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ETC Adoption, Time-of-Travel Choice, and Comprehensive Policies to Enhance Time-of-Day Pricing: A Stated Preference Investigation

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ABSTRACT

The main objective of this paper is to gain insight into the interconnections between the decision to use electronic toll collection (ETC), the choice of time-of-travel, and comprehensive policies that enhance the effectiveness of time-of-day pricing. This is an important topic of research because of pricing's potential role in transportation demand management. To this effect, the paper estimates discrete choice models using stated preference data collected from users of the Port Authority of New York and New Jersey (PANYJ) facilities in the New York City metropolitan area. The paper discusses descriptive analysis, analyzes the results of the models estimated, and identifies policy implications. The research concludes that the choices of payment method and time-of-travel are interconnected, and that the effectiveness of time-of-day pricing could be significantly enhanced through the use of measures that reduce crossing times for the alternatives that produce the least congestion, combined with initiatives that increase time of arrival flexibility.

1. INTRODUCTION

Urban congestion is one of the most challenging issues facing transportation decision makers, local communities, and businesses in large metropolitan areas. Every year, billions of passenger-hours are spent driving in congestion at a significant economic cost in terms of lost productivity and environmental pollution. The congestion problem has been attacked from fundamentally two different perspectives. The first views congestion as the result of inadequate capacity for the demand to be served; thus, the solution is always to add transportation capacity. Widely used in developed countries until the 1970s, this approach proved ineffective as adding capacity lowers transportation costs, thus providing an incentive for users to generate more traffic. Sooner or later, the congestion came back. New York City's experience—a pioneer in urban highway construction—provides plenty of examples. In the 1930s, Robert Moses launched a massive highway construction program that lasted about four decades. The impacts of such a program are exemplified in Caro (1974,515): "The Grand Central, Interborough, and Laurelton parkways opened early in the summer of 1936, bringing to an even hundred the number of miles of parkways constructed by Robert Moses on Long Island and New York City since he had conceived his great parkway plan in 1924." … "The parkways solved the problem for about three weeks. 'It was not more than three weeks after they opened that I decided to go out to Jones Beach on a Sunday,' Paul Windels recalls, 'I got on the Interborough and by God it was as jammed as the Southern State ever was.'"

It would take decades for the transportation community to realize that a different approach was needed. When it did, the realization of the limitations of supply-side-only interventions led to techniques that mitigate congestion by fostering changes in demand, i.e., Transportation Demand Management (TDM). As part of TDM, car users are encouraged to switch to transit, to carpool with other travelers, or to consolidate trips to reduce vehicular traffic and its externalities, among others. One of the families of techniques recognized as having the greatest potential for TDM is road pricing, which is also appealing because of its revenue generation potential. Important to these purposes is the advent of electronic toll collection (ETC), which removed the technical barrier to the implementation of road pricing by providing an efficient mechanism to charge tolls. In doing so, however, ETC has added another layer of complexity to the decision-making process. To start, ETC requires that the users decide whether or not to adopt ETC. The latter is a complex and potentially delicate issue, as many users resist using ETC out of privacy or other, general and frequently unstructured, concerns (Holguín-Veras and Preziosi, 2010; Holguín-Veras and Wang, 2011). There is also compelling empirical evidence to suggest that ETC users are less aware of the actual tolls they pay than cash users (Holguín-Veras et al., 2011b). Ironically, the same technology that has made road pricing possible seems to be obscuring the price signals central to its functioning. These considerations suggest that the decision to use ETC is not isolated from the response to pricing. Significantly, the literature on ETC adoption, behavioral responses to pricing, and time-of-day choice do not consider this possibility.

The goal of this paper is to investigate the interconnections between the choices of payment method and time-of-travel in response to pricing and other complementary policies. To this effect, the authors estimate discrete choice models using stated preference (SP) data collected from passenger car users responding to time-of-day pricing scenarios at the Port Authority of New York and New Jersey (PANYNJ) facilities. This case is unique in a number of ways. First, since the PANYNJ facilities have been in operation for decades, users have a great degree of familiarity with tolls and their impacts. They are able to provide meaningful indications of what they would do in response to toll changes. As a result, insight gained from these analyses is likely to be a more accurate estimate of actual behavior than those collected from users who are less familiar with toll facilities. A second reason is related to demonstration effects. Since the PANYNJ facilities have one of the largest implementations of time-of-day pricing in the world, its lessons could help other toll agencies define effective pricing strategies.

The paper focuses on passenger car peak-hour users who pay in cash, an important user segment because of the congestion they produce by their choice of time-of-travel and payment method. These users have a wide set of choices, as they could switch to ETC (under the brand name E-ZPass), change time-of-travel, or switch to transit. Unfortunately, due to data constraints, mode choice could not be considered. In spite of this, the research makes significant contributions as the first paper to jointly consider payment method and time-of-travel choices. In doing so, the paper expands the work of Holguín-Veras and Preziosi (2010) which, using different data, conducted research on ETC adoption.

The remainder of the paper consists of the following sections. A selective literature review with focus on behavioral impacts of road pricing, time-of-travel choice, and ETC adoption is presented in Section 2. A brief background of the PANYNJ time-of-day pricing implementation is the subject of Section 3, which also discusses the data collected and a basic descriptive analysis. Section 4 describes the modeling approach and the key findings obtained from the models. Policy analysis is conducted and described in Section 5. The overall conclusions are introduced in Section 6.

2. KEY FINDINGS FROM THE LITERATURE

This section discusses the literature on subjects most relevant to this paper: behavioral impacts of road pricing, time-of-travel choice, and ETC adoption. The publications are discussed chronologically by subject matter. It should be mentioned that the number of publications in these subjects is relatively small.

The first group of publications discusses on the behavioral impacts of pricing. Hendrickson and Plank (1984) analyzed departure time and mode choice using discrete choice models. The authors analyzed departure time choices in response to hypothetical policies such as uniform tolls, peak-period tolls, and double transit frequency, among others. Yamamoto et al. (2000) studied departure time and route choice in response to congestion pricing. They found that the most widely implemented behavior was to switch to surface streets without changing departure time. However, the majority of the users who changed departure time traveled before the congestion pricing charge would take place. Moreover, users who made recreation or shopping trips were more willing to change their departure time than for work-based trips. High income individuals also had a strong inclination to change departure time. Yelds and Burris (2000) analyzed the role of user socio-demographics and trip attributes in behavior change after the implementation of a variable toll pricing program in Lee County, Florida. The data showed that 30% of users changed their behavior because of the cost savings. Highly educated single parents and users making recreation trips were found to be more susceptible to changing their travel behavior; while age was found to be negatively correlated with changing behavior. Cain et al. (2001) studied the distribution of travel demand as an impact of differential time-of-day pricing. Burris and Pendyala (2002) examined the impacts of variable tolls in temporal scale in Lee County on time-of-travel choice, and analyzed the elasticities in the short-run; and Burris et al. (2004) analyzed the long-run impacts of variable tolls and found that although the drivers at the beginning of the program changed departure time, over time, the ability of pricing to change departure time decreased. High income individuals and commuters tend to have less flexibility of departure. Supernak et al. (2002) investigated attitudinal attributes of users of the Interstate 15 High Occupancy

Toll lanes (HOT) variable pricing program in San Diego, California. Using an attitudinal panel survey, they gathered data about users of the HOT program, and studied the role of socio-demographic attributes. The analyses showed that higher income individuals and higher educated individuals, homeowners with 2+ vehicles, and middle-aged women were more likely to pay to use HOT lanes. Ozbay et al. (2005) studied the behavioral impacts of pricing and the short-term demand elasticities, and found that the pre-peak hour elasticities are higher than the post-peak hour elasticities. This implies that the travelers are more willing to travel in pre-peak hours as a response to lower prices, which is in line with Yamamoto et al. (2000). Holguín-Veras et al. (2011b) analyzed behavioral impacts of the PANYNJ time-of-day pricing initiative. Using revealed preference data, they concluded that users implemented multi-dimensional behavior changes (3.23 changes per user, on average) comprised of changes in time-of-travel, payment method, and mode choice. A switch to transit without changing time-of-travel was the most frequent response (2.55% of the responses); while changing time-of-travel and using the previous mode was a marginal choice (0.69% of trips). The elasticities were in the range of -0.11 to -0.24, which is consistent with the values reported by other researchers.

