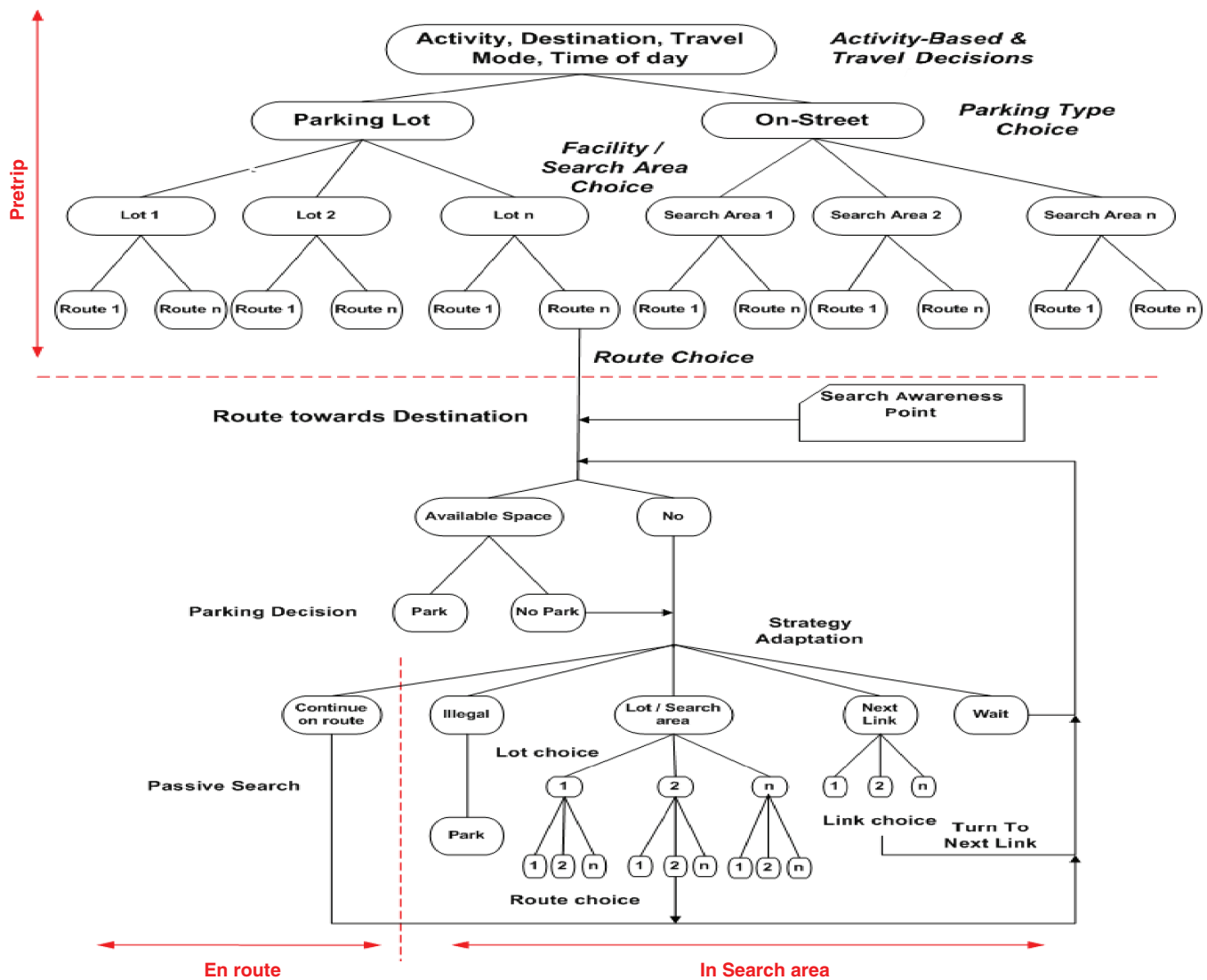

FIGURE 1   Conceptual framework for parking decisions.

an available parking space, he or she will evaluate it to decide whether to use it or to continue toward the destination.

