HOT or Not

Driver Elasticity to Price on the MnPASS HOT Lanes

Michael Janson and David Levinson

The Minnesota Department of Transportation (MnDOT) has added MnPASS High Occupancy Toll (HOT) lanes on two freeway corridors in the Twin Cities. 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. Reasons for these results is discussed as well as the implications these results have on the pricing of HOT lanes.

Keywords

Managed Lanes, HOT, Driver Elasticity, Road Pricing, MnPASS

1 Introduction

Since 1992, the Minneapolis - St. Paul metropolitan area has used managed lanes to increase person throughput during peak periods (Doan, 2013). 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, single occupant vehicle (SOVs) drivers complained of their underutilization. In order to maintain the carpooling/transit incentive while utilizing the lanes to a greater extent, MnDOT explored the concept of HOT lanes. HOT lanes are a form of congestion pricing. They are tolled lanes (on otherwise untolled roads) which give a free or discounted trip for HOV users, and are thus optional. Other forms of congestion pricing may charge for use of all lanes.

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 conservation of LOS on I-394 in Minneapolis after the conversion from HOV to HOT. In an analysis of the HOT lane conversion on I-85 in Atlanta, Kall et al. (2009) determined no statistically significant change in emissions levels due to mode shifting from the conversion. Dahlgren (2002) adds that lower emissions may result from HOT lanes due to reduced GP congestion.

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). The MnPASS Express Lanes, as the HOT lanes are called in Minnesota, have been running since 2005. In 2009, MnDOT added MnPASS lanes to the I-35W corridor. One MnPASS lane runs in each direction, separated by a double white line. In the southbound direction, the lane begins at 42nd Street South in Minneapolis and continues to the southern suburb of Lakeville. The northbound lane begins in Lakeville and continues to 38th Street South in Minneapolis where it becomes a priced dynamic shoulder lane (PDSL). The shoulder lane continues to downtown Minneapolis (MnDOT, 2013a). The success of the lanes has created interest for expansion to other metro freeways (Cambridge Systematics, 2010).

Given that dynamically 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 Background

2.1 Frequency of Use

Each paying MnPASS user has a transponder, which communicates with detectors along the corridor to determine a user's entry and exit point and charge accordingly. The time of entry, amount charged and entry and exit plazas is recorded for each trip. This log was used to determine how frequently MnPASS subscribers pay to use the lanes. Subscribers are charged $1.50 per month for leasing the transponder. The frequency of use analysis includes all subscribers throughout 2011 and 2012 and averages their use over the two-year period. It is not limited to those subscribers whose lease remains active over the entire two-year period.

The frequency of use analysis focused on personal and business accounts separately. No data were provided by MnPASS to specifically determine which accounts are business and which are personal. Therefore, the assumption was made that accounts with more than two transponders were business accounts, while those with one or two were personal. There are likely some personal accounts with more than two transponders and some business accounts with fewer than three, however two transponders was selected as a reasonable limit for most personal accounts. Personal and business accounts were separated based on the assumption that drivers with business accounts are less sensitive to price, because they are not charged the toll personally. This is true regardless of trip purpose. Individual accounts make up around 76 % of all MnPASS accounts. Unless explicitly stated, analysis throughout this paper includes both business and personal accounts due to the inability to distinguish the two using loop detector data.

Figure 1 below depicts the number of MnPASS subscribers in 2011 and 2012 and the breakdown based on frequency of use during the morning peak period (weekdays/year). The data are divided into accounts which had two or fewer transponders ("individual accounts") and accounts with at least 3 transponders ("business accounts"). The data sets were fitted with exponential decay functions. The functions, their equation and respective r^2 values are displayed.

The results indicate that most users do not use the MnPASS lanes every weekday for their commute, but rather select various days to use the lanes. Graphs in the appendix show that the number for trips among different frequencies of users is fairly constant for individual users. For business accounts, the number of trips declines steadily with frequency.