The literature on ETC adoption is also small, in spite of the fact that there is ample recognition of ETC's economic benefits to both users and the overall economy. Part of the reason may be the expectation that, since ETC is generally beneficial, users would enthusiastically embrace its use. However, this has not proven to be the case, as there are segments of users that refuse to use ETC. Chen et al. (2007) studied ETC adoption using data collected in Taiwan, and found that system attributes, usefulness, and ease of use could foster ETC use. Regrettably, they did not assess the role of other individual characteristics. In a sequence of two papers, Holguín-Veras and Preziosi (2010) and Holguín-Veras and Wang (2011) studied the behavioral factors that influence ETC adoption by passenger and freight users of the PANYNJ facilities. Holguín-Veras and Preziosi (2010) found that time saved at the toll booths was not a factor, and theorized that, because of the prevailing downstream congestion, time saved at the toll booths may be seen as inconsequential. They found that ETC adoption is influenced by: the magnitude of the toll discount, drivers' awareness of toll discounts, intensity of use of the facilities, auto ownership, education level, age, and income. Racial minorities were found to be disinclined to use ETC. In the case of freight carriers, Holguín-Veras and Wang (2011) found that ETC usage depends on: frequency of use, company size, origin and destination of deliveries, and the industry sector in which the company operates. They identified commonalities with the passenger case, including that: awareness and marketing campaigns are important to foster ETC use, intensity of use fosters ETC adoption, users expect different things from ETC, and that regardless of marketing there will always be users reluctant to use ETC. Jou et al. (2011) incorporates subjective factors concerning media and "word-of-mouth" effects that could impact the adoption of ETC in Taiwan. The results confirm that the "overall impression" of ETC could indeed play a role in fostering use. Jou et al. (2012) used a Spike model to gain insight into the factors that explain choice of a toll schedule based on distance vs. a per entry fee, and found that socio-economic characteristics and usage patterns influence the choice of toll schedule.

The literature of time-of-day choice is also relevant to this paper. One of the first is Small (1982), who used behavioral models to analyze work-based trip decisions. The author studied user flexibility, and found that under higher flexibility users prefer late arrival over early arrival. Users with high income tend to choose the later departure time during the non-discounted peak period. Bhat (1998a) studied the choice of both mode and departure time for home-based shopping/recreational trips, while Bhat (1998b) analyzed urban shopping trips. They found that: trips starting early are more flexible than trips starting later in the day; employment status, income, number of children, and age affect time-of-day choice, and that employed individuals are less likely to travel for shopping during off-peak hours. Similar findings were confirmed in Steed and Bhat (2000) and Bhat and Steed (2002). Cirillo et al. (2003a) modelled the destination choice including the spatial and temporal dimensions in travel demand using aggregated land use variables and aggregated commercial variables to explain choice of trips. Temporal dimensions were incorporated into the model using the time budget. de Jong et al. (2003) used an error components logit model to analyze the time-of-day choice SP data from The Netherlands. The authors found that respondents are sensitive to increases in peak hours travel time, resulting in shifts of their time-of-day travel to before or after the peak hours. For business or recreational trips, respondents prefer to increase travel time by 30 minutes than arriving 30 minutes too early or too late, while for educational trips the opposite holds true. Tringides et al. (2004) studied the Southeast Florida Regional Household Travel Survey data to identify the order in which the mode and departure time choices are made for non-work trips. In the case of workers, they found that departure time choice is made first, and then mode choice, whereas non-workers decide on mode choice first, and then departure time. The models for both workers and non-workers show that there is a great propensity to pursue non-work tips in off-peak periods. When there are no children, workers do non-work trips during off-peak hours. However, if the travel time is high during peak periods, workers increase the frequency of off-peak departure times. Fujii et al. (2004) enhanced discrete choice modeling of mode and time-of-day choice using an error component structure. The choice structure and substitution patterns that affect the time-of-day choice i.e., switching to early or late departure times, are similar for the datasets studied (i.e., West Midlands, The Netherlands, and London). In the case of the West Midlands and the Dutch data, they found that the substitution towards early departure is higher than the one for late departure, except for the late departures of commuters with fixed working hours. The opposite holds true for London, where commuters tend to shift to later times of day. In all cases, business travelers are sensitive to the retiming of departure times, and to changing the duration of time spent at destination, with the former having a stronger effect than the latter. The analyses were further improved in

Choo and Mokhtarian (2008) with a mixed covariance model with random parameters. The models produced better goodness of fit, values of travel time savings, and demand forecasts. They found that time-of-day choice depends on the mode and variables, such as the type of work, e.g., regularly work from home or part-time. Respondents who work regularly from home are less likely to choose early departures and more likely to choose late departure, whereas part-time workers have negative penalties associated with retiming departures. Hess et al. (2007) examined the substitution patterns among time periods and different modes, and found that respondents have higher substitution between different time-periods than between different modes. When time periods are specified in coarser intervals, the levels of substitution between the time-periods is smaller. Arellana et al. (2012) propose a survey design to estimate time-of-day choice models. The authors use a Bayesian efficient SP-off-RP step design to include the interdependence among attribute levels, where prior information on actual choices and reference point schedule data is available for each respondent. The experiments assess the respondents' inclination to retime their trip or switch mode when work hour flexibility and the implementation of congestion charging are considered. The authors found that people prefer to arrive earlier rather than later at their workplaces and are more concerned about meeting the schedule during the morning. In terms of congestion charging, the respondents are willing to pay approximately $1 per hour to arrive a minute closer to their desired work arrival time.

A relevant publication that does not neatly fit in the groups of papers discussed previously is Parkany (2000). She modeled the choice using/not-using the Express Lanes of SR-91 in California, conditional on having an ETC transponder which implicitly recognizes that there are interconnections between the ETC and Express Lanes choices. She found that availability of the ETC transponder was a key factor influencing the choice of Express Lanes, together with other key variables such as household income, education level, gender, and travel distance.

The literature review clearly indicates that there are no publications that consider the joint choice of payment method and time of travel. By jointly studying both aspects, this paper enhances the research community's understanding of the behavioral impacts of pricing in cases where ETC is present.

3. THE PANYNJ TIME-OF-DAY PRICING INITIATIVE

On January 25, 2001, the Board of Commissioners of the Port Authority of New York and New Jersey (PANYNJ) advanced a major intermodal and regional capital program with $14 billion in investments in the 2001-2006 period (Holguín-Veras et al., 2005a). A new pricing scheme that included time-of-day tolls that depended on the payment method (cash or ETC) was central to the capital program. The time-of-day pricing initiative provided two discounts: one for using ETC during the peak-hours, and another for using ETC during the off-peak hours. The peak hour toll rates would be in effect on weekdays from 6-9 AM and 4-7 PM, and on weekends from 12 noon to 8 PM. The initiative was implemented on March 25, 2001. The promoters expected an increase in ETC usage and a decrease in congestion at the toll booths. There were good reasons to expect such outcomes, as ETC allows the users to save in tolls and time. However, these expectations proved elusive, as major segments of users remained reluctant to use ETC (RopertASW, 2003; Holguín-Veras and Preziosi, 2010; Holguín-Veras and Wang, 2011).

Following the implementation, the Federal Highway Administration funded a research project (Holguín-Veras et al., 2005b) to investigate the behavioral impacts induced by the toll changes. As part of the research, data were collected by means of a single stage random sample using computer-aided telephone interviews. The target population were the individuals that reside in New Jersey and Staten Island and used any of the PANYNJ toll facilities on a regular basis (at least once per week). The data included 505 observations, including 92.5% of current regular users and 7.5% of former regular users; 77.6% resided in New Jersey, and 22.4% in New York. For details, the reader is referred to Holguín-Veras et al. (2011b). The survey consisted of a number of different sections:

- *Attributes of the user's most recent car (and transit) trip*: Such attributes include trip purpose, departure time, arrival time, payment method, time flexibility of the user, and total travel time.
- *Awareness of time-of-day pricing and toll discounts*: This section prompted respondents to discuss their knowledge of current tolls and the time-of-day pricing initiative in effect.
- *Impacts of the 2001 time-of-day pricing initiative*: The main focus here was on gathering behavioral data on the respondent's reaction to the time-of-day pricing initiative. Trip frequency, purpose, time-of-travel, and payment method were some of the data collected.
- *Stated preference (SP) scenarios*: In this section, the user indicated how he/she would respond to hypothetical scenarios of toll rates and travel time savings.
- *Public opinion*: This section gathered respondent's points of view on the fairness of tolls.
- *Socio-demographics*: These questions collected socio-economic data that characterize the respondents, such as their gender, age, education, and household income.

The data indicate that the typical respondent is a middle-aged white man with above average income and education level. The households captured in the survey tended to be small, with attributes shown in Table 1. Generally speaking, the responding households from both New Jersey and Staten Island have similar structures, with about 50% having two adults and two individuals with a driver's license. The sample reported that in 53.7% of the households there were no children. The median household income of the respondents from New Jersey, Staten Island and the entire sample are approximately $120,000,

$95,000 and $110,000 per year, respectively. The data show that respondents have an above average level of education, as more than three quarters of them (79.4%) received some college or higher education. Regrettably, there are no data that could be used to provide comparative statistics for the broad population of users of the facilities. For additional information see Holguín-Veras et al. (2011b) and Holguín-Veras et al. (2005a).

