HOT or Not

Driver Elasticity to Price on the MnPASS HOT Lanes

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The Minnesota Department of Transportation (MnDOT) has added MnPASS High Occupancy Toll (HOT) lanes on two freeway corridors. While not the first HOT lanes in the country, the MnPASS lanes are the first implementation of road pricing in Minnesota and possess a dynamic pricing schedule. Tolls charged to single occupancy vehicles (SOVs) are adjusted every three minutes according to HOT lane vehicle density. Given the infancy of systems like MnPASS, questions remain about drivers' responses to toll prices. Three field experiments were conducted on the corridors during which prices were changed. Data from the field experiments as well as two years of toll and traffic data were analyzed to measure driver responses to pricing changes. Driver elasticity to price was positive with magnitudes less than 1.0. This positive relationship between price and demand is in contrast with the previously held belief that raising the price would discourage demand. In addition, drivers consistently paid between approximately $60-120 per hour of travel time savings, much higher than the average value of time. Reasoning for these results is discussed as well as the implications these results have on the pricing of HOT lanes.

1 Introduction

The Minneapolis - St. Paul Metropolitan area faces peak period congestion. With limited capacity and excess demand, speeds slow during the morning and afternoon commute. I-394 stretches from the western suburbs into downtown Minneapolis. The freeway originally contained high occupancy vehicle (HOV) lanes, including a two lane, barrier separated, reversible section. This section runs along approximately 1/3rd of the freeway's length. The remaining section contains one concurrent, double white line separated HOV lane running in each direction. In 2005, the Minnesota Department of Transportation (MnDOT) converted the HOV lanes on I-394 to high occupancy toll (HOT) lanes.

While the HOV lanes benefited carpools, motorcycles and buses, the lanes did not maximize vehicle throughput. In order to maintain the carpooling/transit incentive while utilizing the lanes to a greater extent, MnDOT explored the concept of HOT lanes. They are tolled lanes (on otherwise untolled roads) which give a free or discounted trip for HOV users, and are thus optional.

Before the MnPASS HOT lanes, no road pricing had been adopted in Minnesota. The Minnesota legislature and governor felt that implementing HOT lanes was an attractive option to increase use of the existing HOV lanes on I-394 (Munnich and Buckeye, 2007). Because the general purpose lanes remain free of charge, HOT lanes presented a more politically feasible option than other forms of congestion pricing (Fielding and Klein, 1993). The MnPASS lanes would remain free of charge for carpools, buses, and motorcycles and the toll would regulate SOV use(Turnbull, 2008). The toll helps ensure a high level of service (LOS) and provides some additional revenue (Konishi and Mun, 2010). Level of service is an A-F scale defined in the Highway Capacity Manual with A representing free flow speeds and F breakdown (Manual, 2000).

Support for HOT lanes appears across various income levels, household sizes and educational levels (Munnich and Buckeye, 2007; Burris et al., 2007). In addition, support tends to increase after implementation and is higher among areas with existing tolled roads (Finkleman et al., 2011; Burris et al., 2007). Safirova et al. (2003) believes that while HOT lanes benefit all income groups, they more greatly benefit the wealthy. Mowday (2006), on the other hand, believes HOT lanes are equitable due to users paying directly for use of the road. Finkleman et al. (2011) remarks that older, non-retired individuals and those new to their location support tolling more than others. While retired individuals may object to tolling due to their fixed income, Burris and Pendyala (2002) suggest that the retired and others on flexible schedules can more easily adjust their trips to avoid tolls and congestion.

While the idea seems to appease all sides of the debate, concerns arose, especially by those already using the HOV lanes (Burris et al., 2007). Transit proponents feared that the LOS in the HOT lanes would degrade (Turnbull, 2008). Turnbull (2008) and Burris and Xu (2006) analyzed the potential mode shift from transit to SOV. All cases resulted in either a statistically insignificant change or small enough change not to affect LOS. Munnich and

Buckeye (2007) observed a similar conversation of LOS on I-394 in Minneapolis after the conversion from HOV to HOT.

In order to guarantee that HOVs could continue to use the HOT lanes at a high LOS, MnDOT adopted a dynamic pricing system. Similar systems had been adopted on several HOT lanes around the country, but none with such frequent price changes. The toll price for SOVs is displayed at various plazas along the corridor. Loop detectors monitor the density in the HOT lanes. As density in the HOT lanes rises, so too does the toll price. As congestion clears and density decreases, the price lowers again. Dynamic pricing, in theory, allows MnDOT to control the amount of SOV traffic in the HOT lanes and maintain a high LOS. This paper reexamines that assumption.