Figure 1: Frequency of Use - 2011 & 2012

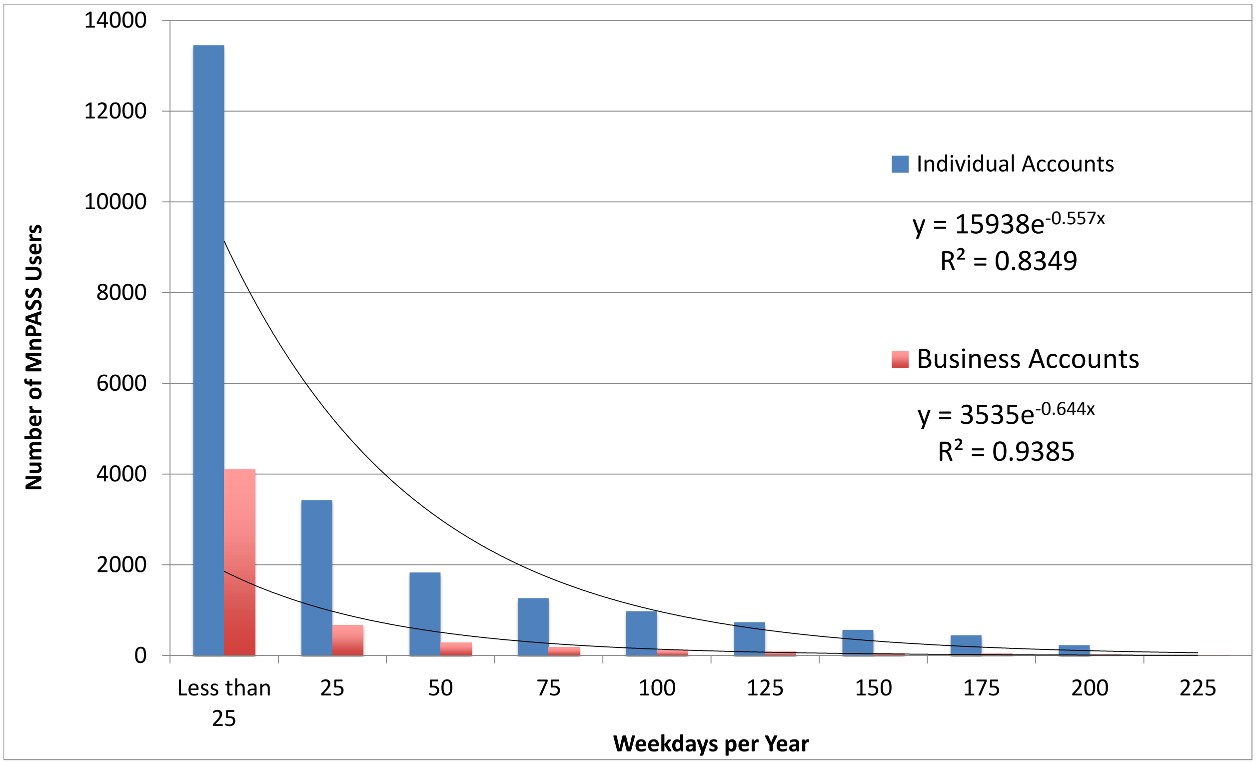


Figure 2: *Data taken over all weekdays in 2011 and 2012*
Trips include any paid use of the MnPASS lanes

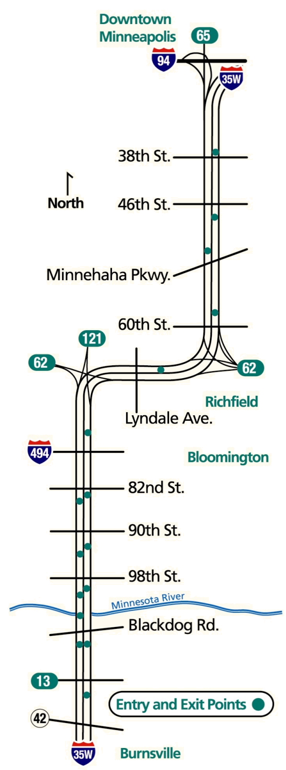
2.2 Current Operation

Figures 3 and 4 display the MnPASS entry and exit points along I-394 and I-35W. Outside of these points, drivers are not supposed to enter or exit the MnPASS lanes. Double white lines separate the lanes except during the entry and exit points, during which the lines are dashed. The hours of operations are summarized in Table 1 below.

Figure 3: MnPASS Entry and Exit Points on I-394

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

Figure 4: MnPASS Entry and Exit Points on I-35W



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

Table 1: Hours of Operation

Corridor	Direction	Section	Start Time	End Time
I-394	EB	I-494 to Hwy 100	6:00	10:00
I-394	EB	Hwy 100 to Downtown Minneapolis	6:00	13:00
I-394	WB	Hwy 100 to I-494	14:00	19:00
I-394	WB	Downtown Minneapolis to Hwy 100	14:00	5:00
I-35W	NB	Crystal Lake Road to Hwy 62	6:00	10:00
I-35W	NB	Hwy 62 to Downtown Minneapolis	6:00, 15:00	10:00, 19:00
I-35W	SB	42nd St to I-494	6:00, 15:00	10:00, 19:00
I-35W	SB	I-494 to Hwy 13	15:00	19:00

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 parallel detectors, one for each lane. 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 2 displays the pricing plan, which regulates the price based on density level. Minimums and maximums for a given LOS must be maintained. Table 3 indicates the changes in price caused by a change in density.

Table 2: Pricing Plan for Normal Operation of MnPASS Lanes (both I-35W and I-394)

Level of Service	Min K	Max K	Min Toll ($)	Default Toll ($)	Max Toll ($)
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 in veh/mi/ln; Prices in $

Table 3: Price Changes Based on Changes in Density - Used for all pricing plans

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
Price increases between \$0.25 and \$1.50 with a change in density between 1 and 6 veh/mi/ln

2.3 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 time savings assumes drivers are entering downtown Minneapolis during the morning commute. It does not account for time savings as a result of avoiding the queue to I-94 eastbound or other similar circumstances. 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. Loop detectors only measure point occupancies and flows. Speeds are estimates and may vary between point measurements. These variations cannot be captured with this 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.

In order to reduce extraneous speeds caused by varying vehicle sizes or detector reading inaccuracies, two filtering methods were applied. First, speeds exceeding 75 mph (120.7 $km{\cdot}h^{-1}$) were eliminated. Speed limits along the MnPASS corridors are most commonly 55 or 60 mph (88.5 or 96.6 $km{\cdot}h^{-1}$), with a stretch of I-35W at 65 mph (104.6 $km{\cdot}h^{-1}$) near the southern edge of the system. Second, interval speeds calculated from a single vehicle were eliminated to reduce the likelihood of inaccurate speed measurements (caused by very large or very small vehicles). A low speed threshold was not applied given that any non-negative speed was possible. Negative speeds were, however, naturally eliminated if they existed.

Travel times for the MnPASS and GP lanes were then calculated using the speeds from each detector series and computing the time required to traverse the entire MnPASS corridor length. 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. Willingness to pay 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.

Table 4 displays willingness to pay values from several previous studies. These studies were selected because they represent similar HOT lane facilities to MnPASS. Burris et al. (2012) also includes values for a study on the I-394 MnPASS lanes. The values from this study represent the average toll prices paid and the respective average time savings. This differs from willingness to pay, because it is not known what users would be willing to pay. These values simply represent what users pay and the resulting time savings they gain as a result.

Average weighted toll prices and time savings during the morning and afternoon peak periods on I-394 and I-35W are displayed in Table 5. 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. Average 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. Steimetz and Brownstone (2005) discuss wide ranging VOT values and methods for better handling noisy data.