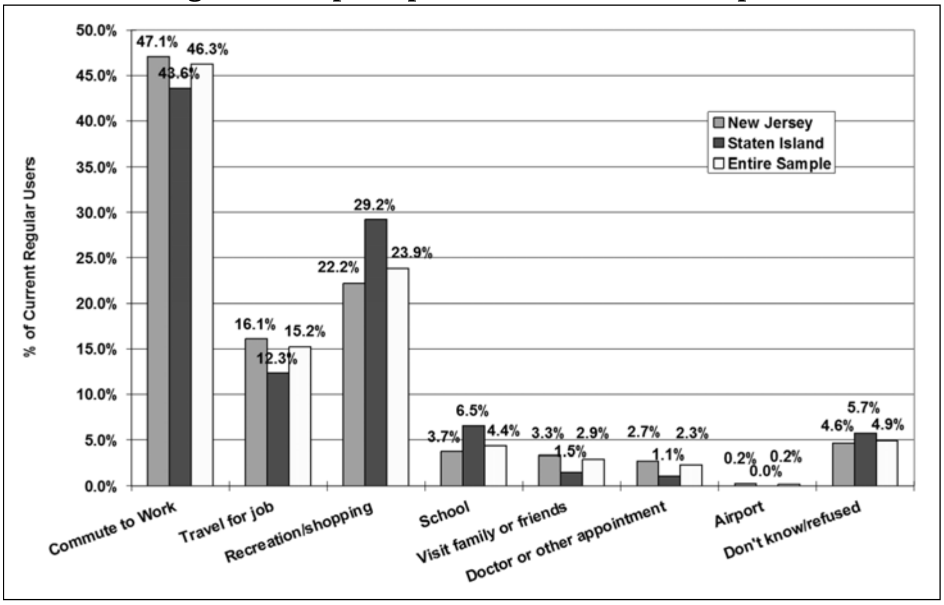
Table 1: Household Structure

Household Structure	New Jersey	Staten Island	Entire Sample
Adults in household (Average)	**2.6 adults**	**2.5 adults**	**2.5 adults**
1	20.0%	19.5%	19.9%
2	49.8%	44.3%	48.6%
3+	26.0%	36.1%	28.4%
Do not know/Refused	4.1%	0.1%	3.2%
Licensed drivers in household (Average)	**2.3 drivers**	**2.1 drivers**	**2.3 drivers**
1	22.4%	28.3%	24.4%
2	51.9%	40.2%	50.5%
3+	22.3%	31.5%	25.1%
Do not know/Refused	3.4%	0.0%	2.6%
Children in household (Average)	**1.2 children**	**0.8 children**	**1.1 children**
0	53.1%	55.6%	53.7%
1	19.1%	19.4%	19.2%
2	12.6%	16.6%	13.5%
3+	11.1%	8.3%	10.4%
Do not know/Refused	4.1%	0.1%	3.2%

In terms of trip characteristics, the data show that the majority of most recent trips passing through the PANYNJ facilities were made for work purposes. The next significant group is that of recreation/shopping trips. Together, these two trip purposes account for almost 90% of the total trips made. Figure 1 shows the distribution by trip purpose in more detail.

Another important trip attribute is time-of-travel flexibility, which is the amount of time earlier/later that an individual is willing to either depart from the origin (departure flexibility), or arrive at the destination (arrival flexibility) and still meet his/her travel needs. The data show asymmetry of preferences (Holguín-Veras et al., 2011b). Car users making work trips, for instance, stated that they could depart earlier up to 19.0 minutes, and depart later up to 14.7 minutes (on average). Similarly, they could arrive earlier up to 20.4 minutes, and arrive later up to 12.3 minutes. Moreover, the relatively narrow flexibility window (about 33 minutes) implies that most users face significant constraints to changes in time-of-travel.

Figure 1: Trip Purpose of Current User Trips



The main objective of the survey's SP section was to assess the impact of hypothetical scenarios of crossing times and tolls. The scenarios were based on the respondent's last trip through the PANYNJ facilities, and considered different values of crossing times (if using ETC) and toll discounts for ETC users (both peak and off-peak travel). In designing the SP scenarios, a number of practical considerations were incorporated in response to requests from the agency partners: (1) the toll discounts only considered whole amounts; (2) the toll discounts for ETC use during the off-peak had to be larger than the one for using ETC in the peak hours by at least US$2; (3) "small" toll discounts were not considered because they were not likely to have a meaningful impact on behavior; and, (4) no scenarios where the tolls would be fully discounted were considered, on account of being unrealistic. The travel time saving associated with ETC was estimated to be 15 minutes (on the basis of the PANYNJ estimates). The experimental setup considered a full factorial design where infeasible combinations had been removed (see Table 2).

Table 2: Stated Preference Scenarios Considered

Scenario	Change in Crossing Time (CT)	E-Zpass/Peak discount (T1)	E-Zpass/Off-Peak discount (T2)
1	-	$2.00	$4.00
2	-	$2.00	$5.00
3	-	$3.00	$5.00
4	15	$2.00	$4.00
5	15	$2.00	$5.00
6	15	$3.00	$5.00
7	15	-	$4.00
8	15	-	$5.00
9	15	-	-

For each scenario, the respondents provided their choices concerning payment method (ETC or cash) and time-of-travel (peak or the off-peak). The typical question was the one used in scenarios 4-6: "*Would you have switched to EZ Pass if it had saved you CT minutes in travel time and T1 or T2 dollars in tolls depending on the time you travel? (You get the $T1 discount in the peak, and the $T2 discount in the off-peak)*". If the participant answered "Yes" a follow-up question was asked: "*What time of the day would have you made your trip?*" The questions for the other scenarios were variations of the one shown above. At the time of the survey, the discounts were $1.00 for ETC peak users, and $2.00 for ETC off-peak users, and Cash toll for the peak hour $6. The responses were coded as electronic data to estimate the models discussed in the next section.

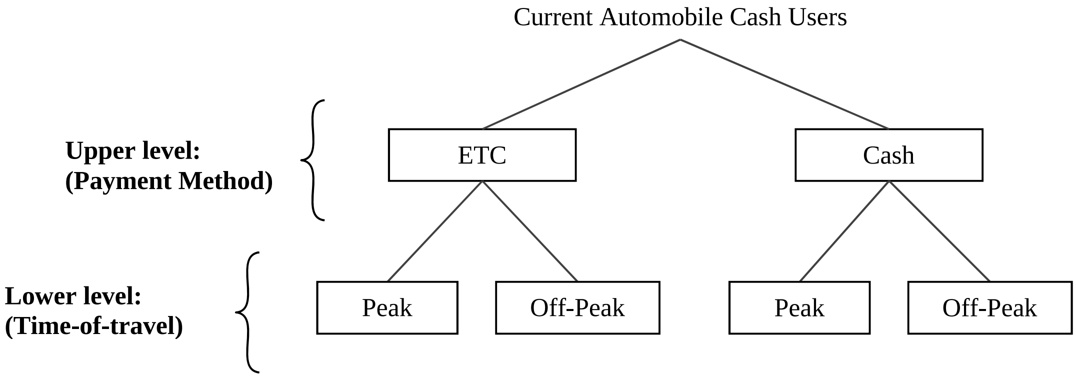
4. MODELING RESULTS

The discrete choice models (DCMs) used in this paper are based on the notion of random utility—the well-being that the user receives from an alternative—that builds on the concept of deterministic utility used in traditional microeconomics. Although basic postulates of rationality still hold, e.g., that an individual will try to maximize the utility derived from choices, DCMs assume observational randomness because it is not possible to have perfect knowledge about the decision-making process an individual uses. As a result, unobserved attributes, individual taste variation, measurement errors, and the use of instrumental variables introduce non-explained effects in the model (Ben-Akiva and Lerman, 1985). To account for those impacts, it is assumed that the total utility for an alternative is comprised of the part of utility captured by the model, termed systematic utility, and a random error component that considers the non-explained factors (Ben-Akiva and Lerman, 1985). Because of the lack of knowledge about the nature of the error terms, assumptions are required. Binary choice models are used in situations where an individual has a choice between two alternatives; if more than two options are available, models such as Multinomial Logit, Joint Logit, and Nested Logit must be used.

