

The impacts of time of day pricing on car user behavior: findings from the Port Authority of New York and New Jersey's initiative

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Published online: 5 October 2010
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Abstract This paper discusses the key findings from a research project that assessed the impacts of the Port Authority of New York and New Jersey's Time of Day Pricing Initiative on the behavior of passenger car users. The survey data, comprised of 505 observations, show that 7.4% of passenger trips changed behavior because of the time of day pricing initiative, and that demand is inelastic to tolls with elasticities in the range of -0.11 to -0.24 . Passenger car users who changed behavior responded to time of day pricing by implementing multidimensional strategies (3.23 different behavioral changes per user on average), involving behavioral responses such as changes in facility usage, changes in time of travel, changes in the payment type, and changes in mode/occupancy. The most frequently cited behavioral response was to shift mode, either to transit or carpool, and maintain the original time of travel (done in 2.55% of trips), instead of changing time of travel and maintaining the use of the passenger car (0.69% of trips). This reluctance to change travel schedules is undoubtedly a reflection of the limited time of travel flexibility that, on average, was estimated to be 20.4 and 12.3 min for early and late arrival for work-related trips. This, in turn, suggests the need for comprehensive policies, possibly involving incentives or regulations to foster employers' participation in staggered/flexible work hour

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programs. Such approaches, combined with time of day pricing, are likely to be more effective in balancing car traffic during the day. Other behavioral responses of significance were reduce the number of trips made during the weekday peak-hours (1.65%), and switching to EZ-Pass to take advantage of the toll discounts (0.81%).

Keywords Road pricing · Time of day pricing initiative · Behavioral changes

Introduction

The idea of charging motorists for the externalities produced by the used of roads can be dated back to the pioneering work of Pigou (1920), who discussed the notion of charging drivers for the road deterioration produced by the cars. Following Pigou's work, a number of researchers made contributions to the nascent field of road pricing (Walters 1961; Nelson 1962; Johnson 1964). The work of Walters (1961), is particularly important as he produced the first comprehensive formulation of road pricing that incorporated the role played by the externalities produced by traffic, and identified the potential role of pricing as a demand management tool (Walters 1961). Later on, Vickrey (1969) reinvigorated the discussion about road pricing, and became a lifetime advocate for the concept. There is a sizable amount of literature on congestion pricing and related subjects that, for space reasons, cannot be discussed here. For a comprehensive review of the congestion pricing literature, the reader is referred elsewhere (Lindsey and Verhoef 2001).

These seminal works spurred a significant amount of research though very few road pricing projects materialized. As a result of this, the implementation of road pricing is something relatively new, as it was hampered by both political opposition, and lack of adequate technologies to efficiently collect tolls. The advent of electronic toll collection technologies removed the latter barrier and made road pricing practical for the first time in history. In recent years, there has been a significant increase in the level of interest in road pricing. This seems to be a consequence of: road pricing's revenue generation potential—which in a context of tightening finances becomes a key consideration; increased awareness of negative externalities, e.g. global warming, caused by car traffic; and road pricing's demand management potential. Nowadays, a number of congestion pricing schemes have been implemented worldwide, with the London congestion pricing scheme as one of the most visible implementations.

However, in spite of the increasing interest in road pricing and the significant amount of research already conducted, the number of publications based on actual implementations remains painfully small. This is an obvious result of the sparse number of actual implementations. This paper intends to help fill this void by reporting the findings from the Evaluation Study of the Port Authority of New York and New Jersey's Time of Day Pricing Initiative (Holguín-Veras 2005) related to the impacts on the behavior of passenger car users. A separate publication discusses the findings pertaining to behavioral changes implemented by the freight industry in response to this pricing initiative (Holguín-Veras et al. 2006).

The remainder of the paper is organized as follows. Section “[The Port Authority of New York and New Jersey \(PANYNJ\) time of day pricing initiative](#)” provides background information on the Port Authority of New York and New Jersey's Time of Day Pricing Initiative. Section “[The survey methodology and data](#)” describes the survey methodology used and data collected. Section “[Demographic characteristics and travel attributes](#)” discusses travelers' demographic characteristics and their travel attributes. Section “[Awareness](#)

of toll discount programs and the amount of tolls paid” summarizes findings of user awareness of the toll discount programs. Section “Impacts of the time of day pricing initiative” analyzes the behavioral changes in response to the time of day pricing initiative. Section “Policy implications” discusses policy implications. The paper ends with conclusions.

The Port Authority of New York and New Jersey (PANYNJ) time of day pricing initiative

On January 25, 2001, the PANYNJ approved a time of day pricing initiative with tolls that depended on: time of travel (peak hours, off-peak hours and overnight), payment technology used (cash or electronic toll collection), and vehicle type (e.g., autos, motorcycles, trucks and buses). The new toll scheme was implemented in March 2001 (see the toll schedules before and after in Table 1). A key feature of the system is that the toll discounts are only available to the users of the electronic toll collection system (E-ZPass). The PANYNJ saw the plan as a mechanism to: help finance its capital budget, reduce congestion, increase the use of mass transit and E-ZPass, and facilitate commercial traffic management.

The tolls were enacted on the six tunnels and bridges controlled by the PANYNJ that connect the State of New Jersey to New York City (see Fig. 1) and charged in the east-bound direction (towards New York City) only. Since the tolls are only charged in one direction, they do not support demand management for the Westbound trips that remains untolled. Approximately 352,000 vehicles use the PANYNJ facilities daily with a vehicle split of 91.2% autos, 6.5% trucks, and 2.3% buses in an average weekday. This translates into 127 million vehicles and 62 million interstate bus passengers annually, which makes the PANYNJ facilities the largest road pricing project in the US (Holguín-Veras 2005).