There are several 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. Furthermore, both individual and business accounts make up the toll paying users. The higher VOT for businesses raises the overall VOT value. The second reason 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 difficult to separately quantify, particularly in dynamic pricing experiments where there is a strong correlation between price and reliability (Brownstone and Small, 2005). 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 MnPASS lanes provide other intangibles which are also important. The more consistent traffic flow makes driving in the MnPASS lanes safer and less stressful. Consistent driving speeds yield better gas mileage. Finally, MnPASS users may take advantage of queue jumps provided by the lanes. Users traveling WB on I-394 and headed south on Hwy 100, can bypass the queue that often forms. Likewise, morning commuters heading east on I-394 can avoid the queue to enter I-94 eastbound. All of these are important benefits provided by the lanes which influence the price drivers are willing to pay for the MnPASS lanes.

Table 4: Willingness to Pay from Literature

Reference	Willingness to Pay	Notes
Brownstone et al. (2003)	\$30/hr	I-15 in San Diego
Burris et al. (2012)	\$73/hr & \$116/hr	I-394 Morning & Afternoon
	\$49/hr & \$54/hr	I-15 Morning & Afternoon
Devarasetty et al. (2012)	\$51/hr	I-10 (Katy Freeway)

Table 5: 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

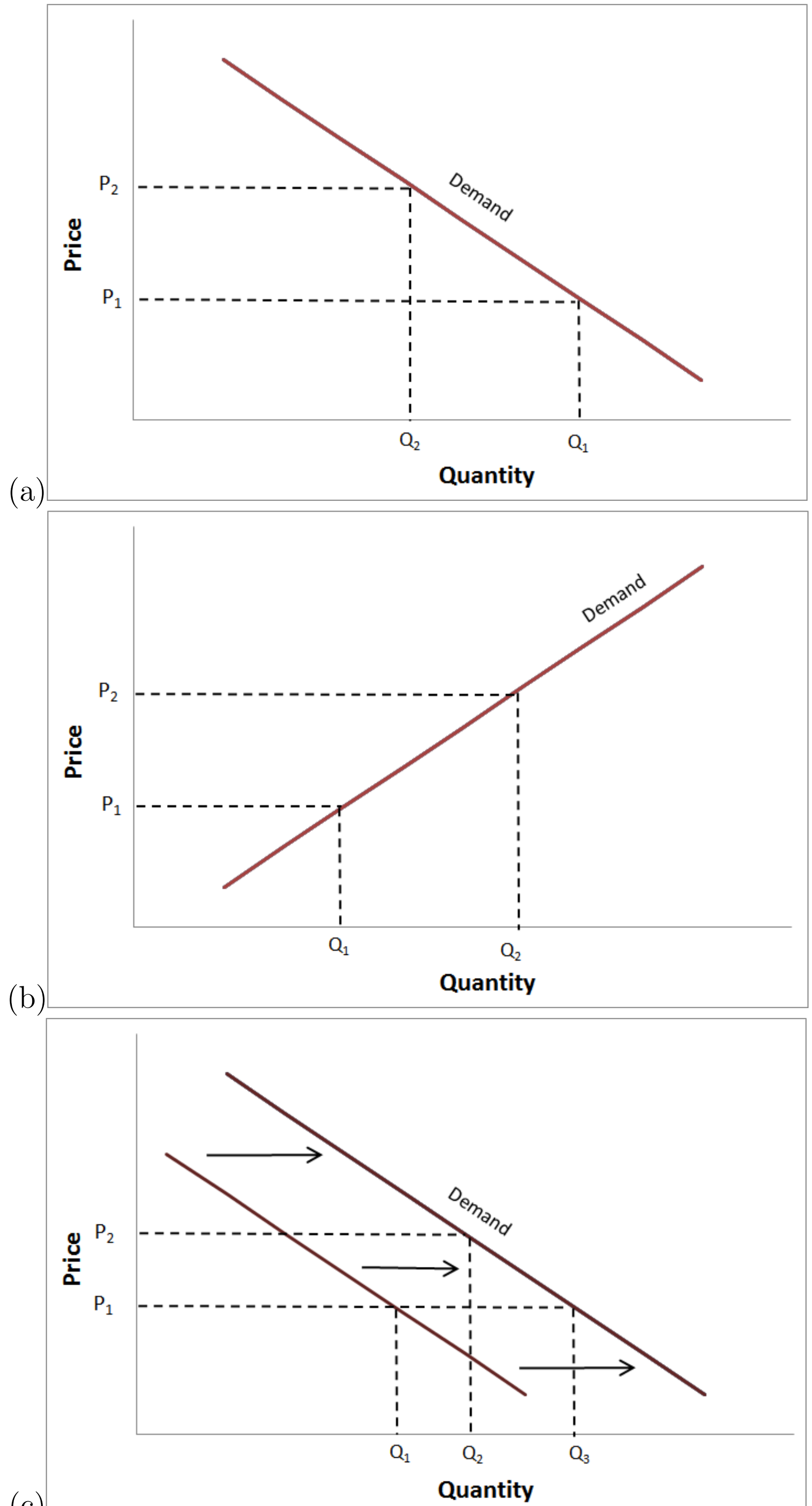
3 Economic Theory - Demand Curve of Toll Roads

Most goods are ordinary goods following the downward sloping demand curve where quantity consumed decreases as price rises as seen in Figure 5a (Beggs, 2010).

Some luxury goods, on the other hand, may see an increase in consumption as price rises (at least for certain prices). Figure 5b represents this phenomenon (Beggs, 2010). 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 up the demand curve in Figure 5b, the assumption is that all other factors are held constant. In the HOT lane case, this assumption breaks down. The belief of drivers is 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 is really happening as price increases, is that the demand curve is shifting to the right as seen in Figure 5c. 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 Q_3 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 5: Demand Curves



(Beggs, 2010)

4 Aggregate Analysis: Methods and Results

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 using several methods. MnPASS logs store the calculated densities, which determine price. These densities measure HOVs and SOVs in the HOT lane. Transponder data provides demand at an individual level. Transponder logs only record paying SOVs. Loop detector data were also used in order to calculate the lane share percentage of the MnPASS lanes as well as the vehicle flow for the SOV and HOV usage section. The MnPASS lane share percentage includes all MnPASS lane users and is not limited to paying SOVs. It measures the percentage of overall flow using the MnPASS lane. This helps control against overall fluctuations in traffic due to various externalities since it accounts for general purpose lane volumes as well as MnPASS. Holidays, poor weather days and other known anomalies, however, were excluded from all analyses in order to maintain more consistent data.

$$S_{MnPASS} = \frac{Q_{MnPASS}}{Q_{MnPASS} + \Sigma Q_{GP}} \tag{1}$$

Where S_{MnPASS} denotes MnPASS lane share percentage. Q represents flow in the respective lane type. Flow for the general purpose lanes is the sum of all general purpose lanes.