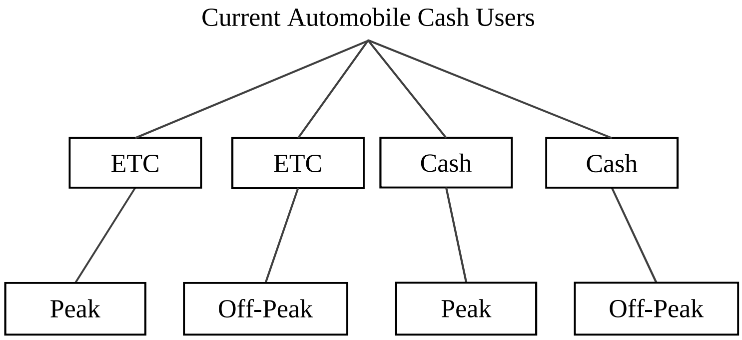
In the case of interest to this paper, the users have a two-dimensional choice set, with one dimension being payment method choice and the second being time-of-travel. Thus a Joint Logit or a Nested Logit are most appropriate (see Figure 2). The main difference between these models is that the Nested Logit considers the correlation among the alternatives in each nest, while the Joint Logit assumes that the alternatives are independent. Since the respondents have to decide on time-of-travel (peak, off-peak) and payment method (ETC, cash), the choice set has four alternatives. Throughout the paper, these four alternatives are referred to as: ETC Peak, ETC Off-Peak, Cash Peak, and Cash Off-Peak.

Figure 2: Multi-Dimensional Choice Structures Considered

A) Nested Logit Structure



B) Joint Logit Structure



During the modeling process, different specifications of the utility functions were tested. The quality of the models was assessed in terms of the statistical significance of the model and parameters, along with the model's conceptual validity. After obtaining the "best" model, a bootstrap procedure was used to eliminate the correlation that arises from using repeated measurements (Cirillo et al., 2003b). Inclusive value parameters and pseudo ρ^2 values were also considered when selecting the model.

The modeling process started with the estimation of meaningful Nested Logit specifications. The inclusive value parameters were used to select the correct structure. However, the final Nested Logit model was rejected because its inclusive value parameters were found to be statistically equal to one, which implies that there is no correlation among the alternatives in the nests and that the Nested Logit model collapses to a Joint Logit. At this point, the authors undertook a comprehensive estimation of Joint Logit models, which resulted in the selection of the model in Table 3 as the final model.

Table 3: Final Joint Logit Model

Description	EZPASS PEAK	EZPASS OFFPEAK	CASH PEAK	CASH OFFPEAK
Alternative Specific Constant	2.211	2.330		0.149
	(4.39)	(3.47)		(0.50)
Binary variable for recreation based trips	-0.793	-0.793		
	(-3.02)	(-3.02)		
Age of the individual			4.06E-02	4.06E-02
			(4.59)	(4.59)
Amount of time an individual is willing to arrive earlier (min)		1.30E-02		1.30E-02
		(2.20)		(2.20)
Amount of time an individual is willing to arrive later (min)		2.03E-02		2.03E-02
		(2.40)		(2.40)
Toll discount ($)	1.98E-01	1.98E-01		
	(1.97)	(1.97)		
Time to cross toll facilities	-4.74E-02	-4.74E-02	-4.74E-02	-4.74E-02
	(-2.77)	(-2.77)	(-2.77)	(-2.77)
Scheduled delay for a user to pay a lower toll		-1.13E-03		-1.13E-03
		(-0.93)		(-0.93)
Door to door travel time	4.00E-02	4.00E-02	4.00E-02	4.00E-02
	(3.20)	(3.20)	(3.20)	(3.20)
Log Likelihood Function		-367.63	R-squared Adj	0.074
Restricted Log Likelihood		-406.38	Observations	320
Chi-squared		67.98		

As shown, the key variables are: age, a binary variable representing recreation trips, early/late arrival flexibility, toll discount, the amount of time a user spends at the toll facility, the total door- to-door travel time of a trip, and the scheduled delay. The parameters of these variables capture the marginal effects of the variables on the utility of the alternative. The alternative-specific-constants (ASCs) are worthy of comment, as they reflect the innate inclination of decision makers to select a specific alternative, in an equality of conditions.

The results are interesting and important. Starting with the ASCs, the results show that users are strongly inclined to use ETC, with a slight preference towards ETC Off-Peak. The least preferred alternative is using Cash Peak. The model suggests that the older an individual is, the less likely he/she is to use ETC, which agrees with Yelds and Burris (2000). Similarly, users making recreation trips are inclined to pay in cash which is consistent with Hunt and Stefan (2006).

With respect to trip and time-of-travel attributes, the model shows that the larger the toll discount, the more likely the individual is to travel during the off-peak. This is important because toll discounts are under the control of policy makers. The model shows that users take into account the time spent going through the toll booths. The lower this time is, the more likely they would choose a given alternative. The amount of scheduled delay needed to switch to a different toll period, has a negative coefficient, meaning that long waits to get a lower toll discourages changing time-of-travel to another period. The coefficients for the variables that measure arrival flexibility (the number of minutes that the user individual is willing to arrive earlier or later to at the destination), indicate that the larger the flexibility, the more inclined the user is to travel in the off-peak periods. The last variable in the model is door-to-door travel time. The positive coefficient of this variable is a bit of a concern, as it implies that the longer the travel time, the more willing individuals are to select the alternative. This may be because the door-to-door travel time is acting as a proxy for unobserved attributes related to peak-hour travel. One of them is the impact of lack of modal alternatives to car use for long trips. Transit operations in New Jersey, the origin of most trips in the survey, are highly fragmented with hundreds of small operators. With the exception of the New Jersey Transit's rail corridors, using transit for relatively long trips (long travel times) is unreliable. In an environment where most users have narrow time windows to arrive at work, the car may be the only practical option. In contrast, passengers doing "short" trips frequently have more flexibility, as mini-buses and buses provide much better service. The coefficient of travel time may reflect the lack of modal options for long trips, which leads to a situation where the number of users seems to increase with travel time.

Although not perfectly comparable, as the data are different (revealed preference data vs. stated preference data) and collected in different years, it is interesting to note the similarities between the results in this paper and those from Holguín-Veras and Preziosi (2010). In all cases, the models show that toll discounts has a positive effect on ETC use, while age has a negative one. However, the models estimated in this paper provide a more nuanced view of the underlying decision process, as they account for the role of the toll discounts on the joint choice of payment method and time-of-travel.

5. POLICY ANALYSIS

Assessing the effectiveness of different policies in fostering ETC use and a switch of traffic out of the peak hours requires determining the market share that each alternative would capture in response to a given policy. The base case market shares correspond to the toll discounts at the time of the survey, which were $1.00 for ETC peak users, and $2.00 for ETC off-peak users. The cash toll for the peak hour was $6. The base case market shares, estimated from the PANYNJ traffic data, are shown in Table 4.

Table 4: Base Case Market Shares

Payment Method	Time of Travel	Market Share
Cash	Peak	17.28%
ETC	Peak	27.06%
Cash	Off-Peak	25.97%
ETC	Off-Peak	29.70%

Notes: (1) Peak hours are weekdays from 6-9 AM, 4-7 PM, and on weekends, 12 noon to 8 PM

From the policy point of view, it is important to identify the variables that have the strongest effect on inducing the desired behavior changes. To this effect, the authors estimated the market elasticities for the key policy variables using a probability weighted average of the individual elasticities. These elasticities are important because they measure the sensitivity of the choices in response to policy changes. Moreover, since the elasticities are comparable to each other, it is easy to identify which variables play the most significant role. The results are shown in Table 5.

Table 5: Elasticities for Policy Variables

Description	ETC Peak	ETC Off-Peak	Cash Peak	Cash Off-Peak
Amount of time willing to arrive earlier (min) (Early Arrival Flexibility)		0.132		0.239
Amount of time willing to arrive later (min) (Late Arrival Flexibility)		0.119		0.216
Toll discount ($)	0.254	0.378		
Time to cross toll facilities (Crossing Time)	-0.332	-0.056	-0.879	-0.609
Schedule delay for a user to switch to a new travel time (Schedule Delay)		-0.022		-0.034

As shown, the largest elasticity is for the time to cross the toll facilities, followed by toll discount and (early/late) arrival flexibility. These results have important policy implications. To begin, they indicate that policies that increase the amount of time to cross the toll facilities for cash users—such as increasing the number of toll booths that accept ETC payments—will be more effective than any other policy. Equally significant is the role played by the arrival flexibility. As shown, increasing the flexibility to arrive late will foster a switch to the off-peak hours. Thus, inducing employers to relax the employees' arrival times will reduce congestion at virtually no cost to the public sector.