Following the implementation of the PANYNJ’s time of day pricing initiative, the Federal Highway Administration’s Value Pricing Program launched a research project to assess the behavioral impacts produced by time of day pricing. This paper provides a summary of the key findings pertaining to passenger behavior changes produced by this initiative.

Table 1 Toll rates before and after the time of day pricing initiative (passenger cars)

Type of vehicle	Passenger cars		Trucks	
	Before	After	Before	After
Cash peak	US\$4.00/car	US\$6.00/car	US\$4.00/axle	US\$6.00/axle
Cash off-peak	US\$4.00/car	US\$6.00/car	US\$4.00/axle	US\$6.00/axle
E-ZPass peak	US\$3.60/car	US\$5.00/car	US\$3.60/axle	US\$6.00/axle
E-ZPass off-peak	US\$3.60/car	US\$4.00/car	US\$3.60/axle	US\$5.00/axle
E-ZPass overnight			US\$3.60/axle	US\$3.50/axle

Tolls are collected in the eastbound (New York bound) direction only

For passenger vehicles, peak hours are 6–9 am, 4–7 pm on weekdays, and 12 noon–8 pm on weekends. All other times and holidays are defined as off-peak hours

For trucks, peak hours are the same as for passenger cars. The overnight hours are from midnight to 6 am on weekdays. All other hours are defined as off-peak hours; and

After the study ended, the toll rates were increased on March 2, 2008 though the concept of time of day pricing remains. The interested readers are referred to PANYNJ (2010) for new toll rates



Fig. 1 PANYNJ toll facilities of interest. *Note:* the Verrazano Bridge that connects Staten Island and Brooklyn (Kings) was not included in the study because its tolls did not change

The survey methodology and data

This section provides a summary of the data collection process used in this investigation. The target population considered in the research consisted of: (a) current regular users who have continued using the toll facilities by car on a regular basis since before March 2001; and (b) former regular users who regularly used toll facilities by car before March 2001 and shifted to public transportation about that time. Regular users were defined as those individuals who use the PANYNJ facilities at least once a week. The data collection focused on current and former regular users from New Jersey and Staten Island because they represent the bulk of the traffic using the PANYNJ facilities. This reflects the key role played by Manhattan as the employment center in the area that translates into heavy commuting from New Jersey and Staten Island to Manhattan for work. It should be said that, in the strictest sense, the sample does not fully represent the entire population of users as this includes thru trips with origins and destinations in the rest of the country. However, since the focus of this research is on regular users—who predominantly come from New Jersey and Staten Island—the authors are confident that the sample collected adequately represents the target population.

The decision to include a sub-sample from Staten Island took into account other factors. By virtue of living on an island and having a car oriented land use, Staten Island residents are more dependent on car use than the rest of residents in the metropolitan area. This may lead them to exhibit a different behavior to time of day pricing. Recognizing this, the PANYNJ agreed to create a special frequent usage discount plan for the toll facilities primarily used by Staten Island users. Under this plan, the pre-registered E-ZPass users prepaid US\$50.00 for up to 20 trips in advance, to be used within a 35-day period, making

the cost per trip as low as US\$2.50. This rate was much lower than the amount other users were paying (US\$4.00 or US\$5.00 for E-ZPass depending on time of day or US\$6.00 cash at all times.)

The passenger survey questionnaire was composed of several sections that gathered data about respondents' socio-economic characteristics, attributes of most recent trip made, public opinion about tolls, E-ZPass usage, and a stated preference section that collected passengers' stated responses to hypothetical toll scenarios. The most important section to the purposes of this paper is the one that collected data about the behavioral changes in response to pricing.

The passenger data, comprised of 505 observations, were collected by means of a single-stage random sampling from telephone calls. The data show that 467 respondents (92.5%) were current regular users; 38 respondents (7.5%) were former regular users. In terms of geographical locations, the sample included 392 respondents (77.6%) from New Jersey, and 113 respondents from New York, specifically from Staten Island (22.4%). The sample was expanded so that they represent the actual use of the toll facilities by respondents. For details, the reader is referred elsewhere (Holguín-Veras 2005).

Demographic characteristics and travel attributes

The survey participants were asked about their socio-economic characteristics, the toll facilities used, and the attributes of their most recent trips. The data indicate that the typical respondent was a middle aged white man with above average education level and household income. The average age of respondents was 43.7 years old. Among them, 63.5% were white, 58.5% were males, and 79.4% received college or higher education degrees. They were found to have household incomes higher than the State median (US\$95,178 vs. US\$55,932 in New Jersey and US\$80,944 vs. US\$58,667 in Staten Island) (U.S. Census Bureau 2004). This reflects the fact that the target areas are indeed wealthier than the rest of the corresponding state.

The households captured in the survey had relatively small families with 2.5 adults, 2.3 licensed drivers and 1.1 children on average. As expected, car ownership was highly correlated with the number of licensed drivers in the household—with an average of 2.3 passenger cars/household—with nearly 80% of the sample households having at least as many cars as licensed drivers. The data show that 87.8% of respondents work either full time (78.2%), or part time (9.6%), and that 69.9% of respondents cannot work at home, which highlights the importance of work trips.