Although I-394 was not the first HOT lane corridor in the country, few before had implemented a dynamic pricing scheme with such frequent pricing changes (every three minutes). MnPASS has been running since 2005. In 2009, MnDOT added MnPASS lanes to the I-35W corridor. The success of the lanes has created interest for expansion to other metro freeways (Cambridge Systematics, 2010).

Given that dynamicly priced HOT lanes is a relatively new concept, questions exist how optimal the current MnPASS pricing algorithm is at maximizing throughput while maintaining free flow speeds. The current algorithm operates by raising prices as the density in the MnPASS lanes rises. The assumption is that higher prices will dissuade usage and lower prices will entice users. Through this fluctuation in price, demand in the MnPASS lanes can be regulated and breakdown prevented.

This paper analyzes driving behavior, specifically looking at how much drivers pay for time savings and and their elasticity to change in price. By better understanding drivers' responses to price, changes can be made to the pricing algorithm to better control the amount of demand. Current assumptions about drivers' responses to pricing changes will be examined. Driving behavior is analyzed by looking at changes to price in demand using various data sources and methods.

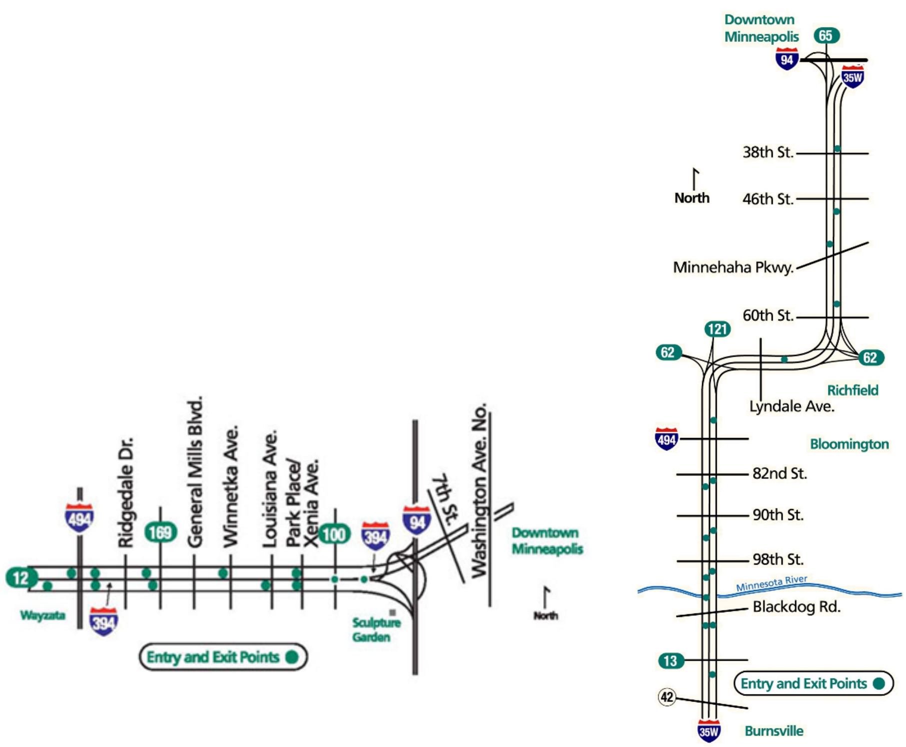
Data sources for the analyses include loop detectors, logs of price and density measurements from MnPASS as well as logs of individual MnPASS subscribers' transponder data. Three field experiments were implemented during which pricing changes were made. The methods and results as well as their implications are discussed in the following sections.

2 Current Operation

The MnPASS lanes are price controlled in the primary commute direction during the morning and afternoon peak periods. With several exceptions, the lanes are free for all vehicles outside of these times.

I-394 Eastbound and I-35W Northbound both operate between 6:00 and 10:00. During this time, the reversible, barrier separated portion of I-394 is only open to eastbound traffic. A Priced Dynamic Shoulder Lane (PDSL) section of I-35 NB is also open during this time. The afternoon peak runs between 14:00 and 19:00 on I-394 WB and between 15:00 and 19:00 on I-35W SB (MnDOT, 2013a).

Figure 1: MnPASS Entry and Exit Points on I-394 and I-35W



MnPASS (http://www.mnpass.org/)

Exceptions to the above description include portions of I-35W which operate during both the morning and afternoon peak periods. I-35W NB between Hwy 62 and downtown, and I-35W SB between 42nd Street and I-494 are controlled during both peak periods, not just in the primary commute direction. The reversible section of I-394 has a modified schedule as well. The section remains open to EB traffic from 6:00 to 13:00. Between 13:00 and 14:00, the lanes are closed for reversal and operate WB from 14:00 until 5:00 the following day (MnPASS Website).