The results summarized in Table 3 suggest that a number of different policies—using one or many of the policy variables in the table—could be considered. To this effect, the authors decided to study four different policies that use: (1) toll discounts, (2) changes in crossing times at the toll booths, (3) increases in arrival flexibility, and (4) toll discounts combined with changes in crossing times and increases in arrival time flexibility. In order to consider the feasibility of the various scenarios, the authors have used shades to classify the scenarios into two groups. The first group, unshaded in the tables, represents the scenarios that may be implementable with relatively little opposition. The second group is comprised of the scenarios where implementation may be harder on account of the magnitude of the changes. In the absence of a better name, the former group is referred to as "likely implementable" and the latter as "less likely". The analyses of the numerical results primarily focus on the "likely" cases, as not considering the feasibility of the scenarios would be misleading. In real life, ideal solutions are constrained by the realities of the politics of implementation. To facilitate the analyses, the authors have calculated the average values of the changes produced for the "likely" scenarios as shown on the bottom of each table. This metric provides an indication of what could be realistically achieved. In all cases, the authors used the model of Table 3 to compute the incremental changes in the alternatives' shares, which were added to the base case values to estimate the market shares for the scenario. The following tables show the market shares for the various policies. The base case values are shown in bold in the upper leftmost cell in the tables.

Policy #1: Toll Discounts

The analyses discussed here assess the role that toll discounts could play to foster ETC adoption and a change of time-of-travel to the off-peak hours. The analyses consider two toll discounts with respect to the Cash Peak toll: one for ETC Peak users (T1), and another for use ETC Off-peak users (T2). Since the goal is to induce a switch from the peak to the off-peak hours, T2 should be larger than T1 to compensate users for the scheduled delay costs. The results are shown in Table 6.

Table 6: Market Shares for Toll Discount Scenarios (percent)

Cash Peak Market Shares									
Toll Discount for ETC Peak (T1)	Toll Discount for ETC Off-Peak (T2)								
	$2	**$3**	**$4**	**$5**	**$6**	**$7**	**$8**	**$9**	**$10**
$1	**17.28**	16.31	15.31	14.29	13.27	12.25	11.26	10.30	9.38
$2	16.53	15.65	14.73	13.79	12.84	11.89	10.96	10.05	9.18
$3		14.94	14.10	13.25	12.37	11.49	10.62	9.77	8.95
$4			13.44	12.66	11.87	11.06	10.26	9.47	8.70
$5				12.04	11.33	10.60	9.87	9.14	8.43
Average change for likely scenarios (unshaded area): -1.67%									

ETC Pass Peak Market Shares									
Toll Discount for ETC Peak (T1)	Toll Discount for ETC Off-Peak (T2)								
	$2	**$3**	**$4**	**$5**	**$6**	**$7**	**$8**	**$9**	**$10**
$1	**27.06**	25.36	23.63	21.89	20.18	18.51	16.91	15.38	13.96
$2	30.37	28.52	26.63	24.72	22.82	20.95	19.15	17.43	15.81
$3		31.96	29.91	27.82	25.74	23.68	21.67	19.74	17.91
$4			33.44	31.20	28.93	26.68	24.47	22.32	20.28
$5				34.83	32.40	29.96	27.54	25.18	22.91
Average change for likely scenarios (unshaded area): 0.87%									

Cash Off-Peak Market Shares									
Toll Discount for ETC Peak (T1)	Toll Discount for ETC Off-Peak (T2)								
	$2	**$3**	**$4**	**$5**	**$6**	**$7**	**$8**	**$9**	**$10**
$1	**25.97**	24.50	23.01	21.53	20.08	18.67	17.32	16.04	14.85
$2	25.16	23.79	22.41	21.03	19.66	18.33	17.04	15.82	14.67
$3		23.02	21.75	20.47	19.19	17.94	16.72	15.56	14.47
$4			21.03	19.85	18.67	17.50	16.37	15.28	14.24
$5				19.18	18.10	17.03	15.98	14.96	13.98
Average change for likely scenarios (unshaded area): -2.27%									

ETC Off-Peak Market Shares									
Toll Discount for ETC Peak (T1)	Toll Discount for ETC Off-Peak (T2)								
	$2	**$3**	**$4**	**$5**	**$6**	**$7**	**$8**	**$9**	**$10**
$1	**29.70**	33.85	38.06	42.30	46.49	50.58	54.53	58.28	61.82
$2	27.95	32.05	36.24	40.48	44.70	48.84	52.86	56.71	60.35
$3		30.10	34.25	38.48	42.71	46.90	50.99	54.93	58.68
$4			32.11	36.30	40.54	44.77	48.92	52.94	56.80
$5				33.97	38.19	42.43	46.63	50.73	54.69
Average change for likely scenarios (unshaded area): 3.07%									

The results indicate that toll discounts would increase ETC Off-Peak use by 3.07%, and ETC peak by 0.87%, and decrease Cash Peak by -2.27%, and Cash Off-Peak by -1.67%. However, increasing ETC Off-Peak use is not the only thing that matters because the largest benefits would take place if the users that produce the most detrimental impacts (Cash Peak users) adopt the least detrimental behavior (ETC Off-Peak). Table 7 shows the source of the increases in ETC Off-Peak use.

Table 7: Sources of Change in ETC Off-Peak Market Shares

Model Results			Source of Change		
ETC Peak discount	ETC Off-Peak discount	Increase for ETC Off-Peak	ETC Peak	Cash Peak	Cash Off-Peak
$1	From $2 to $5	12.60%	-41.03%	-23.74%	-35.21%
$1	From $5 to $10	19.53%	-40.62%	-25.13%	-34.24%
$3	From $3 to $5	8.38%	-49.29%	-20.20%	-30.51%
$3	From $3 to $10	28.59%	-49.13%	-20.94%	-29.93%
$5	From $5 to $7	8.46%	-57.53%	-17.07%	-25.40%
$5	From $5 to $10	20.73%	-57.46%	-17.45%	-25.09%
Average			**-49.18%**	**-20.76%**	**-30.06%**

The results show that the bulk of the increase in ETC Off-Peak would come from ETC Peak users (41% to 58%), followed by the switch from Cash Off-Peak users (25% to 35%), and lastly from Cash Peak users (17% to 25%). Needless to say, this is disappointing, as it suggests that the policy could only achieve a partial success; the goal to reduce Cash Peak transactions was not fully met. This result is consistent with previous research that highlighted the reluctance of users to switch time-of-travel (Yamamoto et al., 2000; Holguín-Veras et al., 2011b).

Another important aspect to consider related to the use of tolls discounts to foster ETC use is that using such discounts may negatively impact transit and carpool use by increasing the attractiveness of the car option. Taking into account that increasing transit/carpool use is more beneficial to society than increasing ETC use—particularly in cases like this, where ETC use is already high—decision makers should assess the necessity of the ETC discount. It is not likely that users, accustomed to the convenience of ETC, will revert back to cash because of the elimination of the discount. The convenience and time savings of using ETC should provide enough incentives to foster ETC adoption.

Policy #2: Changes in Crossing Times at Toll Booths

A second set of analyses assessed the impacts of changes in the time to cross the toll facilities, (crossing time), which was found to be the most important variable explaining the joint choice of time-of-travel and payment method. Such changes could be the result of: implementing fast-toll lanes for ETC users, or changing the reallocation of the toll booths for Cash and ETC transactions, among others. Undoubtedly a sensitive subject, the fact of the matter is that the allocation of toll booths is a legitimate policy variable. A sound allocation could support achieving policy goals, while an unsound one will hinder the effort. These decisions, however, should not be made out of a desire to punish Cash Peak users into changing behavior. Instead, it should be the result of a careful cost/benefit analysis that weighs the economic benefits of the measure against its negative impacts on some users, particularly the poor and disadvantaged. In doing so, however, provisions must be taken to ensure that current Cash Peak users are given all practical opportunities to switch to ETC. Regrettably, there is a lack of methodologies that could undertake the complex simulation-optimization problem associated with defining an optimal allocation of toll booths, in combination with time-of-day pricing.

This section discusses two sets of results corresponding to hypothetical changes in the crossing times during the peak (Table 8) and off-peak hours (Table 9). The hypothetical nature of the scenarios considered should be stressed. Simulation studies must determine the crossing times that could be expected for a given allocation of toll booths and traffic composition.