The survey collected data about the characteristics of current and former regular users' most recent trips (in the Eastbound direction) that for current users is a car trip, and for former users is a transit trip. The data collected information including trip frequency, travel time, trip purpose, day of travel, departure and arrival times, time of travel flexibility, payment technology, among others. The majority of most recent trips made were work related, which represent 64.3% of current regular users' car trips, and 83.9% of former regular users' transit trips. Other trip purposes include recreational/shopping, going to the airport, travel to a medical appointment, or visit to family/friends. The survey participants were asked what time of day they went through the toll booths.

Table 2 shows the breakdown of the responses—using the PANYNJ's definition of peak hours (i.e., 6–9 am and 4–7 pm on weekdays and 12 noon–8 pm on weekends). It was found that approximately 54% of current regular users traveled across toll booths in the peak periods, among which the weekday AM peak trips (33.9%) are the dominant ones.

Table 2 Trip purpose versus time of travel

Trip purpose versus time of travel	Work-related trips (%)	Recreational/shopping trips (%)	Other purposes (%)	Total (%)
Current regular users (car trips)				
Weekday AM peak	29.9	0.7	3.4	33.9
Weekday PM peak	8.1	4.2	0.8	13.0
Weekday Off peak	25.1	6.4	2.9	34.5
Weekend peak	0.3	6.2	0.6	7.1
Weekend off peak	4.7	5.7	1.0	11.4
Total	68.1	23.2	8.7	100.0
Former regular users (transit trips)				
Weekday AM peak	79.0	1.6	0.0	80.7
Weekday PM peak	0.3	0.3	0.0	0.7
Weekday off peak	6.6	7.2	1.3	15.1
Weekend peak	1.0	0.0	2.6	3.6
Weekend off peak	0.0	0.0	0.0	0.0
Total	86.9	9.2	3.9	100.0

Table 3 Reasons for traveling at that time versus trip purpose

Trip purposes reasons	Work related (%)	Recreation/shopping (%)	School (%)	Visit family or friends (%)	Doctor or other appointment (%)
Current regular users (car trips)					
Schedule	67.4	20.2	11.8	14.8	49.4
To avoid congestion	23.9	27.5	3.0	31.5	22.9
Meet people/make appointment	5.2	35.3	64.5	27.8	27.7
Out of habit/what I usually do	1.7	11.2	8.9	15.7	0.0
Easier/cheaper parking	1.1	1.1	0.0	0.0	0.0
Cheaper toll	0.0	1.3	0.0	0.9	0.0
So I could return in time	0.6	3.5	11.8	9.3	0.0
Total	100.0	100.0	100.0	100.0	100.0
	66.8	22.7	4.8	3.1	2.4
Former regular users (transit trips)					
Schedule	88.3	10.0	0.0	0.0	0.0
To avoid congestion	11.7	33.3	0.0	100.0	66.7
Meet people/make appointment	0.0	56.7	100.0	0.0	33.3
Total	100.0	100.0	100.0	100.0	100.0

The data also show that the time of travel was related to trip purpose. Work-related trips were more likely to be made during AM peak hours: 29.9% of car trips, and 79% of transit trips were made during AM peak hours by current and former regular users respectively.

The reasons for traveling at the reported time are broken down by trip purpose to gain insight into the determinants of user choices. As shown in Table 3, the reasons are correlated with the trip purposes. The majority of current regular users who travelled for work related purposes (67.4%) determined their time of travel on the basis of their work

Table 4 Mean and standard deviation of time of travel flexibility (Minutes)

Time of travel flexibility (min)	Trip purpose					
	Work related trips		Recreation/shopping trips		Other trips	
	Car ^a	Transit ^b	Car	Transit	Car	Transit ^c
Earlier departure	19.0 (24.5)	17.9 (9.5)	16.4 (21.2)	30.6 (27.5)	16.2 (20.7)	15.6 (7.8)
Later departure	14.7 (20.8)	14.9 (17.9)	13.8 (21.7)	24.1 (31.8)	14.4 (23.8)	15.6 (7.2)
Earlier arrival	20.4 (24.0)	18.3 (10.3)	16.0 (20.8)	32.6 (26.9)	24.2 (28.2)	19.5 (11.2)
Later arrival	12.3 (19.0)	9.1 (7.5)	12.3 (20.5)	23.6 (31.4)	9.7 (19.2)	8.3 (3.5)

Standard deviations are shown in *parentheses*

^a Car trips are made by current regular users

^b Transit trips are made by former regular users

^c “Others” represents school, airport, doctor or other appointment, visit family or friends

schedules, which conceptually makes sense. Similarly, about half of the current users who traveled for a medical or other appointment (49.4%) cited the same reason.

In contrast, those who traveled for school or recreation/shopping are more likely to choose “meet people/to get to an appointment” as the reason for traveling at the stated time, which is consistent with the nature of these trips. Meanwhile, the group of current regular users who traveled to visit family/friends showed the highest sensitivity to congestion conditions as 31.5% chose avoiding congestion as the key reason. This is likely to be a reflection of the relatively large time of travel flexibility for this type of trip. Former regular users show similar patterns. The data also show that avoiding toll costs is a very minor reason, as only 2.2% of current regular users listed it as the key reason.

The survey asked respondents about their time of travel flexibility, in terms of departure flexibility (i.e., how earlier or later they were willing to depart from the origin and still meet their travel constraints) and arrival flexibility (i.e., how earlier or later they were willing to arrive at their destinations and still meet their travel constraints). Table 4 shows the average flexibility windows, together with the corresponding standard deviations. The analyses of the results lead to a number of general findings. The most obvious one is that users have relatively narrow windows of flexibility, that are in the range of 20 min for early departure or arrival, and about 14 min for late departure or arrival (all users, all modes). The data confirm the asymmetric nature of time of travel flexibility because in all cases respondents have more flexibility to arrive and depart earlier than later.