Prices during operation times range from a minimum of \$0.25 to a maximum \$8.00. I-394 and I-35W are each divided into multiple sections with prices posted for use of each segment. The maximum price applies to use of each section individually, as well as use of all sections.

Prices are adjusted every three minutes based density levels measured in the MnPASS lanes only. Traffic levels in the GP lanes does not influence price. Loop detector counts are taken every 30 seconds. These counts are used to calculate the density in the MnPASS lanes at various plazas along the corridor. Each plaza consists of a multiple sets of detectors. Density measurements are averaged over the last 6 minute period in order to smooth out fluctuations. Drivers are charged based on the maximum density downstream of their entrance point. Densities upstream do not influence the paid price. Price is dictated by the magnitude of density as well as the change in density over the previous 6 minutes. A rise in density creates an increase in price.

Table 1 displays the pricing plan, which regulates the price based on density level. Minimums and maximums for a given LOS must be maintained. Table **??** indicates the changes in price caused by a change in density.

Table 1: Pricing Plan for Normal Operation of MnPASS Lanes (both I-35W and I-394)

Level of Service	Min K	Max K	Min Rate (\$)	Default Rate (\$)	Max Rate (\$)	
A	0	11	0.25	0.25	0.50	
B	12	18	0.50	0.50	1.50	
C	19	31	1.50	1.50	2.50	
D	32	42	2.50	3.00	3.50	
E	43	49	3.50	5.00	5.00	
F	50	50	5.00	8.00	8.00	
Density	Δ 1	Δ 2	Δ 3	Δ 4	Δ 5	Δ 6
0-18	0.25	0.25	0.25	0.25	0.25	0.25
19+	0.25	0.50	0.75	1.00	1.25	1.50

Density in veh/mi/ln; Prices in \$

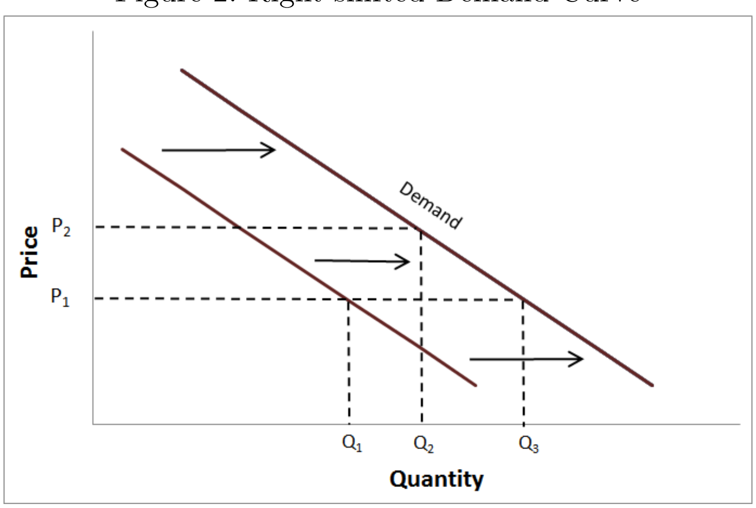
3 Demand Curve of Toll Roads

Most goods are ordinary goods following the downward sloping demand curve where quantity consumed decreases as price rises.

Some luxury goods, on the other hand, may see an increase in consumption as price rises (at least for certain prices). As reported in the Miami Herald (2010), drivers on I-95 may increase consumption of the toll lane as price rises. Drivers see the toll price as a signal of congestion in the untolled lanes and use of the tolled lanes increases. Therefore, a higher price leads to greater consumption. Does this mean toll roads have an upward sloping demand curve like a Veblen Good?

Beggs (2010) believes this is, in fact, not the case. In moving along a given demand curve, the assumption is that all other factors are held constant. In the HOT lane case, this assumption breaks down. The drivers may believe that the higher price indicates greater congestion and increased time savings. Therefore, drivers are assessing their willingness to pay for two different goods with different amounts of time savings. If time savings is held constant, HOT lanes follow a typical downward sloping demand curve where quantity decreases with an increase in price. Beggs (2010) suggests that perhaps, what's really happening as price increases, is that the demand curve is shifting to the right as seen in Figure 2. Drivers regard the higher priced HOT lane as a different good (one which provides greater time savings), for which they have a different demand curve. Beggs (2010) demonstrates this by noting that if price were held constant, but time savings increased, then quantity consumed would increase to Q3 on the right shifted demand curve. Therefore, HOT lanes are likely not Veblen Goods, but rather ordinary goods represented by different demand curves based on their properties (i.e. time savings).