Table 8: Impacts of Changes in Crossing Time during the Peak Hours

Cash Peak Market Shares												
Crossing Time reductions for ETC Peak (mins)	Crossing Time increases for Cash Peak (mins)											
	0	**+5**	**+10**	**+15**	**+20**	**+25**	**+30**	**+35**	**+40**	**+45**	**+50**	**+55**
0	**17.28**	15.01	13.08	11.45	10.09	8.96	8.04	7.28	6.665	6.17	5.765	5.44
-5		14.37	12.53	10.99	9.71	8.65	7.78	7.07	6.5	6.03	5.65	5.35
-10			11.95	10.51	9.31	8.32	7.51	6.85	6.32	5.89	5.54	5.26
-15				9.99	8.89	7.97	7.23	6.62	6.13	5.74	5.42	5.16
-20					8.45	7.62	6.94	6.39	5.94	5.59	5.30	5.07
-25						7.27	6.65	6.16	5.76	5.43	5.18	4.97
-30							6.37	5.93	5.57	5.29	5.06	4.88
Average change for likely scenarios (unshaded area): -5.55%												

ETC Peak Market Shares												
Crossing Time reductions for ETC Peak (mins)	Crossing Time increases for Cash Peak (mins)											
	0	**+5**	**+10**	**+15**	**+20**	**+25**	**+30**	**+35**	**+40**	**+45**	**+50**	**+55**
0	**27.06**	27.73	28.29	28.77	29.17	29.51	29.78	30	30.19	30.33	30.45	30.55
-5		31.78	32.4	32.91	33.34	33.7	33.99	34.23	34.43	34.58	34.71	34.81
-10			36.88	37.43	37.88	38.26	38.57	38.82	39.02	39.18	39.31	39.42
-15				42.26	42.73	43.12	43.44	43.69	43.90	44.07	44.21	44.31
-20					47.81	48.20	48.52	48.78	48.99	49.16	49.30	49.41
-25						53.41	53.73	53.98	54.19	54.36	54.49	54.60
-30							58.94	59.19	59.39	59.56	59.69	59.79
Average change for likely scenarios (unshaded area): 5.36%												

Cash Off-Peak Market Shares												
Crossing Time reductions for ETC Peak (mins)	Crossing Time increases for Cash Peak (mins)											
	0	**+5**	**+10**	**+15**	**+20**	**+25**	**+30**	**+35**	**+40**	**+45**	**+50**	**+55**
0	**25.97**	26.5	26.97	27.36	27.7	27.98	28.21	28.4	28.56	28.68	28.79	28.87
-5		25.66	26.08	26.44	26.74	26.99	27.19	27.36	27.5	27.62	27.71	27.78
-10			25.10	25.42	25.68	25.90	26.08	26.23	26.36	26.46	26.54	26.60
-15				24.31	24.54	24.73	24.89	25.02	25.13	25.21	25.28	25.34
-20					23.34	23.50	23.64	23.75	23.84	23.91	23.97	24.01
-25						22.24	22.35	22.44	22.51	22.57	22.62	22.65
-30							21.04	21.11	21.17	21.22	21.26	21.29
Average change for likely scenarios (unshaded area): 0.36%												

ETC Off-Peak Market Shares												
Crossing Time reductions for ETC Peak (mins)	Crossing Time increases for Cash Peak (mins)											
	0	**+5**	**+10**	**+15**	**+20**	**+25**	**+30**	**+35**	**+40**	**+45**	**+50**	**+55**
0	**29.70**	30.77	31.68	32.43	33.06	33.57	33.99	34.33	34.61	34.83	35.01	35.15
-5		28.2	29	29.67	30.22	30.67	31.04	31.34	31.59	31.78	31.94	32.06
-10			26.08	26.66	27.14	27.53	27.85	28.11	28.32	28.49	28.62	28.73
-15				23.44	23.85	24.18	24.45	24.67	24.85	24.99	25.10	25.19
-20					20.41	20.68	20.91	21.09	21.23	21.35	21.45	21.52
-25						17.10	17.28	17.43	17.55	17.65	17.72	17.78
-30							13.66	13.78	13.87	13.95	14.01	14.05
Average change for likely scenarios (unshaded area): -0.16%												

The results in Table 8 indicate that changes in the crossing times at the different time periods could indeed have a noticeable effect on the market shares of the various alternatives. As shown, increasing crossing times for Cash-Peak users while reducing crossing times for ETC-Peak users produces a host of differential effects on the market shares. To start, the Cash-Peak share drops as a consequence of the combined effects of its higher crossing time and the lower crossing time for the ETC-Peak option. The opposite effect is noticed for the ETC-Peak alternative. The results for the off-peak alternatives are quite nuanced. Both the Cash-Off-Peak and ETC-Off-Peak market shares increase with Cash-Peak crossing times, and decrease with ETC-Peak crossing times. Conceptually, these results make sense, as some users may switch to the off-peak alternatives in response to higher congestion in the Cash-Peak alternative; and switch to the ETC-Peak alternative if the crossing time reductions are noticeable. However, the results for the likely scenarios suggest that the main impact would be a switch of payment method, as the drop in Cash Peak (-5.55%) is almost entirely captured by an increase in ETC Peak (5.36%). The switch to the off-peak is negligible (0.36% for Cash Off-Peak, and -0.16% for ETC Off-Peak).

The results for changes in crossing times in the off-peak hours, shown in Table 9, are discussed next.

Table 9: Impacts of Changes in Crossing Time during the Off-Peak Hours

Cash Peak Market Shares

Crossing Time reductions for ETC Off-Peak (mins)	Crossing Time increases for Cash Off-Peak (mins)											
	0	**+5**	**+10**	**+15**	**+20**	**+25**	**+30**	**+35**	**+40**	**+45**	**+50**	**+55**
0	**17.28**	17.82	18.28	18.69	19.03	19.31	19.55	19.75	19.91	20.05	20.15	20.24
-5		16.56	16.95	17.28	17.57	17.80	18.00	18.16	18.30	18.41	18.49	18.56
-10			15.62	15.90	16.13	16.32	18.08	17.95	16.72	16.81	16.88	16.94
-15				14.55	14.74	14.89	15.02	15.12	15.21	15.28	15.34	15.38
-20					21.14	13.54	13.64	13.72	13.79	13.84	13.89	13.92
-25						12.28	12.36	12.42	12.47	12.51	12.55	12.57
-30							11.19	11.23	11.27	11.31	11.33	11.35

Average change for likely scenarios (unshaded area): -0.02%

ETC Peak Market Shares

Crossing Time reductions for ETC Off-Peak (mins)	Crossing Time increases for Cash Off-Peak (mins)											
	0	**+5**	**+10**	**+15**	**+20**	**+25**	**+30**	**+35**	**+40**	**+45**	**+50**	**+55**
0	**27.06**	27.75	28.34	28.84	29.25	29.59	29.87	30.10	30.29	30.44	30.56	30.66
-5		25.29	25.77	26.16	26.49	26.76	26.98	27.16	27.31	27.43	27.52	27.60
-10			23.26	23.57	23.83	24.04	24.21	24.35	24.46	24.55	24.62	24.68
-15				21.11	21.31	21.47	21.60	21.71	21.79	21.86	21.91	21.96
-20					18.97	19.09	19.19	19.27	19.33	19.39	19.43	19.46
-25						16.93	17.00	17.06	17.11	17.15	17.18	17.20
-30							15.05	15.09	15.12	15.15	15.17	15.19

Average change for likely scenarios (unshaded area): -0.83%

Cash Off-Peak Market Shares

Crossing Time reductions for ETC Off-Peak (mins)	Crossing Time increases for Cash Off-Peak (mins)											
	0	**+5**	**+10**	**+15**	**+20**	**+25**	**+30**	**+35**	**+40**	**+45**	**+50**	**+55**
0	**25.97**	23.14	20.72	18.67	16.95	15.52	14.35	13.39	12.63	11.97	11.46	11.05
-5		21.67	19.48	17.63	16.09	14.81	13.77	12.92	12.22	11.66	11.21	10.85
-10			18.28	16.63	15.27	14.14	13.22	12.47	11.86	11.37	10.98	10.66
-15				15.70	14.50	13.51	12.71	12.06	11.57	11.10	10.76	10.49
-20					13.79	12.93	12.24	11.68	11.22	10.86	10.57	10.33
-25						12.41	11.82	11.34	10.95	10.64	10.39	10.19
-30							11.44	11.03	10.71	10.45	10.23	10.07

Average change for likely scenarios (unshaded area): -7.38%

ETC Off-Peak Market Shares												
Crossing Time reductions for ETC Off-Peak (mins)	Crossing Time increases for Cash Off-Peak (mins)											
	0	**+5**	**+10**	**+15**	**+20**	**+25**	**+30**	**+35**	**+40**	**+45**	**+50**	**+55**
0	**29.70**	31.30	32.67	33.82	34.79	35.58	36.24	36.77	37.21	37.56	37.84	38.07
-5		36.49	37.82	38.94	39.87	40.63	41.26	41.77	42.19	42.52	42.79	43.00
-10			42.85	43.91	44.79	45.51	46.10	46.58	46.97	47.28	47.53	47.73
-15				48.65	49.47	50.14	50.68	51.12	51.48	51.77	52.00	52.18
-20					53.83	54.44	54.94	55.34	55.66	55.92	56.13	56.30
-25						58.38	58.83	59.19	59.48	59.71	59.89	60.04
-30							62.33	62.65	62.91	63.10	63.27	63.41
Average change for likely scenarios (unshaded area): 8.23%												

The results indicate that, from the standpoint of reducing Cash-Peak use, it maybe counter-productive to increase crossing times for Cash Off-Peak users, as this would lead to an increase in Cash Peak usage and a much smaller increase in ETC Peak traffic. Essentially, although this policy would reduce Cash Off-Peak traffic, the possibility of increasing Cash Peak traffic is very problematic. In terms of the likely scenarios, the results are the mirror image of those in Table 9. There is a noticeable drop in Cash Off-Peak use (-7.38%), with a concomitant increase in ETC Off-Peak (8.23%), and almost no change for the peak hours (-0.02% for Cash Peak, and -0.83% for ETC Peak).