Search Area

The third phase begins as the driver enters the search area, which is defined as the area in which the driver reduces travel speed while he or she scans for a vacant space near the destination. If a parking space is not found, the driver chooses one of several possible parking strategies. Relevant strategies include to park illegally, drive to another parking facility or an alternative search area, continue to search for parking in the same area and thus to choose the next segment on the search route, or to wait at the parking lot entrance, or in the street, for a parking space to become available. The decision on parking strategy is made dynamically and could be revised by the driver during the search.

The various decisions that drivers make depend on their own characteristics and on the attributes of the trip and the intended activity (e.g., purpose of trip, duration of activity). Values for these variables may be input from activity-based models or traditional demand models.

The remainder of this paper focuses on the pretrip phase of the parking behavior framework (i.e., choice of parking type and facility or search area), which functions as the basis of dynamic parking behavior en route and in the search area.

DATA COLLECTION

Successful design and implementation of parking policies depend on the ability to predict their implications for traveler behavior. For this purpose, an individual-level, disaggregate parking behavior model was developed. Model development commonly involves administration of surveys to collect data on individual preferences.

Data collection in this study focused on the central area of Tel Aviv, Israel, whose parking problems are severe, for both residents and visitors. The Tel Aviv metropolitan area has a population of 3.2 million, with 0.4 million in the city itself. It is the country's major economic center, especially in the business and finance sectors. The average household income in the city is 14% higher than the national average. The city center suffers an acute shortage of parking, with search time estimated at 20 to 25 min (13).

Given the advantages and disadvantages of SP and RP data (14), it was decided to estimate a model on the basis of combined preference data. The combined approach allowed for improvement in the efficiency of the estimation and a higher validity in the results than otherwise. The SP data were collected through a controlled experiment design. It was therefore feasible to collect a larger data set with varying attribute levels that supported estimation of trade-offs. At the same time, the use of the RP data ensured that the validity of the estimation results would be maintained at a high level.

Earlier studies on parking behavior used face-to-face interviews as the primary survey instrument, mainly because of the need to recall a specific part of the trip related to parking. In the study reported in this paper, data were collected with a web-based survey, which examined the parking habits and preferences of respondents. Web-based questionnaires are an efficient tool to collect preference information at low cost. Data provided in Internet surveys are at least as good in quality as those provided by traditional methods (15).

In the RP part of the survey, the respondents were first asked about their most frequent trip as drivers. The next questions referred to that trip and its parking characteristics (e.g., trip origin, destination and purpose, parking search time, walking time to the destination, parking costs, parking duration, trip frequency). Respondents also were asked about any alternative parking options that they had considered. If the most frequent trip did not involve a search for a parking space (i.e., driver had a designated space), respondents were asked to report the most recent trip (within a month) in which they needed to search for parking. For respondents that reported that they did not search for parking, the RP part of the survey was skipped, and the respondent was presented with the SP part only.

The SP experiment included nine hypothetical choice situations with three parking alternatives for each respondent. The alternatives were composed of bundles of five parking attributes: parking duration; type (on-street or off-street); price; search time, if on-street parking was sought, or wait time at the lot entrance, if a space in an off-street facility was sought; and walk time to the destination. The number of attribute levels was set to three for each attribute, except parking type, which had two levels.

The attribute levels used in the experiment were selected to allow a trade-off between values that made sense to the respondents and were close to their own experience (14), and a statistical preference for a wide range. For example, the average hourly parking price for on-street parking in Tel Aviv at the time of this study was 5.3 New Israeli Shekels (NISs) (approximately US $1.50), and the average, off-street hourly price was 12 NIS (approximately US $3.40). These values were used as midpoints of their respective attribute levels. The midpoint values for the time variables in the survey were chosen in a similar way on the basis of midvalues found in a pilot and in previous studies in the Tel Aviv area. Table 1 shows the various attributes and their possible values in the experiment. Figure 2 shows an example choice scenario.