Figure 2: Right-shifted Demand Curve



(Beggs, 2010)

4 Methods

4.1 Average Tolls and Time Savings

The average payment for time savings on the MnPASS lanes was calculated for I-394 and I-35W for both the morning and afternoon peak periods. Two years of toll and loop detector data (2011 & 2012) were gathered in order to compute the average time savings for using the MnPASS lanes and the average paid toll. Pricing data came directly from logs provided by the MnPASS operators. Prices were provided for each plaza along the corridor, every 3 minutes. These represent posted prices and not individually paid prices. Average toll prices were computed by weighing the posted prices by the number of users experiencing a given price (reported MnPASS lane density). The average paid toll price also assumes use of the entire MnPASS corridor. Averages are calculated over the entire paid MnPASS periods 6:00-10:00 & 14:00-19:00 for I-394 and 6:00-10:00 & 15:00-19:00 for I-35W.

Time savings was calculated using loop detector data from the MnPASS and GP lanes. Commute times for the GP and MnPASS lanes were calculated assuming use of the entire corridor. The MnPASS corridor stretches approximately 12.4 miles (19.96 km) on I-394 and 16 miles (25.75 km) on I-35W. Calibrated field lengths were used for the detectors, which provide occupancy data every 30 seconds. From the occupancy data, average speeds were calculated for each series of detectors along the corridor. Speeds were averaged over a three-minute time period, corresponding to the frequency of pricing changes.

Calculations were carried out for I-394 and I-35W over the entire morning and afternoon price enforced periods and averaged. Travel time savings were the differences in commute times between the MnPASS and GP lanes. Like the average prices, time savings was weighted based on density. Cost for time savings was computed using the weighted averages of time savings and toll price. Therefore, although data were averaged over the entire peak period, heavier demand periods were given greater weight. The resulting values are discussed later.

4.2 Field Experiments

Several field experiments were conducted between October 2012 and January 2013. Drivers were never made aware of any changes to the pricing plan.

The first field experiment took place on I-394 between October 8, 2012 and November 2, 2012. Prices during this period were raised on higher densities and lowered at lower densities. The second field experiment took place on I-35W between October 29, 2012 and November 23, 2012. Prices during this period were lowered across all density levels.

A third field experiment was conducted on I-394 lasting five weeks. This experiment took place between December 7-21, 2012 and January 7-25, 2013. Price was increased by an estimated 15% on average by raising the density thresholds at each level of service. All other algorithm operations were left constant. Again, drivers were not made aware of the changes and prices were reverted back after the close of the experiment.

The field experiments were analyzed by comparing to the same days one year prior. For example, if the experiment began on the first Monday in October, that same Monday the year before was used as the start date. In order to account for changes occurring between 2011 and 2012, a control period was analyzed. The control period usually consists of several weeks prior to the field experiment. The changes in the control period between 2011 and 2012 can then be compared to the changes between the baseline period and the field experiment. The control periods and baseline period all contained the same pricing plan. This helps determine which changes are caused by the changes to the pricing plan and helps eliminate other confounds.

Price and demand data from the field experiments were taken from specific plazas along the corridor. The selected points represent plazas which typically have the maximum density compared to upstream plazas. Therefore, the density at these critical plazas (as they will be referred to) is often responsible for the posted prices upstream. Data for I-394 used price and demand measurements from plaza 1003 in the eastbound direction and plaza 2003 westbound. These plazas include the section of I-394 between Hwy 169 and Louisiana Ave.

On I-35W, both plazas 3006 and 3013 in the northbound direction, along with 4009 and 4011 southbound were analyzed. Plaza 3006 includes the area around Black Dog Road and 3013 includes the section of south Minneapolis between 42nd Street and 26th Street. Plazas 4009 and 4011 are located near 98th Street S and Cliff Road respectively.

4.3 Driver Elasticity

Understanding the elasticity to price of MnPASS drivers is important to determine an optimal pricing plan. Very inelastic behavior would mean large price changes would do very little to change the demand of the MnPASS lanes. This would cause difficulty in regulating MnPASS demand. Very elastic behavior, on the other hand, would mean large changes to demand from a small price change. This could lead to erratic changes in demand from small toll fluctuations.

Equally important to the magnitude of elasticity is the positive or negative relationship between price and demand. Does MnPASS demand increase or decrease with an increase in price? The assumption until now how has been that MnPASS lanes are a simple ordinary good, meaning an increase in price corresponds to a decrease in demand. However, as discussed by Beggs (2010), this is not always the case for HOT lanes, which may see increases in demand corresponding to higher prices.

Prices for elasticity calculations came directly from the MnPASS system logs. The MnPASS logs store posted prices and their corresponding density levels. Demand was measured in two ways, MnPASS lane density which determines price as well as the share of traffic using the MnPASS lanes compared to the general purpose lanes. This is referred to as the MnPASS lane share percentage, noted in the equation below. The percentage represents the share of traffic flow in the MnPASS lanes over total flow on the freeway in the respective direction.