Policy #3: Increases in Time of Arrival Flexibility

This section estimates the impacts of increases in the time of arrival flexibility, of the kind that could materialize if employers are incentivized to relax the time of arrival constraints on their employees. To illustrate the impacts of increasing time of arrival flexibility, the authors estimated the market shares for different scenarios. The increases in arrival time considered here range from 0 to 60 minutes. The results are shown in Table 10.

Table 10: Impacts of Increases in Time of Arrival Flexibility

Cash Peak Market Shares							
Increase in time flexibility to arrive earlier (min)	Increase in time flexibility to arrive later (mins)						
	0	**+10**	**+20**	**+30**	**+40**	**+50**	**+60**
0	**17.28**	15.85	14.50	13.23	12.07	11.01	10.05
+10	16.33	14.95	13.65	12.45	11.36	10.37	9.48
+20	15.41	14.08	12.85	11.72	10.69	9.77	8.96
+30	14.52	13.26	12.09	11.03	10.07	9.22	8.47
+40	13.68	12.48	11.38	10.39	9.50	8.72	8.03
+50	12.87	11.74	10.71	9.79	8.97	8.25	7.62
+60	12.11	11.05	10.09	9.24	8.49	7.83	7.26
Average change for likely scenarios (unshaded area): -2.29%							

ETC Peak Market Shares							
Increase in time flexibility to arrive earlier (min)	Increase in time flexibility to arrive later (mins)						
	0	**+10**	**+20**	**+30**	**+40**	**+50**	**+60**
0	**27.06**	24.49	22.09	19.87	17.83	16.00	14.36
+10	25.35	22.89	20.60	18.50	16.60	14.89	13.37
+20	23.71	21.36	19.20	17.23	15.45	13.87	12.47
+30	22.14	19.91	17.87	16.03	14.39	12.93	11.65
+40	20.65	18.55	16.64	14.93	13.40	12.06	10.89
+50	19.24	17.27	15.49	13.90	12.50	11.27	10.20
+60	17.92	16.07	14.42	12.96	11.67	10.55	9.58
Average change for likely scenarios (unshaded area): -4.09%							

Cash Off-Peak Market Shares							
Increase in time flexibility to arrive earlier (min)	Increase in time flexibility to arrive later (mins)						
	0	**+10**	**+20**	**+30**	**+40**	**+50**	**+60**
0	**25.97**	27.11	28.18	29.19	30.12	30.97	31.74
+10	26.72	27.82	28.86	29.81	30.69	31.49	32.20
+20	27.46	28.51	29.50	30.40	31.23	31.96	32.62
+30	28.16	29.17	30.10	30.95	31.72	32.41	33.01
+40	28.83	29.79	30.67	31.47	32.18	32.82	33.37
+50	29.48	30.38	31.21	31.95	32.61	33.19	33.70
+60	30.08	30.94	31.71	32.39	33.00	33.53	34.00
Average change for likely scenarios (unshaded area): 1.82%							

ETC Off-Peak Market Shares							
Increase in time flexibility to arrive earlier (min)	Increase in time flexibility to arrive later (mins)						
	0	**+10**	**+20**	**+30**	**+40**	**+50**	**+60**
0	**29.70**	32.56	35.25	37.72	39.99	42.04	43.86
+10	31.61	34.35	36.90	39.24	41.36	43.27	44.96
+20	33.44	36.06	38.47	40.67	42.64	44.40	45.96
+30	35.19	37.67	39.94	41.99	43.83	45.45	46.88
+40	36.85	39.20	41.32	43.23	44.92	46.42	47.72
+50	38.42	40.62	42.60	44.37	45.93	47.30	48.49
+60	39.90	41.95	43.79	45.42	46.85	48.10	49.18
Average change for likely scenarios (unshaded area): 4.56%							

The estimates suggest the potential benefits of increasing arrival time flexibility. Essentially, making it easier for users to arrive within a wider delivery window foster a switch of time of travel to the off-peak hours. The implication is that employers could play a key role in congestion mitigation, as they are the ones that set the time of arrival constraints on their employees. Providing incentives to employers so that they relax time of arrival constraints, as suggested by Yushimito et al. (2013) could enhance the efficiency of time-of-day pricing. It is worth noting that such approach is at the core of the successful Off-Hour

Delivery program implemented in New York City (Holguín-Veras et al., 2011a). The results for the likely scenarios indicate that the largest impacts would be a switch to the off-peak (1.82% for Cash Off-Peak, and 4.56% for ETC Off-Peak), at the expense of the peak traffic (-2.29% for Cash Peak and -4.09% for ETC Peak).

There is a compelling case for the use of policies aimed at inducing changes of in the behavior of employers, in the passenger case, and in the behavior of receivers of deliveries, in freight transportation. The reason is that they are the ones with the power to modify the demand that creates the vehicular traffic, and ultimately, the congestion. Employers set work hours and the arrival time flexibility of the employees; in the same way that receivers specify the delivery times that their delivery companies have to meet. At the same time, both employers and receivers of supplies do not internalize the congestion and inconvenience produced by their decisions, which directly impact their employees the delivery companies that make the deliveries, and, ultimately, the traveling public. Moreover, since employees and freight carriers have less power than employers and receivers, they have little influence on the behavior of the latter because of the asymmetry of power. The power flows from employers and receivers towards employees and delivery companies. Thus, policies that target employees traveling to work, and freight carriers making deliveries in the peak traffic hours—such as congestion pricing—are bound to be of limited effectiveness if there are not suitable alternatives that allow these users to arrive within the constraints imposed by employers and receivers. As clearly demonstrated in the freight case, policies that target the key decision maker who controls how the demand is generated are more effective than policies that target the vehicular traffic. See Holguín-Veras (2008) and Holguín-Veras (2011) for mathematical formulations, and Holguín-Veras et al. (2007), Holguín-Veras et al. (2008), and Holguín Veras et al. (2014) for econometric results.

Policy #4: Toll Discounts, Changes in Crossing Times, and Increases in Arrival Flexibility

The cases discussed in the preceding sections consider the impacts of policies that use a single policy instrument. This section, in contrast, assesses the impacts of a simultaneous implementation of toll discounts, changes in crossing times, and increases in time of arrival flexibility. In conducting the simulations, however, only selected cases were considered, as the number of potential combinations is astronomical. The scenarios are based on: an increase in crossing time for Cash Peak of 10 minutes; a decrease of 5 minutes for ETC Peak, Cash Off-Peak and ETC Off-Peak; and increases in arrival flexibility of 20 minutes (both early and late). The use of such a multi-dimensional approach is likely to lead to policies that are more effective, yet politically feasible. The results are shown in Table 11.