The choice scenarios were constructed from a $3^4 \times 2$ full factorial design, which resulted in 162 alternatives. To reduce the number of choice combinations, an orthogonal fractional factorial design was applied, which resulted in 27 alternatives (16). In addition, the efficient

TABLE 1   Attributes and Their Levels in Choice Experiment

Attribute	Levels	
	On Street	Off Street
Price per hour (NIS)	0	8
	5	12
	10	16
Searching time, on street (minutes)	0	na
	10	na
	20	na
Waiting time, off street (minutes)	na	0
	na	5
	na	10
Walking time (minutes)	0	0
	10	10
	15	15
Parking duration (hours)	1	1
	3	3
	5	5

NOTE: 3.5 NIS ≈ US $1; na = not applicable.

	Alternative 1A	Alternative 2	Alternative 3
The planned parking duration is 1 hour. Which alternative will you choose?			
Parking type	On-street (5 NIS/hr)	Off-street (16 NIS/hr)	Off-street (8 NIS/hr)
Overall parking price (NIS)	5	16	8
On-street parking search time (min.)	10	—	—
Off-street parking entry queue time (min.)	—	0	10
Walking time to destination (min.)	15	0	10

FIGURE 2   Example scenario in stated preference questionnaire (— = not applicable).

design approach (*17*) was adopted to generate the combinations of three alternatives in each choice set and rule out dominant choice situations. The 27 choice sets in the final design were too many for respondents to evaluate. Therefore, they were blocked into three balanced sets of nine choice sets. Respondents were randomly assigned to blocks and then presented with the nine SP choice sets within this block. This number was reasonable and consistent with recommendations in the SP experiments' literature (*18*). The order of the questions within a block was randomized for every respondent.

The last part of the survey solicited demographic and socioeconomic information regarding age, marital status, household size, number of children, auto ownership, number of weekly driving hours, and income.

The survey was conducted during the months of July and August 2010. It was advertised through an e-mail message that contained a web link to the questionnaire. In addition, 500 colored, postcardsized leaflets were distributed among residents of the center of Tel Aviv. To encourage participation in the survey, respondents were entered into a drawing for 20 electronic parking payment devices (worth about $40 each). The resulting sample consisted of observations from 165 respondents that completed the SP part of the survey; of these respondents 112 also completed the RP part. The combined data set included 1,597 observations.

MODEL FORMULATION

In accordance with random utility theory, the utility of an alternative is specified by

$$U_{in} = X_{in}\beta_i + v_{in} \tag{1}$$

where

U_{in} = utility of alternative i to individual n,
X_{in} = vector of attributes,
β_i = corresponding parameters, and
v_{in} = random error terms.

The preference data consisted of up to 10 observations for each respondent (one RP and nine SP). Therefore, the MNL assumption (i.e., that the error terms were independently and identically distributed, which implied no correlation between observations and alternatives) was not realistic. Instead, it could be assumed that the error components of the utility were independent across respondents

but not within the choice situations of the same individual (*19*). To neglect these correlations might cause serious estimation errors (*20*). To capture a variety of heterogeneity sources among individuals, a more flexible mixed logit error structure model was adopted. The error term was decomposed into two parts, which were mutually independent: an individual-specific error term, which was independent across respondents but did not vary across the observations of the same individual; and a generic error term, which was independent across both individuals and choice scenarios. The resulting utility formulation is given by

$$U_{int} = X_{int}\beta + \eta_n + \varepsilon_{int} \tag{2}$$

where the error term ε_{int} is an independently and identically distributed Gumbel random variable and η_n is an individual-specific random term. The individual effect was assumed to be normally distributed. The resulting choice probabilities, conditional η_n, are given by

$$P(y_{in} = 1|\eta_n) = \frac{e^{\mu(X_{in}+\eta_n)}}{\sum_{j\in C_n} e^{\mu(X_{jn}+\eta_n)}} \tag{3}$$

where

y_{in} = choice indicator (equal to 1 if alternative i is chosen, and 0 otherwise),
j = specific alternative (choice set),
C_n = choice set considered by individual n, and
μ = scale parameter.