Table 6 displays driver elasticity to price results from several previous papers. Several of the studies come from an analysis by Burris (2003). All values are negative and smaller in magnitude than -1.0. Elasticity results using various methods are displayed and discussed in the following sections.

Table 6: Driver Elasticity to Price from Literature

Reference	Elasticity(ε)	Notes
Wuestefeld and Regan (1981)	-0.03 to -0.31	
Oum et al. (1992)	-0.09 to -0.52	
The Transportation Research Board (1994)	-0.10 to -0.40	
Hirschman (1995)	-0.10	Bridges and tunnels in NYC
The Urban Transportation Monitor (2000)	-0.20	
Burris and Pendyala (2002)	-0.03 to -0.36	Toll bridges in Lee County, FL
Odeck & Bråthen (2008)	-0.45 & -0.82	Short-run and Long-run

Several studies taken from Burris (2003)

Two years of MnPASS demand and pricing data (2011 and 2012) were gathered to examine aggregate demand responses to changes in price. Average price and demand (density and MnPASS lane share %) were plotted every 3 minutes throughout the peak period. The data is taken from the critical plazas discussed earlier. The prices and densities correspond to the logs from the MnPASS system. S_{MnPASS} is calculated from loop detector data.

The MnPASS pricing algorithm operates by changing price at time, [t+3:t+6], according to changes in demand between [t:t+3] (which is also averaged with the change in the previous 3 minutes). Price is responding to demand. In order to measure driver elasticity to price, it is necessary to examine changes to demand following changes in price. We are interested in how demand is responding to changes in price and not the other way around. Elasticity was, therefore, calculated using the change of price between [t:t+3] minutes, and demand change between [t+3:t+6].

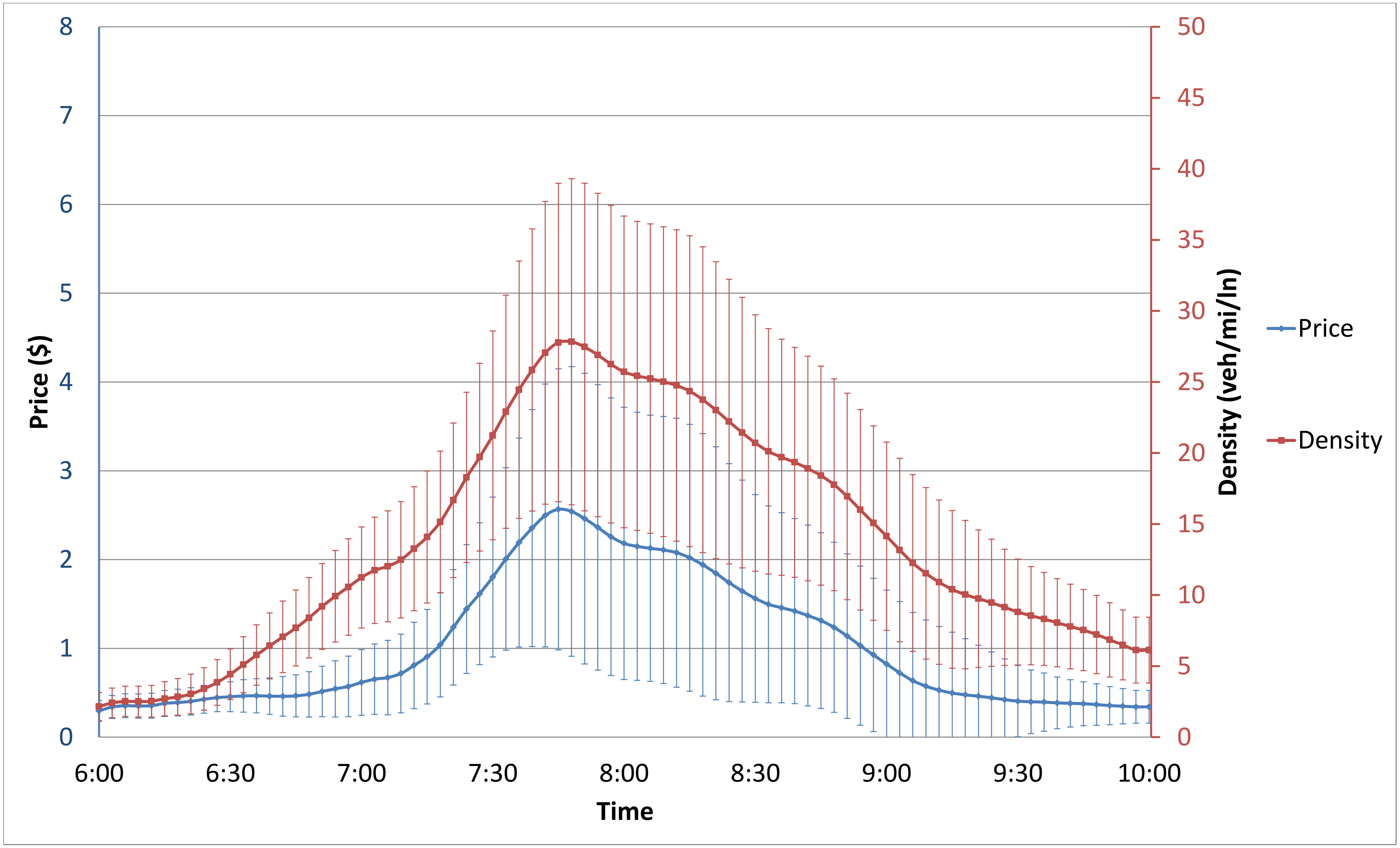
The elasticity equation:

$$\varepsilon_t = \frac{\frac{D_{t+6} - D_{t+3}}{D_{t+3}}}{\frac{P_{t+3} - P_t}{P_t}} \tag{2}$$

Where D represents demand (density or S_{MnPASS}), P represents price and epsilon the resulting elasticity.