S denotes MnPASS lane share percentage. Q represents flow. Flow for the general purpose lanes is the sum of all general purpose lanes.

$$S_{MnPASS}=\frac{Q_{MnPASS}}{Q_{MnPASS}+\Sigma Q_{GP}}$$

Driver elasticity for the field experiment was calculated by comparing price and demand to a baseline period. Average price and demand every three minutes throughout the peak period was calculated as well as the overall weighted average price and density. This was done for each week of the field experiments as well as same period one year prior. Data corresponds to the critical plazas discussed earlier. Prices and densities for this analysis come from the MnPASS system logs. S_{MnPASS} is calculated from loop detector data. Elasticity was calculated twice. Once by looking at the changes in price and demand between the two periods for every three-minute period. Elasticity values were then calculated for each 3 minute period and averaged to yield an average of elasticities. The other method compared the overall weighted prices and densities for the two periods. This yielded an elasticity of averages measurement. This same procedure was done for a control period, comparing 2011 and 2012 one month before each field experiment. The control periods utilized the same pricing plan as the baseline period. The final elasticity for the field experiments was the net change occurring between the baseline and field experiment, subtracting out any changes between 2011 and 2012 in the control.

The subscript F denotes the field experiment and subscript B denotes the baseline period. The 2012 control period is noted by subscript 2 and 2011 control by subscript 1. D represents demand (density or S_{MnPASS}), P represents price and epsilon the resulting elasticity.

Average of Elasticities

for field experiment

$$\varepsilon=\frac{\frac{D_{F,t}-D_{B,t}}{D_{B,t}}}{\frac{P_{F,t}-P_{B,t}}{P_{B,t}}}$$

for control

$$\varepsilon=\frac{\frac{D_{2,t}-D_{1,t}}{D_{1,t}}}{\frac{P_{2,t}-P_{1,t}}{P_{1,t}}}$$

Elasticity of Averages

$$\varepsilon = \frac{\frac{\overline{D}_F - \overline{D}_B}{\overline{D}_B} - \frac{\overline{D}_2 - \overline{D}_1}{\overline{D}_1}}{\frac{\overline{P}_F - \overline{P}_B}{\overline{P}_B} - \frac{\overline{P}_2 - \overline{P}_1}{\overline{P}_1}}$$

5 Results and Discussion

5.1 Average Tolls and Time Savings

Average weighted toll prices and time savings during the morning and afternoon peak periods on I-394 and I-35W are displayed in Table 2. Averages are weighted based on the number of users experiencing the price or time savings. The average toll price for the peak periods ranges from \$1.37 to \$2.91. The minimum and maximum tolls are \$0.25 and \$8.00 respectively. Time savings for MnPASS users ranges from less than a minute (0.78 min) on I-394 in the afternoon to 2.87 minutes on I-35W in the morning peak. With the I-394 corridor running 12.4 miles (20 km), MnPASS users experienced 8.1 seconds/mile (5.0 sec/km) average time savings in the morning and 3.8 seconds/mile (2.4 sec/km) in the afternoon. The MnPASS lanes on I-35W stretch 16 miles (25.7 km), providing 10.8 second/mile (6.7 second/km) average time savings during the morning commute and 4.8 seconds/mile (2.98 second/km) in the afternoon. These values allow for better direct comparison of the time savings between I-394 and I-35W.

The average time savings and toll price values yielded price paid for time savings values from \$60.77 to \$124.10 per hour. These values are much higher than typical values of time (VOT). MnDOT, for example, uses a VOT of \$15.60 (MnDOT, 2013b). Burris et al. (2012) found similarly high values of time on I-394, \$73/hr during the morning commute and \$116/hr in the afternoon.

There are several other possible explanations for the high VOT. First, it is expected that users of HOT lanes have a higher than average VOT as most travelers do not use the lanes. The second is distorted driver perception. As shown by Ghosh (2001) and Yan (2002), drivers have a distorted perception of reality and likely perceive their time savings to be greater than reality. MnPASS users probably do not realize how minimal their time savings is on average (Parthasarathi et al., 2012). A third factor is that the VOT includes value of reliability (VOR), which represents the monetary value placed on reduced travel variability (Carrion and Levinson, 2012b). VOR is more difficult to quantify. Studies have placed the reliability ratio (VOR/VOT) anywhere between 0.10 and 2.8 (Carrion and Levinson, 2012a,b). The MnPASS lanes provide consistent travel time with a very small likelihood of breakdown. Therefore, some of the VOT is likely due to the increased reliability provide by the lanes. The more consistent traffic flow also makes driving in the MnPASS lanes safer and less stressful. Finally, MnPASS users may take advantage of queue jumps provided by the lanes. Users travelling WB on I-394 and headed south on Hwy 100, can bypass the queue that often forms. Advantages like this are more diffucult to measure, but nevertheless, are important benefits provided by the lanes.