The motivation for a combined RP-SP model estimation was the potential to gain in the accuracy of parameter estimates and to avoid biases inherent in SP responses. The combined estimation consisted of maximization of the joint likelihood function. The RP and SP formulations for an individual n can be stated as follows:

$$p(y_{int}^{SP})|\eta_n = \frac{e^{\mu^{SP}(\beta X_{int}+\gamma Z_{int}-\eta_n)}}{\sum_j e^{\mu^{SP}(\beta X_{jnt}+\gamma Z_{jnt}+\eta_n)}} \tag{4}$$

$$p(y_{int}^{RP})|\eta_n = \frac{e^{\mu^{RP}(\beta X_{int}+\alpha W_{int}+\eta_n)}}{\sum_j e^{\mu^{RP}(\beta X_{jnt}+\alpha W_{jnt}+\eta_n)}} \tag{5}$$

where

> α, β and γ = vectors of unknown coefficients;
> X, Y and Z = vectors of explanatory variables common to RP and SP data, and specific to RP and to SP, respectively;
> μ_{int}^{SP} and μ_{int}^{RP} = scale parameters of error terms for SP and RP data, respectively; and
> jnt = a combination of specific alternative j in the choice set C_n (of individual n) that is in observation/ question t.

The probability, conditional on the individual-specific term, that an individual n makes the sequence of nine SP choices and a single RP observation is the product of the individual probabilities as follows:

$$p(Y_n | \eta_n) = \prod_{t=1}^{T=9} p(y_{int}^{SP} | \eta_n) \times p(y_{in}^{RP} | \eta_n) \qquad (6)$$

where $Y_n = [y_{n1}^{SP}, \ldots, y_{n1}^{SP}, y_n^{RP}]$ is the vector of choices made by individual n.

The unconditional probability of the sequence of choices is given by

$$p(Y_n) = \int p(Y_n | \eta) f(\eta) d\eta \qquad (7)$$

where $\eta \sim N(0, \sigma^2)$.

Finally, the log-likelihood function is given by

$$LL = \sum_{n=1}^{N} \log p(Y_n) \qquad (8)$$

RESULTS

Sample Characteristics

In the RP data, 40% of the respondents reported on their frequent trip, 53% referred to the last trip, and only 7% indicated that they did not search for parking at all during the last month (and thus did not provide an RP observation). Of the reported trips, 48% were for work or educational purposes. Of the respondents, 52% were students, and 44% were employed. Thus students were overrepresented in the sample, perhaps for several reasons. First, young adults, and students in particular, constitute a large proportion of the population in the Tel Aviv city center. Of the adult population, 33% are 29 years of age or younger (*13*). Second, drivers were not included in the sample that did not need to search for parking (e.g., they had access to employer-provided or other designated parking). Designated parking often was available to employees in the area but not to other travelers. Finally, the use of a web-based survey might have resulted in overrepresentation of technologically affluent populations.

The potential for bias, introduced by the overrepresentation of students in the sample, was addressed through interaction variables of student status with various parking attributes in the model. In the reported trips, 53% of the drivers drove alone, 30% traveled with a single passenger, and 17% had two or more passengers. Of the respondents, 72% indicated that a car was their main transportation mode, 15% used public transportation, 4% used a motorcycle or bicycle, and 3% walked. Most respondents drove their cars more than 2 h a week (79%). The high share of respondents that indicated

that a car was their main transportation mode was confirmation, in addition to the data on car use, of the intended target population. In terms of type of parking used, 60% of the respondents reported parking on the street, 27% parked off the street, and 13% had reserved parking. The average parking duration was 3:22 h. The average parking price was 5 NIS (~$1.4). Of the respondents, 83% paid up to 10 NIS (~$2.8) to park. In their search for parking, 44% spent less than 5 min, 34% spent between 5 and 10 min, and the remaining 22% searched for more than 10 min. For off-street parking, the average wait time in front of the parking facility was 1:38 min. In terms of travel on foot from their parking spaces to their destinations, 68% walked for less than 5 min, 26% walked between 5 and 10 min, and the remaining 6% walked more than 10 min.