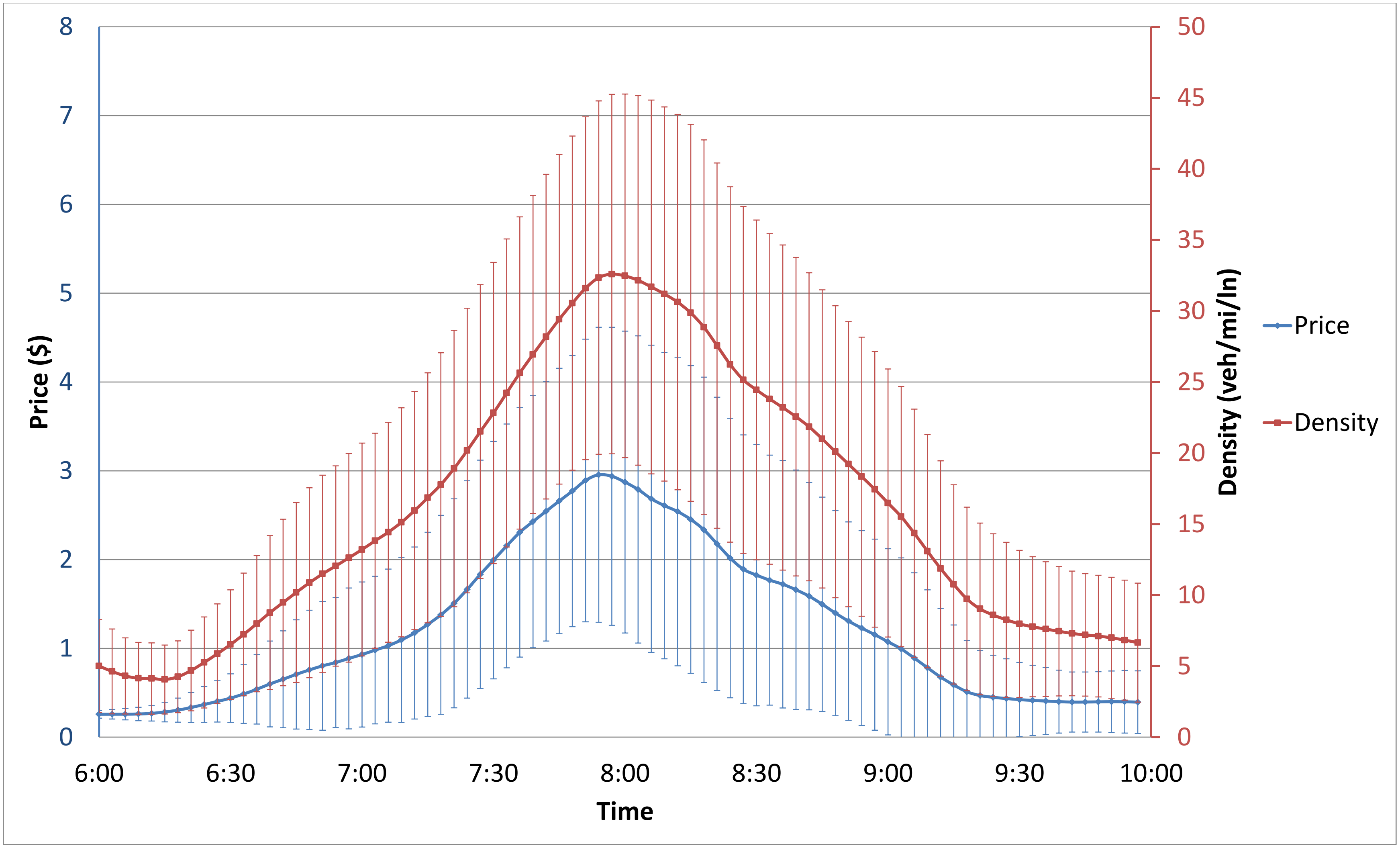
Two years (2011 & 2012) of price, density and S_{MnPASS} data for the I-394 and I-35W morning peak periods are plotted in Figure 6 and Figure 7. Afternoon peak data are displayed in Figure 8 and Figure 9. Points are plotted every 3 minutes to correspond with the price changes. Twelve minute moving averages were used to smooth the data. The error bars represent one standard deviation in each direction. With the exception of 6 weeks during 2011 and 2012, the pricing plan for the lanes remained constant. Any changes which occurred were similar to the field experiment described earlier.

Figure 6: I-394 Morning Peak Period - Average Price and Density for 2011 and 2012