In terms of time of travel flexibility by trip purpose, the data show that there are significant differences between work and recreational/shopping trips (not much could be said about “others” as this group includes a number of disparate trip purposes). As seen in the table, the time of travel flexibilities for work trips by car and transit are pretty much the same (in fact, they are statistically equal). However, for recreational/shopping trips the story is completely different. As shown, transit users reported consistently larger values of time of travel flexibility than car users. It is not clear if this reflects differences in the type of trips made by either car or transit, or a reflection of modal attributes such as level of service provided during the off-hours (when the majority of recreational/shopping trips are made).

In order to assess different travel cost encountered, respondents were asked about parking fees. The data show that the majority of respondents did not pay for parking

Table 5 Who paid for parking?

Area	Paid for parking				Parking Free (%)	DK/REF (%) ^b	Total (%)
	Self (%)	Self and passengers (%)	Employer (%)	Others (%)			
Downtown	35.3	1.7	27.3	0.0	35.7	0.0	100.0
Midtown	33.2	6.0	9.9	7.4	32.8	10.6	100.0
Others	17.1	0.2	6.6	0.4	75.6	0.0	100.0
DK/REF ^a	23.5	4.2	8.6	0.1	59.7	3.9	100.0
Average citywide	23.4	2.9	9.3	1.1	60.1	3.2	100.0

^a Do not know/refused to provide destination; and

^b Do not know/refused to indicate who paid

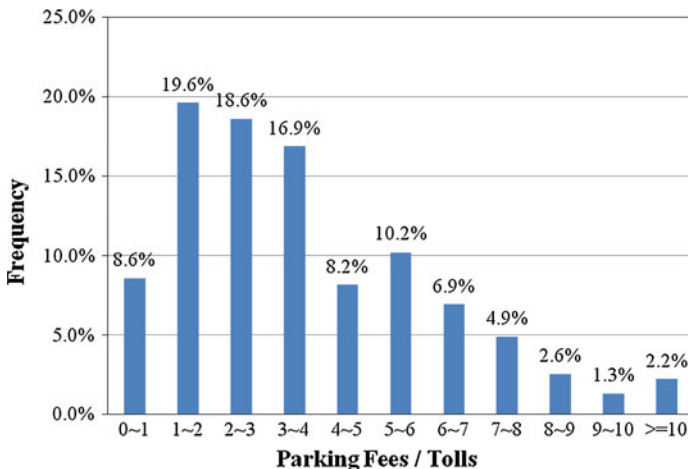


Fig. 2 Distribution of the ratio of parking fees to tolls (for users who pay for parking). *Note:* 70.5% of users do not pay for parking

(70.5%) either because the parking was free (60.1%), or their employers (9.3%), or others (1.1%) paid for it (see Table 5). Only a quarter of current regular users (26.3%) paid for parking, either by themselves (23.4%) or sharing with others (2.9%). The responses were then broken down by destination (Table 5), which revealed that a significant proportion of users enjoy free parking when they travelled to very congested areas such as Downtown and Midtown Manhattan (35.7 and 32.8%, respectively). This indicates the opportunity to use parking pricing as a demand management tool. In this context, increasing the coverage of priced parking could become a potent deterrent to car travel by making it more expensive to use passenger cars.

In terms of cost, the average fee for those who paid for parking was US\$16.65 with a standard deviation of US\$11.2. The comparison between tolls and parking fees (Fig. 2) clearly indicates that tolls are significantly smaller than parking fees. As shown, for the majority of trips (71.8%), the parking fee paid is at least double the tolls paid. On average, parking fees are 3.6 times the toll paid.

In terms of the transit costs, former regular users (current transit users) reported an average travel cost by transit (US\$5.6) that is much lower than the average transit cost estimated by current regular users (car users) (US\$9.6). At the same time, the average car trip cost estimated by transit users (US\$18.40) is more than three times higher than the transit costs they pay. This suggests that the significant difference in costs may have played an influential role in their decisions to switch to transit.

Awareness of toll discount programs and the amount of tolls paid

Data were collected about the E-ZPass users' levels of awareness of the toll discounts available to them. This is important as the majority of users are E-ZPass users (78.3%) and their awareness of tolls obviously influences the response to time of day pricing. The data show that Staten Island users have a solid level of awareness of toll discounts (see Table 6). This could be explained in part by the significance of the toll discount offered to them, and the geographic proximity to the toll facilities due to the relatively small geographic area. These factors may lead these users to be more aware of the toll structure at the bridges they depend on.

In contrast, New Jersey users—who could be arguably considered the best representatives of the regular users of the PANYNJ facilities—showed a low level of awareness. As shown in Table 6, only 36.5% were aware of one of the discount programs offered, while another 24.0% declared to be “vaguely aware.” Most telling is that only 19.4% declared knowing about the time of day toll discount (this number climbed to 40.6% when prompted). This low level of awareness is, without any doubt, a factor hampering the effectiveness of time of day pricing in the area.

E-ZPass users and cash users exhibit different levels of awareness. The data showed that E-ZPass users are much more likely to know about the toll discounts than cash users (76.7 vs. 25.9%), which is consistent with what one would expect. This pattern stands out especially for Staten Island users where more than 90% of E-ZPass users' trips reported some knowledge about the toll discounts; while less than 14% of Staten Island's cash users did so.