Model Estimation

Three models were estimated for the parking choice: (*a*) MNL model with RP data, (*b*) panel model with SP data, and (*c*) joint RP-SP panel model with all available data. Table 2 presents the estimation results for the three models and the definitions of the variables included in them.

Model 1. RP Model

The model included attributes of the various alternatives and the sociodemographic interaction variables. Consistent with earlier studies of parking and modal choice and with economic theory, the coefficients of the hourly price (PricePerHr) and the price squared (PriceSqr) variables were both negative. However, the relatively low value of the PriceSqr coefficient suggested that drivers mainly considered the hourly parking price and paid less attention to the total price. The coefficients of the In-Vehicle and Walk time variables were both significant and negative, as expected. No-Walk was a dummy variable for parking alternatives that involved little or no walking at all (under 1 min). The coefficient of this variable was insignificant and, contrary to expectations, negative. This result may be explained by the small number of RP observations with short walking times. The coefficient of the off-street type dummy variable was significantly negative, which meant that drivers preferred on-street parking, ceteris paribus. For drivers more than 50 years old, this effect was offset by the positive coefficient of the interaction variable TypeOld. Student-Price and PriceAlone represented additional price sensitivities for students and drivers that traveled alone.

Model 2. SP Model

The additional parameter SIGMA was the standard deviation of the normally distributed, individual-specific error term η. Unlike the RP model, in this model, all parameters were statistically significant, and had the expected sign, with the exception of the coefficient of the TypeOld variable. Most parameter estimates aligned well with those obtained in the RP model but not in the case of the coefficient of the off-street type dummy variable. This parameter was positive and significant. The variable SP-RPChoice aimed to capture any justification biases. It referred to the parking type preference of drivers that reported in the RP survey that they parked on the street. The significant negative coefficient of this parameter indicated a consistent aversion to off-street parking by these respondents. The

TABLE 2 Model Estimation Results

Variable	Description	(1) RP Model Estimates (t-stat.)	(2) SP Model Estimates (t-stat.)	(3) RP-SP Model Estimates (t-stat.)
InVehTime	Waiting time + search time (minutes)	−0.0836 (−2.20)	−0.0868 (−10.61)	−0.0880 (−10.80)
PricePerHr	Overall parking price or parking duration (NIS)	−0.0707 (−1.12)	−0.121 (−7.18)	−0.122 (−7.33)
PriceSqr	Squared overall parking price (NIS²)	−0.000397 (−0.83)	−0.0011 (−12.88)	−0.00111 (−12.96)
PriceAlone	Price per hour × drive alone dummy	−0.131 (−1.59)	na	−0.168 (−1.02)
RP-Type	Dummy for off-street parking type (RP)	−1.31 (−2.51)	na	−1.42 (−2.29)
SP-Type	Dummy for off-street parking type (SP)	na	0.745 (3.18)	0.643 (2.85)
SP-RPChoice	RP on-street parking type dummy × SP off-street parking type dummy	na	−0.488 (−1.90)	−0.345 (−1.33)
Walk	Walking time to the destination (minutes)	−0.144 (−2.35)	−0.0913 (−5.09)	−0.0970 (−5.53)
No-Walk	Dummy for a short walking time (≤ 1 min).	−0.568 (−0.42)	0.451 (2.19)	0.390 (1.93)
TypeOld	Interaction: old age (>50) × parking type dummy	1.31 (2.03)	−0.0263 (−0.08)	na
Student-Price	Interaction: student dummy × overall parking price	−0.0270 (−0.94)	−0.0154 (−2.38)	−0.0156 (−2.42)
SIGMA	STD (σ) value for the normal distributed error term [η ~ N(0, σ²)]	na	1.16 (9.04)	−1.15 (−9.00)
MU	SP-RP scale parameter (μ)	na	na	0.556 (2.63)
Number of observations		112	1,485	1,597
Number of cases		112	165	204
Number of parameters		9	10	12
L(0)		−77.632	−1,631.439	−1,709.072
L(β)		−56.001	−1,281.379	−1,342.004
McFadden $\bar{\rho}^2$		0.163	0.208	0.208

NOTE: na = not applicable; t-stat. = t-statistic.

parameter of the No-Walk dummy variable was significant and positive, which implied that drivers preferred parking alternatives that did not involve the need to walk. The additional price sensitivity of student status was captured by the coefficient of the StudentPrice interaction variable. The student status might have served here as a proxy for low income.