Table 2: Average Toll Prices and Time Savings - 2011 & 2012

	Avg. Price ($\overline{P}$)	Avg Time Savings (min)	Cost/Time Savings ($/hr)
I-394 Morning	2.579	1.673	92.49
I-394 Afternoon	1.369	0.777	105.70
I-35W Morning	2.909	2.872	60.77
I-35W Afternoon	2.533	1.224	124.10

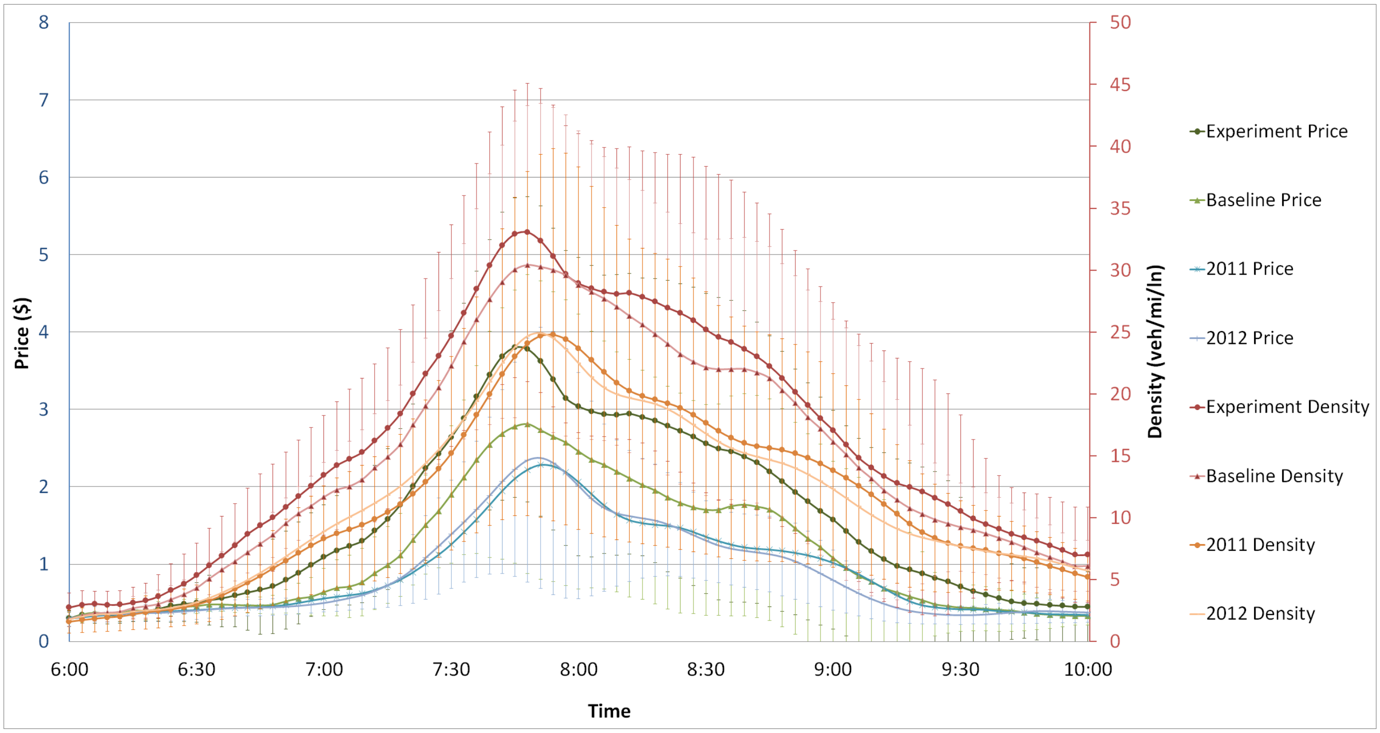
I-394 Morning: 6:00-10:00
I-394 Afternoon: 14:00-19:00
I-35W Morning: 6:00-10:00
I-35WAfternoon: 15:00-19:00
Data taken over all weekdays in 2011 and 2012

5.2 Elasticity

Figure 3 displays changes in price and density for the third field experiment and its control period. Twelve minute moving averages were used to smooth the data. The error bars represent one standard deviation in each direction. Average price and density levels during the morning peak period on I-394 for all periods are shown. The experiment includes 2 weeks in December 2012 (12/7-12/21) and 3 weeks in January 2013 (1/7-1/25). The baseline period includes the same days as the field experiment, but one year prior. The control period compares November 2011 (2011-11-18 to 2011-12-9) and November 2012 (2012-11-16 to 2012-12-7).