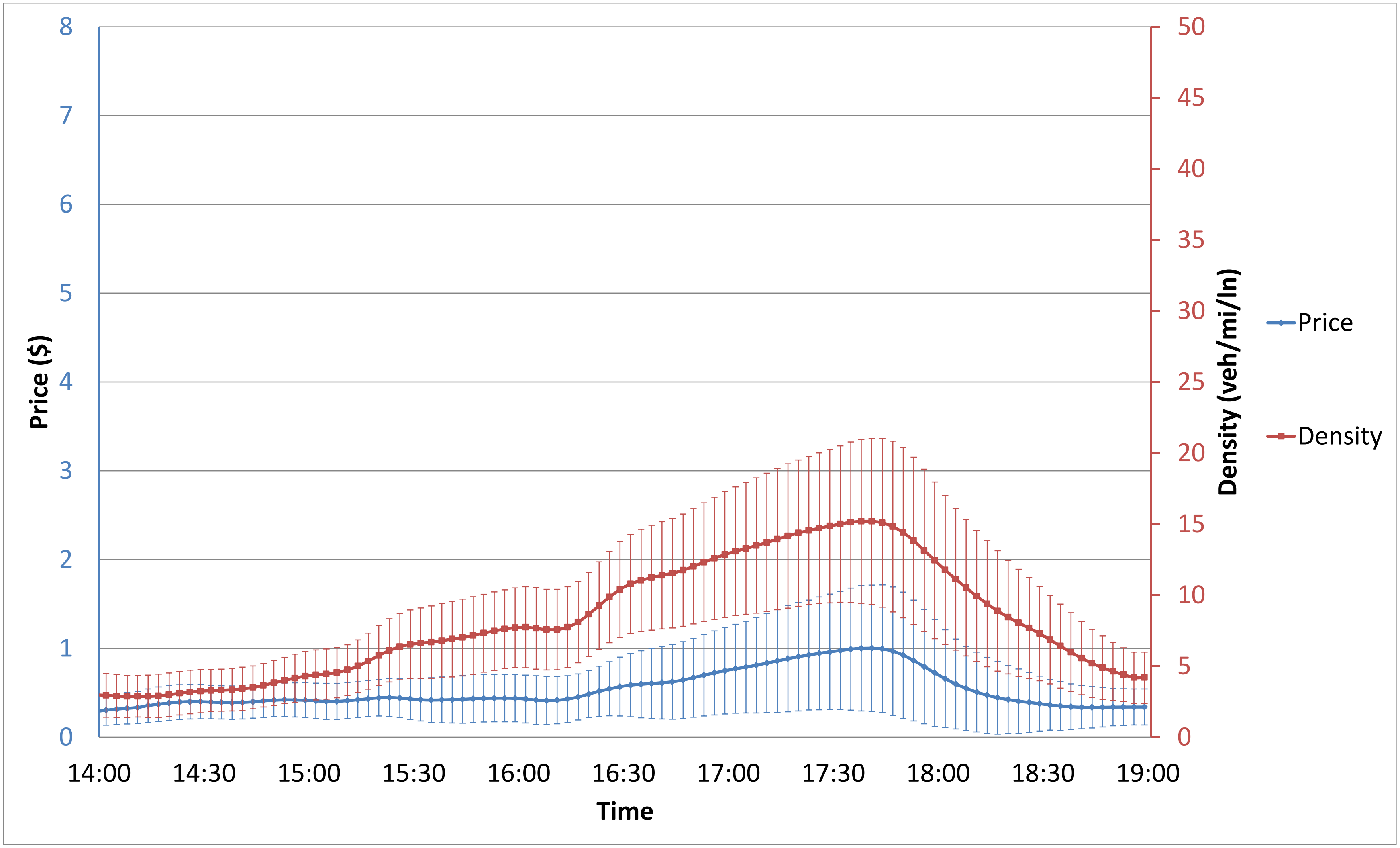
I-394 Morning: 6:00-10:00
Data taken over all weekdays in 2011 and 2012
Data from Plaza 1003, between Hwy 169 and Louisiana Ave on EB I-394

Figure 7: I-35W Morning Peak Period – Average Price and Density for 2011 and 2012



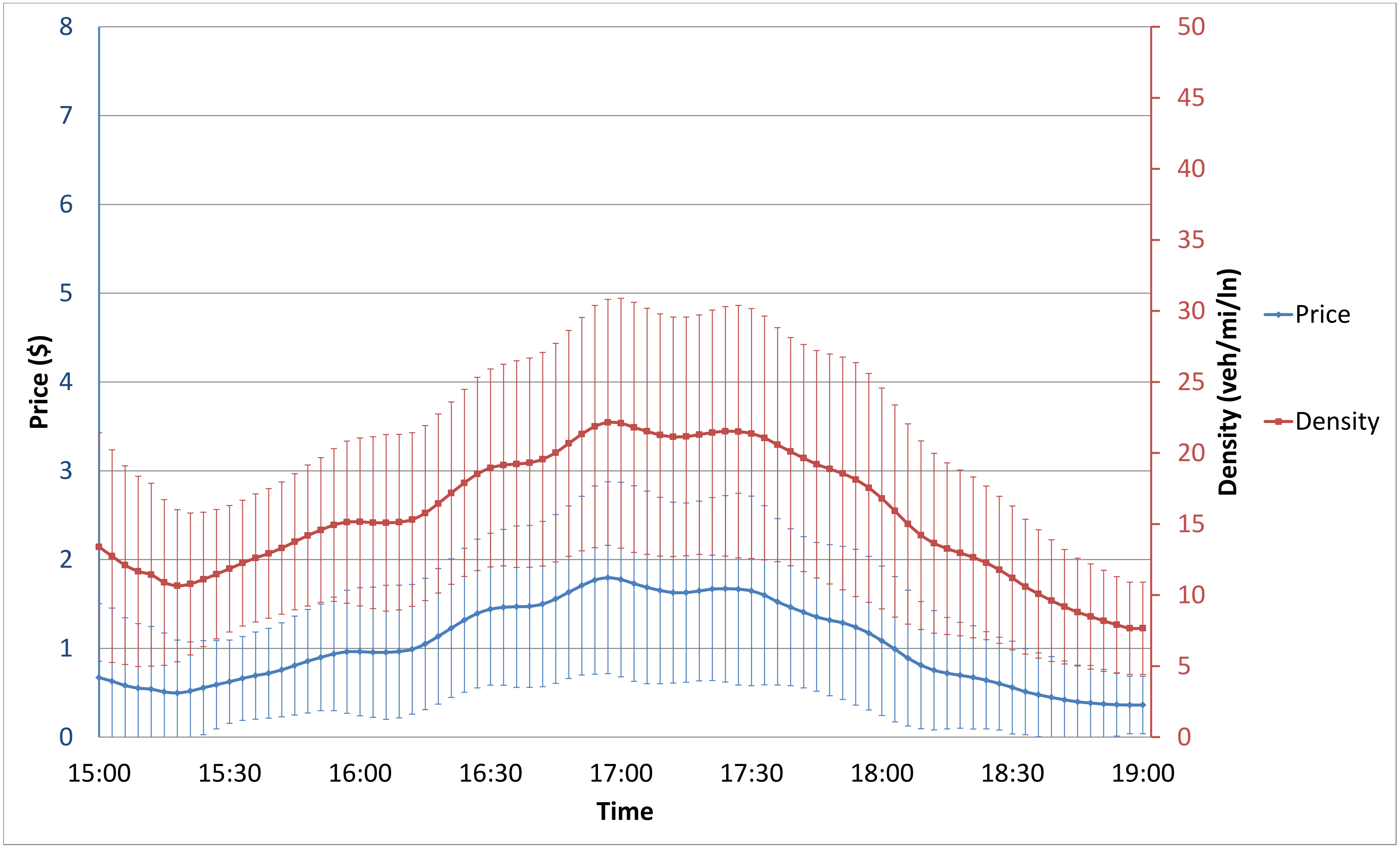
I-35W Morning: 6:00-10:00
Data taken over all weekdays in 2011 and 2012
Data from Plaza 3012 near 46th Street on NB I-35W