Model 3. Joint RP-SP Model

The signs of the coefficients of the off-street type variables (RP and SP) in Models 1 and 2 were opposite. For this reason, in the joint model, the type parameter was estimated separately for the two data sources. In this way, the SP and RP data were pooled because differences between data sources were allowed in the type parameter. The coefficients of the No-Walk and TypeOld variables also were opposite in the two models. However, the No-Walk parameter was not significant in the RP data, and its parameter was estimated jointly for the two data sets. The resulting parameter value was positive and significant. The TypeOld interaction parameter was not significant in the model and therefore omitted from the final model. The parameter of the SP-RPChoice variable in the SP utility specification was kept in the

model despite its relatively low t-statistic (−1.33) because it captured justification bias. The relative scale parameter MU equaled 0.556. This value implied that the variance of the utilities was substantially smaller in the SP data than in the RP data. The likelihood ratio test statistic to test the joint RP-SP model against the two separate models was given by −2[−1342.004 − (−1281.379 + (−56.001))] = 9.3 with 7 degrees of freedom. Thus the pooled model could not be rejected at the 0.05 level of significance on the basis of the test statistic value, which was lower than the critical value $\chi^2_{7,0.05} = 14.07$.

The ratio between out-of-vehicle (walk) time and in-vehicle (search or wait) time in the pooled model was equal to 1.1. This ratio was higher than the values reported by Hess and Polak (8) and Axhausen et al. (10), which were in the range of 0.8 to 1. However, it was much lower than values of time commonly found in the transportation literature, which ranged between 1.5 and 2.5 (21). The difference might be explained by the fact that drivers were more time-sensitive with respect to the parking search than to other parts of the trip. The search for parking was carried out in proximity to the destination, and might have been perceived as a distinct task and not as part of the trip itself. The dummy variable No-Walk represented short walk times from the parking space to the destination (under 1 min). The positive sign of its coefficient suggested that drivers had an

added preference for parking alternatives that involved next to no walks to their destinations.

Two parking type coefficients were estimated in the model for the two data sources: RP type and SP type. The estimation results revealed opposite signs for the two parameters. Both were statistically significant. The difference in the estimates might be explained by the fact that respondents acted differently with respect to parking type attributes in the RP and SP parts of the survey. Off-street parking was in general more expansive but involved less in-vehicle time compared with on-street parking. Thus, in the hypothetical SP scenarios in which no actual costs were incurred and no time was spent, respondents preferred the off-street alternatives. In contrast, the RP data, which represented actual respondent behavior, demonstrated that respondents preferred on-street parking alternatives. This result was similar to one found by Teknomo and Hokao, who also found a preference for on-street parking (6). In contrast, Hess and Polak found that drivers tended to prefer off-street parking (8).

Because most of the respondents were students, with relatively homogeneous characteristics, the effect of the sociodemographic variables was not expected to be significant. The only sociodemographic variable included in the final model was student-Price. The variable captured the additional sensitivity of students to the overall parking price. Its coefficient was negative, which implied that students were more sensitive to parking price than other respondents.

MODEL APPLICATION

The estimated model was applied to a common parking choice scenario to investigate the potential sensitivities of parking choice in response to various changes in the parking attributes. Table 3 presents the parking scenario, which was developed on the basis of the RP survey data. The values of the parking attributes in the scenario were set according to their average values in the RP survey data.

The off-street share, calculated on the basis of the baseline scenario attribute values, was 20%, whereas the on-street share was 80%. To investigate the effects of possible parking policies, changes were made in the attribute values of the baseline scenario. Each policy measure was represented as a change of a specific attribute (i.e., shift from the value set in the baseline scenario) while all other attribute values remained constant.