However, the data show that not many current regular users, especially E-ZPass users, know exactly how much they paid for tolls. As shown in Fig. 3, more E-ZPass users in

Table 6 Awareness of various toll discounts by type of users

Toll discount programs	New Jersey (%)	Staten Island (%)	Entire sample (%)
Aware of discounts	36.5	63.1	42.8
Frequent use of Staten Island bridges	11.0	50.2	20.4
Time of day/off-peak use	19.4	5.5	16.0
Time of day/off-peak use (with prompting)	40.6	34.6	39.1
Carpool	6.1	7.4	6.4
Vaguely aware of discounts	24.0	16.1	22.1
Just general E-ZPass discount	8.9	11.6	9.6
Heard of discounts but do not know specifics	15.0	4.4	12.5
Not aware of any discount	39.6	20.9	35.1
Total	100.0	100.0	100.0

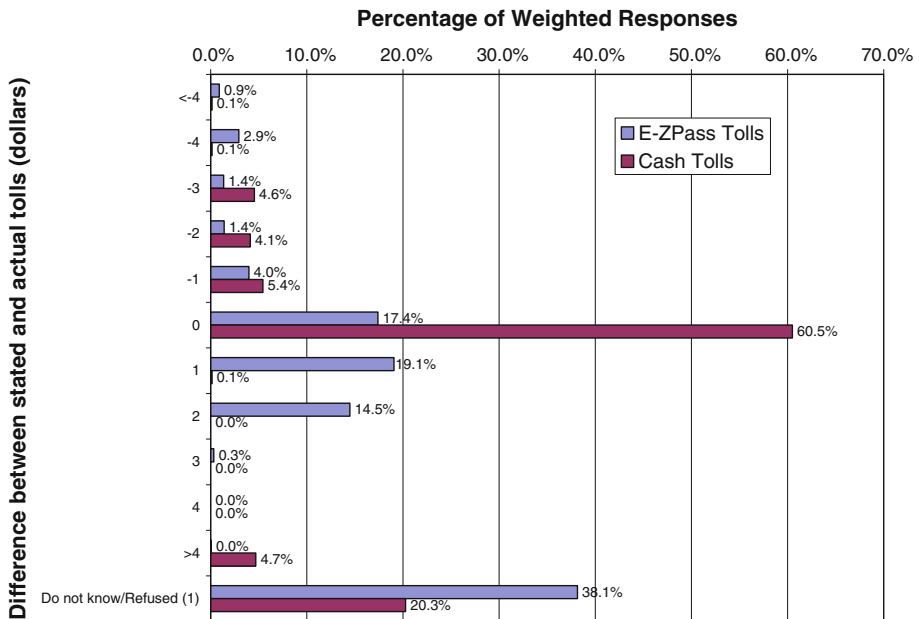


Fig. 3 Difference between stated and actual tolls—New Jersey—(dollars). *Notes:* (1) For E-ZPass users, the category of “Do not know/Refused” includes respondents whose actual tolls are unknown because they either did not report time of travel and/or day of travel at the toll plaza, since E-ZPass has different toll rates during different times of day and day of week; and the mean value of the misreported toll for E-ZPass users is US\$0.35 (*positive sign* means overestimated) with a standard deviation of US\$1.64; while the mean value for cash users is –US\$0.12 (*negative sign* means underestimated) with a smaller standard deviation (US\$1.32)

New Jersey (38.1%) reported “Do not know/Refused” than cash users (20.3%). Furthermore, while the majority of cash users (60.5%) correctly reported the tolls, only 17.4% of those paying E-ZPass did so. Both types of users’ trips underestimated tolls in similar proportions: E-ZPass users’ trips (10.6%) and cash users’ trips (14.3%). However, the fractions of users who overestimated tolls were vastly different: while 33.9% of E-ZPass users overestimated tolls, only 4.8% of cash users did so. The likely reason is that since E-ZPass users pay their toll bills every month by credit card they may not necessarily know the actual amount of tolls paid every time when they use the facilities. Staten Island users are not included in this analysis because some of them enrolled in a frequent use discount program that has a different toll structure.

Impacts of the time of day pricing initiative

This section analyzes the impacts of the 2001 PANYNJ time of day pricing on passenger travel behavior. The data show that passenger car users were inelastic to tolls. Only 35 out of 505 individuals (representing 6.9% of individuals and 7.4% of passenger trips) changed behavior because of the time of day pricing initiative. The majority of these individuals (28 out of 35 individuals) still traveled through the six PANYNJ toll facilities by car on a regular basis even though they adjusted their travel patterns because of time of day pricing.

Table 7 Elasticities of demand with respect to tolls (travelers)

User type	Time of travel	% Change in tolls	% Changes in trips	Elasticity of demand
Cash users	Peak hours	50.0	-11.1	-0.22
	Off-peak hours	50.0	-5.7	-0.11
E-ZPass users	Peak hours	38.9	-4.8	-0.12
	Off-peak hours	11.1	-2.7	-0.24
Average for all users		33.0	-4.7	-0.14

Note: the estimates include all trips that changed behavior (not only those who changed facility usage)

These respondents account for 5.5% of individuals and 4.6% of passenger trips. The other group of individuals reporting behavioral changes (7 out of 35 individuals) is the group of former regular users, which accounts for 1.4% of individuals and 2.7% of passenger trips. These are individuals who reported switching to public transportation specifically because of time of day pricing. Most respondents who changed behavior were from New Jersey which had 27 out of the total of 35. It should be mentioned that, although the impacts of pricing could be measured in terms of number of passenger-trips or individuals that changed behavior, most of the analysis in the paper are based on passenger-trips. The reason is that this metric provides a more accurate idea about the impact of the change on the total traffic using the facilities.