Figure 8: I-394 Afternoon Peak Period – Average Price and Density for 2011 and 2012



I-394 Afternoon: 14:00-19:00
Data taken over all weekdays in 2011 and 2012
Data from Plaza 2003, between Louisiana Ave and Hwy 169 on WB I-394

Figure 9: I-35W Afternoon Peak Period – Average Price and Density for 2011 and 2012



I-35WAfternoon: 15:00-19:00
Data taken over all weekdays in 2011 and 2012
Data from Plaza 4009 near 98th Street on SB I-35W

Table 7: Elasticity Values Using Density and MnPASS Lane Share: 2011 & 2012 Aggregate

	Density	Elasticity (Density)		
	Average	Average	Median	Std Dev
I-394 Morning (1003)	23.75	0.8005*	0.6164	0.8387
I-394 Afternoon (2003)	14.05	0.4885*	0.6170	1.018
I-35W Morning (3005)	25.99	0.7448*	0.7331	0.9176
I-35W Morning (3012)	22.64	0.8400*	0.7813	0.3804
I-35W Afternoon (4009)	19.99	0.6320*	0.6117	1.140
I-35W Afternoon (4011)	15.28	0.4880	0.4487	2.332
	S_{MnPASS}	Elasticity (S_{MnPASS})		
	Average	Average	Median	Std Dev
I-394 Morning (1003)	19.82	0.7010*	0.6487	0.7754
I-394 Afternoon (2003)	12.69	0.4638*	0.3818	1.129
I-35W Morning (3005)	22.37	0.1775	0.3911	1.124
I-35W Morning (3012)	13.55	0.6491*	0.5936	0.5044
I-35W Afternoon (4009)	23.75	0.3943*	0.2964	0.7842
I-35W Afternoon (4011)	17.58	0.3392*	0.2264	0.6292

** Significant at 0.05 significance level*
Plaza in parentheses
Density in units veh/mi/ln
S_{MnPASS} is percent of overall flow using the MnPASS lane
I-394 Morning: 6:00-10:00
I-394 Afternoon: 14:00-19:00
I-35W Morning: 6:00-10:00
I-35W Afternoon: 15:00-19:00
Data taken over all weekdays in 2011 and 2012
Plaza 1003, 2003 lanes: 1 HOT, 2 GP, 1 Auxilliary
Plaza 3005, 4009 lanes: 1 HOT, 2 GP
Plaza 4011 lanes: 1 HOT, 3 GP
Plaza 3012 lanes: 1 HOT, 4 GP

All statistically significant elasticity values from the aggregate data are positive and between 0.3392 and 0.8400.

The MnPASS pricing algorithm operates by changing price to match changes in demand (raising price with increasing demand). This analysis, however, looks at changes to demand immediately following pricing changes, in order to examine the response of demand to price. Overall, the analysis revealed that demand (both density and S_{MnPASS}) typically increased immediately following a price increase and vice versa.

5 Field Experiment Analysis: Methods and Results

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. The second field experiment took place on I-35W between October 29,2012 and November 23, 2012. Details of these experiments including methodology and analysis can be found in Janson and Levinson (2013). However, some of the results are included below for reference. The third field experiment was conducted on I-394 lasting five weeks. The experiment consisted of changes to the pricing plan displayed in Table 8 and took place in December 7-21, 2012 and January 7-25, 2013. No changes were made to Table 3, displayed above. The holiday season at the end of December and beginning of January was excluded. The density thresholds at which prices changed were lowered during this experiment, effectively increasing price. The change was estimated to increase the average price by around 15%. All other operations of the pricing algorithm were left the same. After the experiment, prices were reverted to their previous levels.

Table 8: Modified pricing plan for second field experiment on I-394
2012-12-10 to 2012-12-21 & 2012-1-7 to 2013-1-25

Level of Service	Min K	Max K	Min Toll ($)	Default Toll ($)	Max Toll ($)
A	0	9	0.25	0.25	0.50
B	10	15	0.50	0.50	1.50
C	16	25	1.50	1.50	2.50
D	26	34	2.50	3.00	3.50
E	35	39	3.50	5.00	5.00
F	40	50	5.00	8.00	8.00

Density in veh/mi/ln; Prices in $

The field experiments were analyzed by comparing to the same days on 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 one month 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 such as fuel prices and employment. MinnesotaGasPrices.com (2013) reveals, however, that average fuel prices in Minnesota between 2011 and 2012 are within $0.50. Anomalies such as holidays and poor weather days were removed from analysis. In addition, no changes to express transit service on the corridors were made during the analysis period (Metropolitan Council, 2013)

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.