TABLE 3   Model Application for Parking Scenario

Parking Attribute	Parking A	Parking B
Type	Off street	On street
Hourly price (NIS)	10	4
Duration (h)	3	3
Walking time to destination (min)	2	5
In-vehicle time (min)	2	10
Parking utility	−3.379	−2.01284
Parking share	20%	80%

NOTE: U.S. $1 = 3.5 NIS.

Changes in Parking Pricing

Figure 3 shows the on-street and off-street parking shares as a function of the on-street hourly price.

At the time of this study, the average on-street, urban parking price in Israel was about 4.5 NIS per hour (22). When this price level was applied to the on-street parking alternative in the scenario, the results indicated that most drivers (78%) preferred the on-street option. At this price, drivers were willing to spend more time in their vehicles (10 min) and to take a longer walk to their destinations (5 min) than under the higher priced, off-street alternative (off-street share of 22%).

Value of In-Vehicle Time

The value of parking search (in-vehicle) time can be estimated as (23)

$$\text{VOT} = \frac{\dfrac{\partial U}{\partial \text{InVehTime}}}{\dfrac{\partial U}{\partial \text{PricePerHr}}}$$

$$= \frac{\beta_{\text{invehtime}}}{\beta_{\text{priceperhr}} + 2\left(\begin{array}{l}\beta_{\text{pricesqr}} \times \text{duration}^2 \times \text{PricePerHr} \\ + \beta_{\text{pricealone}} \times \text{AloneDummy}\end{array}\right)} \tag{9}$$
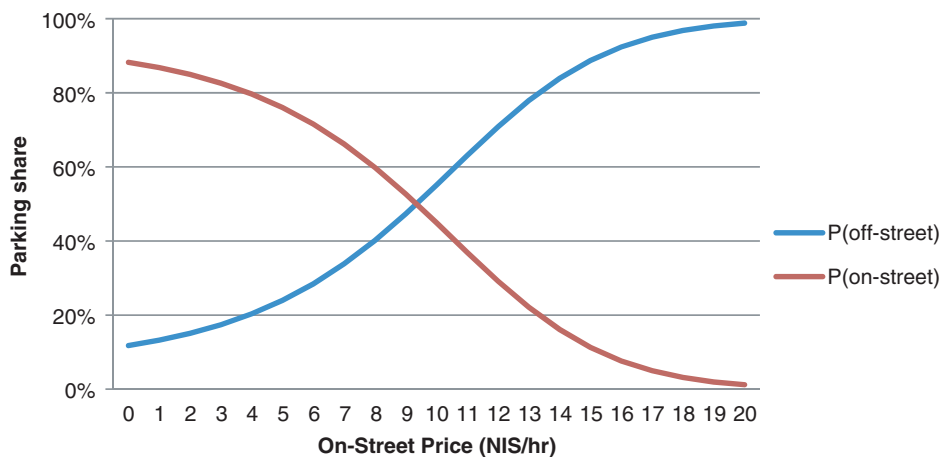

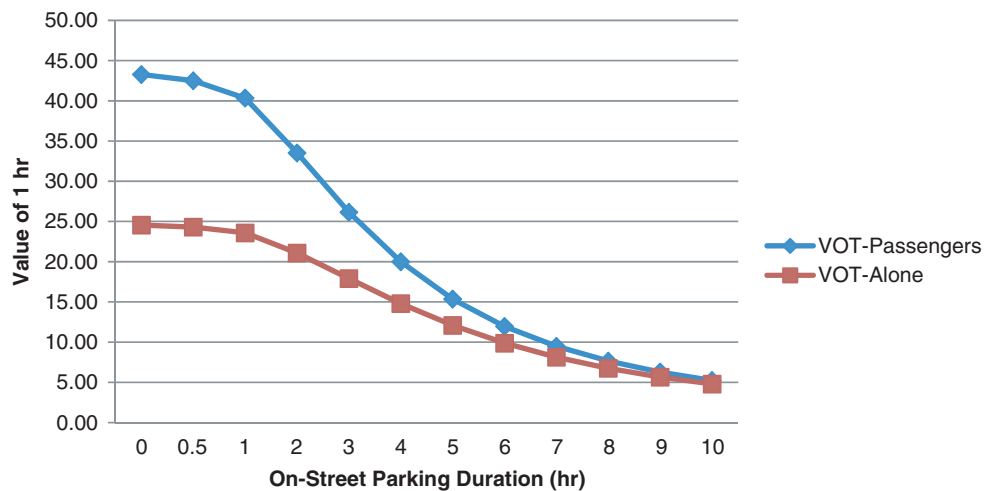FIGURE 3   On- and off-street shares as function of on-street parking price.