Prices were increased during the field experiment by lowering density thresholds. Average paid prices throughout the morning peak period were consistently higher during the 5 week experiment. Figure 3 reveals that the MnPASS lanes saw a consistent increase in density throughout the peak period during the field experiment. Although less than the price increase, density at nearly every time segment during the analyzed periods was higher. This led to the positive elasticity results displayed in Tables 4 and 5.

Figure 3: I-394 Field Experiment: 2012-12-10 to 2012-12-21 & 2013-1-7 to 2013-1-25



2012-12-10 to 2012-12-21 & 2013-1-7 to 2013-1-25
2011-12-12 to 2011-12-23 & 2012-1-9 to 2012-1-27
2011-11-18 to 2011-12-9
2012-11-16 to 2012-12-7
Plaza 1003, between Hwy 169 and Louisiana Ave on EB I-394
Weekdays only

Table 3: Weighted Averages

	Baseline	Field Experiment	% Change	Control % Change	Net % Change
(1) Plaza 1003					
Price	2.024	2.418	19.45*	16.09*	3.353
Density	25.31	27.50	10.54*	9.657*	0.885
S_{MnPASS}	20.76	21.50	3.566	1.627	1.939
(2)					
Plaza 3005					
Price	2.010	2.229	10.88*	68.75*	-57.87
Density	24.98	30.92	23.79*	37.41*	-13.62
S_{MnPASS}	22.36	24.13	7.871*	16.17*	-8.301
Plaza 3012					
Price	1.71	1.882	9.717	38.04*	-28.33
Density	21.74	25.78	18.61*	22.45*	-3.840
S_{MnPASS}	13.36	15.56	16.49*	12.02*	4.471
(3) Plaza 1003					
Price	2.192	3.044	38.84*	-2.569	41.41
Density	26.03	28.07	7.830*	-6.381	14.21
S_{MnPASS}	20.9	20.99	2.980	-8.217*	11.20

** Significant at 0.05 significance level*
Time of Day: 7:00-9:00
Density in units veh/mi/ln
S_{MnPASS} *is percent of overall flow using the MnPASS lane*
(1) I394: FE: 2012-10-8 to 2012-11-2, Base: 2011-10-10 to 2011-11-4, Control: September 2011 and 2012
(2) I35W: FE: 2012-10-29 to 2012-11-23, Base: 2011-10-31 to 2011-11-25, Control: October 2011 and 2012
(3) I394: FE 2012-12-10 to 2012-12-21 & 2013-1-7 to 2013-1-25, Base: 2011-12-12 to 2011-12-23 & 2012-1-9 to 2012-1-27, Control: November 2011 and 2012
Plaza 1003 lanes: 1 HOT, 2 GP, 1 Auxilliary
Plaza 3005 lanes: 1 HOT, 2 GP
Plaza 3012 lanes: 1 HOT, 4 GP

Table 4: Elasticity of Averages

Demand Measure	Without Control	Net (with control)
(1) Plaza 1003		
Density	0.5421	.2641
S_{MnPASS}	0.1829	.5784
(2)		
Plaza 3005		
Density	2.186	0.2354
S_{MnPASS}	0.7234	0.1435
Plaza 3012		
Density	1.915	0.1356
S_{MnPASS}	1.697	-0.1578
(3) Plaza 1003		
Density	0.2016	0.3431
S_{MnPASS}	0.0767	0.2704

Time of Day: 7:00-9:00
(1) I394: FE: 2012-10-8 to 2012-11-2, Base: 2011-10-10 to 2011-11-4, Control: September 2011 and 2012
(2) I35W: FE: 2012-10-29 to 2012-11-23, Base: 2011-10-31 to 2011-11-25, Control: October 2011 and 2012
(3) I394: FE 2012-12-10 to 2012-12-21 & 2013-1-7 to 2013-1-25, Base: 2011-12-12 to 2011-12-23 & 2012-1-9 to 2012-1-27, Control: November 2011 and 2012

Table 5: Average of Elasticities

Demand Measure	Mean	Median	Std Dev
(1) Plaza 1003			
Density (FE)	-0.9719	0.1245	7.385
S_{MnPASS} (FE)	-1.192	-0.0719	7.920
Density (Control)	0.5058*	0.4613	0.8900
S_{MnPASS} (Control)	0.1377*	0.0495	0.3914
(2)			
Plaza 3005			
Density (FE)	-2.769	-0.2377	18.05
S_{MnPASS} (FE)	-1.624	-0.2695	9.520
Density (Control)	0.6654*	0.5440	0.0236
S_{MnPASS}(Control)	0.3131*	0.2836	0.1752
Plaza 3012			
Density (FE)	-2.581	0.7562	22.44
S_{MnPASS} (FE)	-2.8290	0.4052	22.29
Density (Control)	0.6925*	0.6035	0.2870
S_{MnPASS} (Control)	0.4522*	0.3965	0.3129
(3) Plaza 1003			
Density (FE)	0.2110*	0.2307	0.0874
S_{MnPASS} (FE)	0.0981*	0.1011	0.0755
Density (Control)	1.016	1.159	3.148
S_{MnPASS} (Control)	0.8144	0.9299	2.447