Table 11: Impacts of Toll Discounts, Changes in Crossing Time, and Arrival Flexibility

Cash Peak Market Shares

Toll Discounts for ETC Peak (T1)	Toll Discounts for ETC Off-Peak (T2)									
	BC $2	**$2**	**$3**	**$4**	**$5**	**$6**	**$7**	**$8**	**$9**	**$10**
$1	**17.28**	7.31	6.86	6.40	5.95	5.52	5.10	4.70	4.32	3.97
$2		7.09	6.67	6.25	5.82	5.41	5.01	4.63	4.27	3.93
$3			6.46	6.07	5.68	5.29	4.91	4.55	4.20	3.88
$4				5.88	5.52	5.16	4.80	4.46	4.13	3.83
$5					5.34	5.01	4.68	4.36	4.05	3.76

Average change for likely scenarios (unshaded area): -10.64%

ETC Peak Market Shares

Toll Discounts for ETC Peak (T1)	Toll Discounts for ETC Off-Peak (T2)									
	BC $2	**$2**	**$3**	**$4**	**$5**	**$6**	**$7**	**$8**	**$9**	**$10**
$1	**27.06**	20.21	18.53	16.89	15.33	13.85	12.48	11.22	10.08	9.06
$2		23.06	21.17	19.32	17.54	15.85	14.27	12.81	11.47	10.28
$3			24.13	22.07	20.06	18.14	16.32	14.64	13.10	11.70
$4				25.14	22.90	20.73	18.68	16.76	14.98	13.36
$5					26.06	23.66	21.35	19.17	17.15	15.28

Average change for likely scenarios (unshaded area): -6.40%

Cash Off-Peak Market Shares

Toll Discounts for ETC Peak (T1)	Toll Discounts for ETC Off-Peak (T2)									
	BC $2	**$2**	**$3**	**$4**	**$5**	**$6**	**$7**	**$8**	**$9**	**$10**
$1	**25.97**	32.64	30.26	27.92	25.65	23.48	21.44	19.53	17.77	16.17
$2		31.81	29.57	27.36	25.20	23.13	21.16	19.31	17.61	16.05
$3			28.80	26.72	24.68	22.71	20.83	19.06	17.41	15.90
$4				26.00	24.09	22.24	20.45	18.77	17.19	15.73
$5					23.43	21.70	20.02	18.43	16.92	15.52

Average change for likely scenarios (unshaded area): 3.42%

ETC Off-Peak Market Shares

Toll Discounts for ETC Peak (T1)	Toll Discounts for ETC Off-Peak (T2)									
	BC $2	**$2**	**$3**	**$4**	**$5**	**$6**	**$7**	**$8**	**$9**	**$10**
$1	**29.70**	39.85	44.37	48.80	53.08	57.16	61.00	64.56	67.83	70.81
$2		38.06	42.60	47.09	51.45	55.63	59.58	63.27	66.66	69.76
$3			40.62	45.16	49.59	53.87	57.94	61.76	65.30	68.53
$4				43.00	47.51	51.88	56.07	60.03	63.71	67.10
$5					45.18	49.65	53.96	58.05	61.89	65.44

Average change for likely scenarios (unshaded area): 13.62%

Note: BC $2 represents the base case (without the rest of the incentives)

The results clearly suggest that the combined policy is significantly more effective than any single policy tool used in isolation. As shown, combining all possible incentives leads to average decreases in Cash Peak of 10.64% and increases in ETC Off-Peak of 13.62%. Worthy of notice is that these increases have a very good chance of being implemented as they are the result of relatively small changes in the policy variables, which are likely to be enacted with minimal or no opposition.

Summary

In order to facilitate comparisons, the performances of the various policies are summarized in Table 12. The table shows the average changes in market shares for the likely scenarios and the various alternatives.

Table 12: Summary of Market Share Changes for the Different Policies

Policy		Cash Peak	ETC Peak	Cash Off-Peak	ETC Off-Peak
Policy #1: Toll Discounts		-1.67%	0.87%	-2.27%	3.07%
Policy #2: Changes in Toll Crossing Time	During Peak	-5.55%	5.36%	0.36%	-0.16%
	During Off-Peak	-0.02%	-0.83%	-7.38%	8.23%
Policy #3: Increases in Arrival Flexibility		-2.29%	-4.09%	1.82%	4.56%
Policy #4: Combined Incentives		-10.64%	-6.40%	3.42%	13.62%

As shown, Policy #1 has a slight effect on the market shares, with its main impact on ETC Off-Peak that increases its market share by attracting, primarily, Cash Off-Peak users. Policy #2 is very effective in inducing a switch to ETC (both peak and off-peak) by inducing Cash users to switch to ETC while retaining their original time of travel. Policy #3 induces a change in the time of travel that benefits Cash Off-Peak and ETC Off-Peak. The results clearly show that the largest impacts are produced by the combined incentives of Policy #4, for which ETC Off-Peak increases by 13.62%, and Cash Off-Peak by 3.42%, while Cash Peak and ETC Peak decreases by 10.64% and 6.39% respectively. In essence, Policy #4 shows that the combined incentives are the most effective way to induce the changes desired.

The superior performance of the combined incentives, particularly when compared to the tolls-only policy, has tremendous policy implications. It clearly suggest that policy makers should look beyond pricing to achieve policy goals. Complementing pricing with policies that increase time-of-arrival flexibility and change crossing times in an appropriate fashion could increase the power of pricing as a TDM tool. Moreover, this multidimensional approach is not only more effective than pricing, it is also politically implementable. The latter is an important consideration as road pricing efforts are frequently derailed by the political realities of implementation.

6. CONCLUSIONS

The research reported in the paper studied the joint choice of payment method and time-of-travel. Using stated preference data collected in the New York City metropolitan area, the authors gained insight into the behavioral factors that influence this important choice process, and identified a set of complementary policies that increase the effectiveness of time-of-day pricing. A key finding is that the selection of ETC—in a context in which users receive differential price signals that depend on payment method—should not be necessarily construed as a decision process in isolation of other decisions. In essence, modeling the payment choice without considering other choices is valid, if and only if, differential price signals (such as lower tolls for ETC users) are not at play, or if they are too small to enact behavior changes that go beyond the decision on payment method. The models also suggest that high income individuals are more likely to use ETC, and that the willingness to use ETC is determined by the age of the individual, and trip purpose.

The modeling process revealed that the most important variables influencing the choice of payment method and time-of-travel are, in descending order of importance: (1) time to cross the toll booths (crossing time); (2) toll discounts; and, (3) time of arrival (early and late) flexibility. These results have profound policy implications, as they suggest that inducing the desired behavior changes on the part of the users could be fostered by means other than pricing. Reallocating toll booths in favor of ETC users will impact crossing times in a way consistent with policy goals. Similarly, inducing employers to increase the arrival time flexibility of employees could also help achieve a more balanced traffic pattern. Such holistic approaches are bound to work better than policies that rely exclusively on toll discounts.

To assess these effects, the final model was used to assess the effectiveness of various policies: (1) toll discounts; (2) changes crossing times; (3) increases in arrival flexibility; and (4) toll discounts combined with changes in crossing times and increased time of arrival flexibility. The market share analysis for the only-toll-discounts policy indicate that increases in toll discounts for ETC Off-Peak users will increase the use of this alternative. However, the analyses of the source of the increase in ETC Off-Peak indicate that the bulk of the increase comes from ETC Peak users (56%), Cash Off-Peak (26%), and lastly from Cash Peak users (18%). This is disappointing, because of the minimal effect on Cash Peak users, which is the segment that produces the most detrimental effects on congestion. The second set of policies consider changes in crossing times at the toll facilities, of the kind that could be achieved by reallocating the toll booths by payment method and time of day. The results indicate that changes in crossing times could indeed increase ETC use and off-peak travel. Such measures, however, must be taken on the basis of cost-benefit considerations that weigh the potential congestion reduction benefits against negative impacts on some users, particularly the poor and disadvantaged. The third set of policies considers the case where arrival flexibility increases. This scenario could be the result of the implementation of flex-time or other programs that increase the arrival flexibility of individuals traveling to work. The results indicate that increasing arrival flexibility by 20 minutes increases ETC Off-Peak use by 4.56% on average. This implies that employers could play a critical role in congestion mitigation, as they control the work hours and arrival time flexibility of their employees. Policies that target the employers, to induce them to relax arrival times (or offer staggered work hours) could be of great assistance to time-of-day pricing. The similarities between the relations between employer and employees, and receivers and freight carriers lead the authors to believe that policies aimed at the employers, such as providing incentives for them to relax the arrival time flexibility of their employees, could work equally well in the passenger transportation case, as programs aimed at receivers of freight have worked in recent years in freight transportation.

The final set of scenarios considers the simultaneous implementation of toll discounts, changes in crossing times, and increases in arrival flexibility. In contrast to the other policies, the combined use of the various policy levers produces a significant impact on Cash Peak and ETC Peak use, for a drop of -10.64% and -6.39% respectively. This would be accompanied with increases in Cash Off-Peak and ETC Off-Peak in the range of 3.42% and 13.62%, respectively. These results are encouraging, as they demonstrate the potential of the combined policy to advance the goals of time-of-day pricing.

The research reported in this paper has demonstrated the importance of considering the interconnections between the choices of payment method and time-of-day travel, in response to time-of-day pricing; and has established the key role that complementary policies could play. In doing so, a new set of questions concerning the determination of the optimal combination of the various policy variables, and how best to induce employers to relax the time of arrival constraints on their employees, among many others, have been generated. Such important questions should be addressed by future research.

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