The direct elasticities of the different demand segments with respect to tolls were calculated (see Table 7). In all cases, the demand was inelastic with an average elasticity of -0.143 , which is consistent with previous research (Oum et al. 1990; Cain et al. 2001; Burris and Pendyala 2002). As a technical comment, it is important to note that, since cross-effects between the tolls at different time periods were not taken into account when computing the elasticities, it is likely that the elasticities overestimate the impact of pricing because they did not take into account how the lower toll rate in the off-peak periods, for instance, impacts the demand during the peak hours.

Behavioral changes

The survey participants were asked to list the behavioral changes they implemented after time of day pricing. Since the New Jersey users are considered to be the best representative of the typical regular users, the discussion in this section focuses on the New Jersey data. The reader interested in the Staten Island results is referred elsewhere (Holguín-Veras 2005).

The data show that the most typical response was to switch mode, either to transit (1.91%) or to carpooling (0.64%), for a combined (2.55%). This was followed by reduction in the number of trips made during the weekday peak-hours (1.65%), switching to EZ-Pass to take advantage of the toll discounts (0.81%), and increase in the number of trips during weekday off-peak hours (0.69%), and “Others” with 1.95%. Another important finding pertains to the multidimensional nature of their responses as all respondents reported between three and eight different behavioral changes, with an average of 3.23 changes/person. This obviously suggests that the user response to pricing is significantly more complex and nuanced than previously thought, and that users seek multiple ways to mitigate the impacts of pricing.

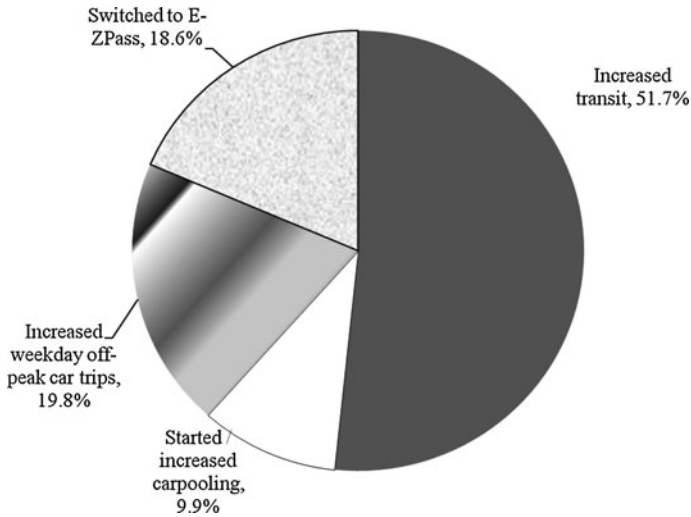


Fig. 4 Behavioral changes adopted by New Jersey users who reduced weekday peak hour car trips. *Note:* The percentages correspond to the subsample of respondents who reduced weekday peak hour car trips. This group of users represents 1.65% of total trips

The data collected in the project enable the analysis of the substitution patterns exhibited by the users. This analysis is important because it provides crucial information for policy making regarding what the users do with the car trips they reduced because of time of day pricing. Figure 4 shows the new behaviors implemented by the New Jersey respondents who reduced their weekday peak car trips (representing 1.65% of trips). As shown, the predominant choice was to switch to another mode (i.e., transit or carpooling), which was selected by 61.6% of the participants who reduced their weekday peak-hour car trips. In terms of modes used, the majority of participants chose to increase transit usage (51.7%), with a smaller group deciding to start/increase carpooling (9.9%) to compensate for the reduced car trips. In contrast, a relatively smaller group of users (19.8%) increased their off-peak travel. Compared with the patterns mentioned above, switching to E-ZPass was less significant, with 18.6% of respondents. It is important to mention that none of the users who switched to E-ZPass changed their time of travel. This indicates that these users had done so to take advantage of the general E-ZPass discount but not the E-ZPass off-peak discount.

Reasons for not changing behavior

As mentioned before, the majority of travelers (93.1%) did not change behavior. Figure 5 shows the breakdown of the reasons stated by the New Jersey users who reported no behavioral changes. As shown, “Lack/no flexibility” and “Lack/no willingness to change” were the two major reasons for not changing behavior. The data show that participants did not change behavior because they had no choice or no flexibility to change (45.1%), or because they believe they should travel whenever they want to (30.9%). Other respondents indicated that: the toll difference was not enough to justify a change of time of travel (11.3%), it was paid by their employers (5.0%), or they did not use the facilities enough in order to justify a change (2.6%). These findings suggest that different factors were at play.