** Significant at 0.05 significance level*
Time of Day: 7:00-9:00
(1) I394: FE: 2012-10-8 to 2012-11-2, Base: 2011-10-10 to 2011-11-4, Control: September 2011 and 2012
(2) I35W: FE: 2012-10-29 to 2012-11-23, Base: 2011-10-31 to 2011-11-25, Control: October 2011 and 2012
(3) I394: FE 2012-12-10 to 2012-12-21 & 2013-1-7 to 2013-1-25, Base: 2011-12-12 to 2011-12-23 & 2012-1-9 to 2012-1-27, Control: November 2011 and 2012

Table 3 displays weighted averages of price and density for the baseline, field experiment and control periods. A net change between the baseline and field experiment, including changes in the control, are also displayed. The number of lanes corresponding to the S_{MnPASS} are displayed below the table. Elasticity was calculated using both density and S_{MnPASS} as a measure of demand. Table 4 shows the elasticity values calculated from the weighted averages in Table 3. Results in Table 5 include the mean, median and standard deviation of elasticity values for every three minutes between 7:00-9:00.

The first field experiment on I-394 resulted in statistically significant changes in price and density. The control period also resulted in significant changes in price and density between 2011 and 2012. Overall, there was a net increase in price, density and S_{MnPASS}. Although the intention was to decrease the price, the varied structure of the pricing plan for this field experiment led to higher prices and higher densities. The averages were taken between 7:00-9:00. Over this time period, price was primarily higher during the field experiment than the baseline. The increase in both price and demand led to positive elasticity of averages values for the first field experiment. The mean, median and standard deviation of individual elasticity measurements displayed in 5 reveal no statistically significant difference for the field experiment. There was a high standard deviation of the individual measurements. There was, however, a statistically significant positive elasticity measured in the control period between 2011 and 2012.

Values for the I-35W field experiment were separated into measurements from plaza 3005 and plaza 3012. At both plazas, there was a statistically significant increase in price, density and S_{MnPASS} between 2011 and 2012. The price increases between the baseline and field experiment were less pronounced due to the "price decrease" caused by increasing the density thresholds. This led to a net price decrease in price in both plazas. In all cases except S_{MnPASS} on plaza 3012, demand also saw a net decrease when including the control period. This resulted in nearly all positive elasticity results in Table 4. Similarly to the first field experiment, high standard deviation values in Table 5 resulted in no statistically significant average elasticity measurements between the baseline and field experiment. The control, however, saw statstically significant increases between 2011 and 2012.

Results from the third field experiment (second on I-394) were the most consistent. Price and density both saw statistically significant increases between the baseline and field experiment. The control period only saw a significant change in S_{MnPASS} between 2011 and 2012. The net values were all positive, resulting in positive elasticity values in Table 5. The average of individual elasticity measurements were also positive and statistically significant between the baseline and field experiment for both density and S_{MnPASS}. Unlike the other field experiments, price, density and S_{MnPASS} for this experiment saw consistent increases across all time periods and density levels. This can be seen in Figure 3. This consistency led to steady elasticity results and the small standard deviation values. Another indication of consistency are the similar mean and median values.

6 Conclusion

With the increasing interest in HOT lanes around the US, it is important to understand drivers' responses to varying toll prices. Specifically focusing on the MnPASS lanes on I-394 and I-35W in Minneapolis, this paper found drivers paid between \$60 and \$124 per hour of travel time savings. Consistent with other studies, these values suggest drivers are paying for more than just travel time savings, but other factors such as reliability.

Analysis of driver elasticity using various methods yielded positive demand elasticity to price. Both SOVs and HOVs increased usage of the MnPASS lanes with higher prices. Statistically significant elasticities ranged between about +0.03 to +0.85. The increased demand resulting from higher prices (and decreased demand from lower prices) is likely a result of driver perception of the posted price. Drivers likely view the price as an indication of time savings and GP congestion, suggesting higher prices provide greater time savings. No travel times or congestion levels are made available to drivers entering MnPASS corridors, therefore, the MnPASS price may act as a signal of downstream congestion. As Beggs (2010) suggests, drivers are consuming different goods. Higher priced toll lanes are, theoretically, providing greater time savings and represent a right shifted demand curve. Therefore, although price is higher, quantity consumed is also higher.

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