FIGURE 4   Value of search time versus parking duration time.

The value of search time was calculated on the basis of the baseline scenario (parking price of 4 NIS per hour for 3-h parking duration) and the model estimates. The resulting value was equal to 18 NIS per hour for solo drivers, and 26.4 NIS per hour for drivers with passengers. Figure 4 illustrates the monetary value of the search time as a function of the parking duration with respect to the on-street alternative in the baseline scenario. These values were somewhat lower than the average wage rate per hour in Israel, which was about 37 NIS per hour.

As Figure 4 shows, the value of search time decreased as the intended duration of parking grew longer. Thus the time that drivers spent in search of parking might have become less distressing the longer the time they planned to park. In other words, drivers were willing to spend more time in search of parking if the duration of the activity was long. Another result indicated that lone drivers valued the time they spent in search of parking less than when they drove with passengers. This result was reasonable, given that the solo driver spent only his or her own time in search of parking. When passengers were present, other people lost time in the search too.

CONCLUSIONS

In this study, a framework for the complete parking search process was conceptually specified. This framework provided insights on parking-related decisions made before a trip. Analysis of the survey results on the timing of parking decisions suggested that most drivers made their final parking decisions dynamically, in proximity to their destinations, and thus the results supported the proposed approach. Further research and exploration of the framework phases may provide additional insight into the choice process and the relations between the various subdecisions that compose the search.

A model was specified and estimated for the pretrip portion of this framework. The model estimation made use of both RP and SP data. The joint RP-SP estimation process and the integration of heterogeneity component improved the results compared with the estimation of two separate models.

The estimation results revealed parking behavior patterns. As expected, the dominant factor in parking-related decisions was its price. The results suggested that drivers considered the price of park-

ing in two ways: (*a*) as the overall cost for the entire parking duration and (*b*) as the price paid per hour of parking. The in-vehicle time and walk time to the destination also were important variables. Their coefficients were almost identical, which suggested that, in contrast to other transportation decisions, the in-vehicle time dedicated to the search for parking was valued almost as highly as the time to walk to the destination. Another result illustrated the effect that passengers had on the value that drivers placed on time (i.e., to search, to walk). The value of time was lower for solo drivers than for ones that traveled with passengers. Additional factors that affected parking choices were parking type (i.e., on-street or off-street) and parking duration and student status.

This case study demonstrated the capability of the model to evaluate the effects on parking decisions of various parking policies and measures, such as changes in the price of parking, and availability (that would affect search times), allowed parking durations, incentives, and penalties with respect to employer provision of parking facilities, and so on. In stand-alone, the parking model captured only the direct effects on parking choice. A more complete evaluation would embed the parking choice model within wider, urban transportation planning frameworks that would also capture the effects of parking attributes on activity locations and timing decisions and mode choices.

The estimation results presented in this paper addressed only the pretrip parking choice model. The proposed parking behavior framework is more comprehensive and also addresses decisions made en route and in the search phase close to the destination. Follow-up research will attempt to address these aspects of parking behavior and, in particular, the choice dynamics that stem from the view of parking behavior as a series of dynamically made, interrelated subdecisions (e.g., search strategy adaptation, alternative evaluation, route choice). This goal offers significant challenges in the useful formulation of the models, development of data collection technologies and instruments, and subsequent estimation of behavior models.

ACKNOWLEDGMENTS

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