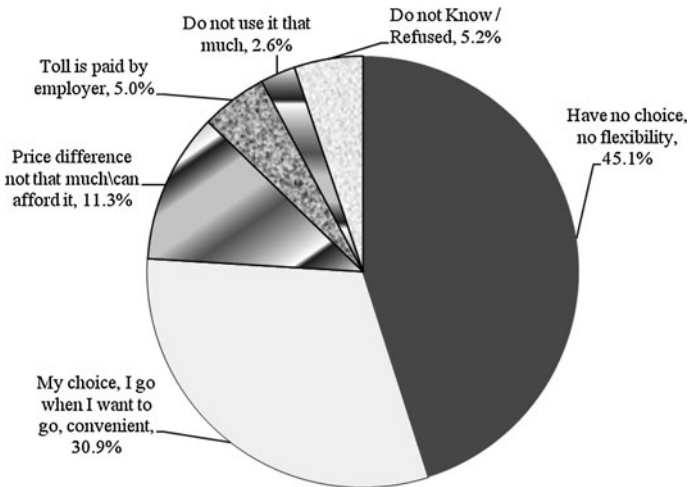


Fig. 5 Reasons for not changing behavior (New Jersey respondents)

Table 8 Comparisons of socio-economic characteristics

Variable	Changed behavior	Did not change	Statistically different at the 5% probability level?
% of Females	57.6	40.2	Yes
Mean age	38.3 years	45.2 years	Yes
% of with college education	38.6	56.1	Yes
Number of adults in household (mean)	2.1	2.5	Yes

First, travel constraints such as work schedules make it difficult for users to change their travel schedules. Second, the toll increase seemed to be too small to force changes on a sizable number of travelers, which may explain the behavior of those users who indicated lack of willingness to change.

Characteristics of the travelers who changed behavior versus travelers who did not

Although the sample of individuals who changed behavior is relatively small (35 observations), statistical analyses indicated that that this group has a statistically different socio-economic profile than the group of users who did not change behavior. Table 8 shows the results of the statistical tests conducted to assess the significance of the observed differences in the socio-economic characteristics. As shown, the individuals who changed behavior tend to:

- Be females, suggesting that women are more sensitive to price changes.
- Be younger than those who did not change behavior.
- Have a relative lower education level than those who did not change.
- Have fewer adults in their families.

The possibility of pricing having a negative impact on such a vulnerable segment of the population is something that stresses the importance of providing suitable transit alternatives. Failing to do so may have a detrimental impact on the quality of life of these groups.

Policy implications

In this section, key findings are discussed in more detail as they have important policy implications. This discussion is relevant to planning and implementation of time of day pricing projects in urban areas where there are no non-tolled alternatives, and transit is available.

The first aspect that should be highlighted is that the users have limited flexibility to change time of travel. On average, regular car users can depart 19 min earlier and 14.7 min later, or arrive 20.4 min earlier and 12.3 min later for work-related trips (that represent the bulk of the trips in the peak hours). These numbers have important implications because they clearly show that changing time of travel is not something the typical users are prepared to do, as they simply do not have enough time of travel flexibility to shift from peak to off-peak hours. Obviously, if the goal is to induce a switch in time of travel, the corresponding constraints must be relaxed for this to be possible. This necessitates comprehensive approaches aimed at convincing/inducing employers to relax work hours. In this context, voluntary programs or regulations promoting the implementation of staggered/flexible work hours undoubtedly have an important role to play in demand management. The relaxation of work hour constraints, coupled with time of day pricing is bound to have a dramatic effect on the hourly distribution of traffic. This conclusion is supported by previous research that highlighted the importance of the constraints imposed by employers on the employees' time of travel choices (Saleh and Farrell 2005). It should not come as a surprise that rescheduling of trips to off-peak hours accounted for only 0.69% of the sample.

It is important to mention that the use of incentives as a way to relax travel constraints—so that a more balanced traffic pattern could emerge—has been successfully designed (Holguín-Veras 2008, Holguín-Veras et al. 2007, 2008) and pilot tested for the urban deliveries case (Holguín-Veras 2010). This experience clearly suggests that incentives to companies, in exchange for their commitment to relax work hours, could play a key role in spurring the adoption and implementation of staggered and flexible work hours, with the net result of an attenuation of the peak traffic.

As a result of the lack of time of travel flexibility, switching to transit was the most common behavioral response implemented by the users because it enabled them to maintain their travel schedules. The data show that more than half of the passenger car users who changed behavior chose to either shift or increase their usage of public transportation. Worthy of mention is that the individuals that switched to transit reported transit fares that, in relation to car travel costs, were much lower than the sum of parking fee and tolls reported by current regular car users (\$5.6 vs. \$21.65). This suggests that the availability of inexpensive and convenient transit was a key factor in their choice of behavioral response. The implications seem clear: since users prefer to maintain their travel schedules, it is crucial to accompany time of day pricing with significant increases in the provision of inexpensive and reliable transit service, as done in London.

The large amount of free parking (60.1%) clearly indicates the opportunity to use parking pricing as a demand management tool. Even in chronically congested areas, such as Downtown and Midtown Manhattan, a sizable number of car users (more than one-third)

reported the use of free parking. In this context, increasing the coverage of metered parking could become a potent deterrent to car travel by making it more expensive to use the passenger car.

Another aspect worthy of discussion in this section is the impact that electronic toll collection seems to be having on the users' perception about tolls. As discussed in the paper, EZ-Pass users were less aware of the actual tolls they paid than cash users. This is rather surprising as the electronic displays at toll booths visibly show the toll paid by EZ-Pass users. It seems possible that the users do not register the price signals sent by the electronic displays in the same way as when they pay in cash. Regardless of the reason, the fact of the matter is that the price signal sent by pricing is not reaching an important segment of users. It is rather ironic that electronic toll collection—the technology that has made modern road pricing possible—is, at the same time, obscuring the price signals that are crucial to the success of any pricing implementation.

Conclusions

This paper has outlined a set of conclusions of interest to the road pricing community. According to the survey results, 7.4% of passenger trips changed behavior due to the PANYNJ time of day pricing initiative. The corresponding elasticities of passenger car demand with respect to tolls indicate that, as expected, demand is inelastic with the elasticity values in the range of -0.1 to -0.24 . These values are similar to the ones computed in previous studies.

The analyses of the passenger data suggest that individuals who changed behavior are more likely to: be female, younger than those who did not change behavior, have a relative lower education level, and have relatively smaller families with fewer adults, than those who did not change. These individuals adopted combinations of various strategies to deal with time of day pricing. Most of the respondents who changed behavior reported multiple changes, for an average of 3.23 changes/person.

The data clearly show that most users preferred to switch mode, and maintain their preferred time of travel (61.6% of those who reduced weekday peak hour car travel), to the alternative approach of changing time of travel to the off-peak hours and maintaining the preferred mode (passenger car). This is undoubtedly a reflection of the limited time of travel flexibility that, on average, was estimated to be 20.4 and 12.3 min for early and late arrival for work-related trips. This, in turn, suggests the need for comprehensive policies that combine incentives or regulation to foster widespread implementation of staggered/flexible work hours, combined with the provision of additional transit service as a car substitute, and road pricing as a disincentive to car traffic. Such policies, by relaxing the time of travel constraints, increasing the availability of suitable substitutes, and providing a financial penalty on car traffic, may represent the only way towards achieving a more balanced distribution of traffic during the day and the sustainable cities the Nation needs and deserves.

Acknowledgments This project was sponsored by a grant from the Federal Highway Administration's Value Pricing Program, through the University Transportation Research Center. Additional support was provided by the Port Authority of New York and New Jersey. Special thanks are due to Mark Muriello and Danny Jiji (PANYNJ) for their support and assistance throughout this investigation. The opinions and conclusions presented are the sole responsibility of the authors and do not necessarily reflect the views of sponsors and participating agencies.

References

- Burris, M.W., Pendyala, R.M.: Discrete choice models of traveler participation in differential time of day pricing programs. *Transp. Policy* **9**(3), 241–251 (2002)
- Cain, A., Burris, M.W., et al.: The impact of variable pricing on the temporal distribution of travel demand. *Transp. Res. Rec.* **1747**, 36–43 (2001)
- Holguín-Veras, J.: Necessary conditions for off-hour deliveries and the effectiveness of urban freight road pricing and alternative financial policies. *Transp. Res. A: Policy Pract.* **42A**(2), 392–413 (2008)
- Holguín-Veras, J., Ozbay, K., et al.: Evaluation study of the Port Authority of New York and New Jersey's time of day pricing initiative. In: Trenton, N.J. (ed.) New Jersey Department of Transportation. <http://www.rpi.edu/~holguj2/PA/index.html> (2005)
- Holguín-Veras, J., Ozbay, K. et al.: Integrative freight demand management in the New York City metropolitan area. http://www.transp.rpi.edu/~usdotp/DRAFT_FINAL_REPORT.pdf (2010)
- Holguín-Veras, J., Silas, M., et al.: An investigation on the effectiveness of joint receiver-carrier policies to increase truck traffic in the off-peak hours. Part I: the behavior of receivers. *Netw. Spatial Econ.* **7**(3), 277–295 (2007)
- Holguín-Veras, J., Silas, M., et al.: An investigation on the effectiveness of joint receiver-carrier policies to increase truck traffic in the off-peak hours. Part II: the behavior of carriers. *Netw. Spatial Econ.* **8**, 327–354 (2008). doi:10.1007/s11067-006-9011-6
- Holguín-Veras, J., Wang, Q., et al.: Impacts of time of day pricing on the behavior of freight carriers in a congested urban area: implications to road pricing. *Transp. Res. A: Policy Pract.* **40**(9), 744–766 (2006)
- Johnson, M.B.: On the economics of road congestion. *Econometrica* **32**(1–2), 137–150 (1964)
- Lindsey, R., Verhoef, E.T.: Traffic congestion and congestion pricing. In: Button, K., Hensher, D. (eds.) *Handbook of transport systems and traffic control*, pp. 77–105. Pergamon, Amsterdam (2001)
- Nelson, J.C.: The pricing of highways, waterways, and airways facilities. *Am. Econ. Rev.* **52**(2), 426–435 (1962)
- Oum, T.H., Waters, W.G., et al. A survey of recent estimates of price elasticities of demand for transport. Policy Research Working Paper Series. No. WPS 359. The World Bank (1990)
- Pigou, A.C.: *The economics of welfare*. London: MacMillan and Co. (1920)
- Port Authority of New York and New Jersey (PANYNJ): *Tolls of Six Hudson Crossings*. <http://www.panynj.gov/bridges-tunnels/tolls.html> (2010). Retrieved 30 August 2010
- Saleh, W., Farrell, S.: Implications of congestion charging for departure time choice: work and non-work schedule flexibility. *Transp. Res. A: Policy Pract.* **39**(7–9), 773–791 (2005)
- U.S. Census Bureau: Median income of households by state: 1984 to 2003 two-year moving averages. <http://www.census.gov/hhes/income/histinc/h08a.html> (2004). Retrieved 22 July 2007
- Vickrey, W.S.: Congestion theory and transport investment. *Am. Econ. Rev.* **59**(2), 251–260 (1969)
- Walters, A.A.: The theory and measurement of private and social cost of highway congestion. *Econometrica* **29**(4), 676–699 (1961)

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