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.

Average of Elasticities

For Field Experiment

$$\varepsilon_E = \frac{\frac{D_{E,2012,t} - D_{B,2011,t}}{D_{B,2011,t}}}{\frac{P_{E,2012,t} - P_{B,2011,t}}{P_{B,2011,t}}} \tag{3}$$

For Control

$$\varepsilon_C = \frac{\frac{D_{C,2012,t} - D_{C,2011,t}}{D_{C,2011,t}}}{\frac{P_{C,2012,t} - P_{C,2011,t}}{P_{C,2011,t}}} \tag{4}$$

Elasticity of Averages

$$\varepsilon_{avg} = \frac{\frac{\overline{D}_{E,2012} - \overline{D}_{B,2011}}{\overline{D}_{B,2011}} - \frac{\overline{D}_{C,2012} - \overline{D}_{C,2011}}{\overline{D}_{C,2011}}}{\frac{\overline{P}_{E,2012} - \overline{P}_{B,2011}}{\overline{P}_{B,2011}} - \frac{\overline{P}_{C,2012} - \overline{P}_{C,2011}}{\overline{P}_{C,2011}}} \tag{5}$$

Where the subscript E denotes the field experiment and the subscript B denotes the baseline period. The control period is noted by subscript C and each period is marked with its respective year. D represents demand (density or S_{MnPASS}), P represents price and ε the resulting elasticity.

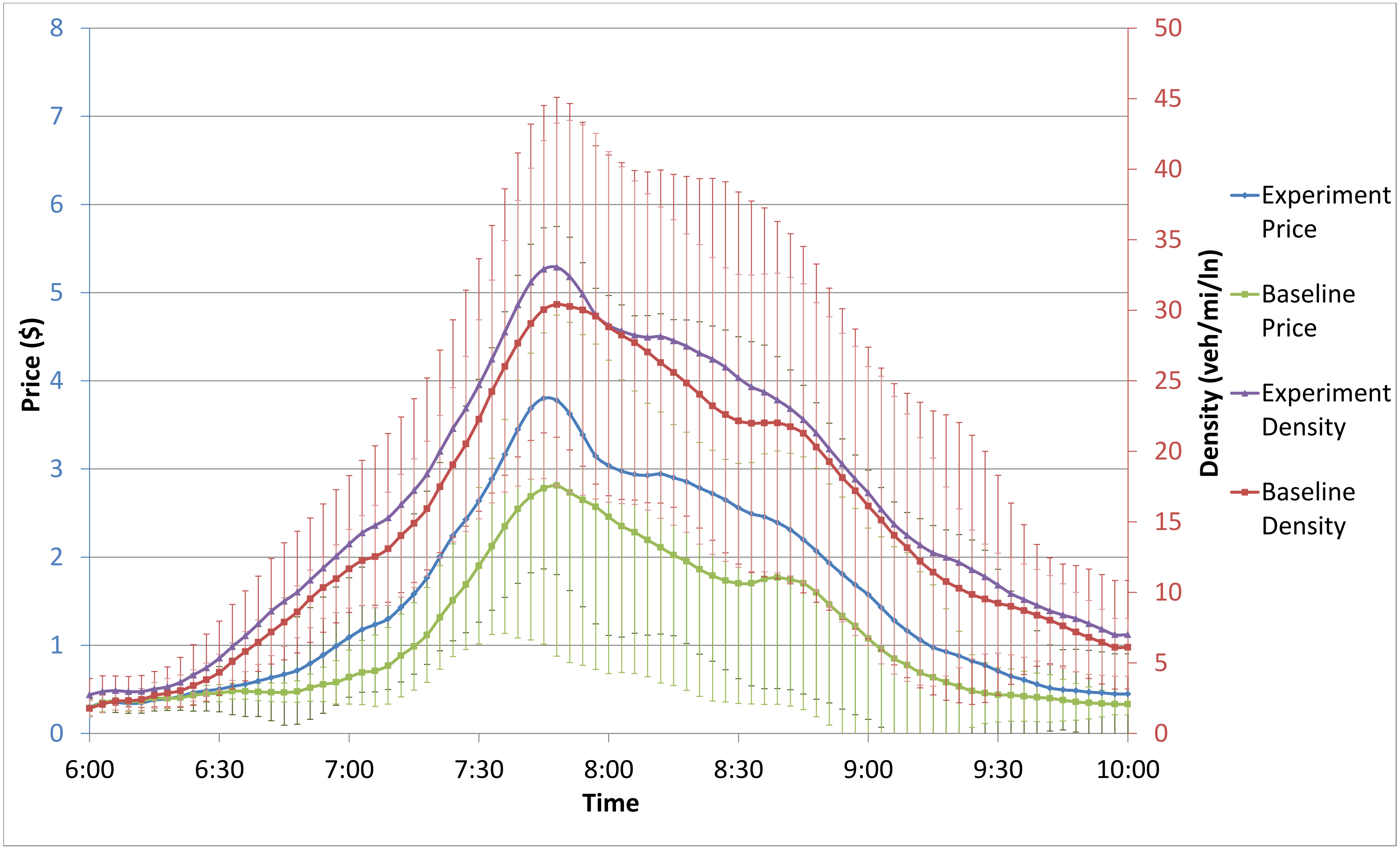
The following figures display changes in price and density for the third field experiment and its control. Twelve minute moving averages were used to smooth the data. The error bars represent one standard deviation in each direction.

Data in Figure 10 show the average price and density levels during the morning peak period on I-394. The field 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. 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 11 represents the control period which compares November 2011 (2011-11-18 to 2011-12-9) and November 2012 (2012-11-16 to 2012-12-7). This period represent 3 weeks preceding the field experiment. The first two weeks in November could not be used in the control because the pricing plan during these weeks in 2012 was set to match the pricing plan from 2005 instead of the baseline plan in Table 2. The resulting changes in the control were relatively small compared to the changes seen in Figure 11 between the baseline and field experiment.

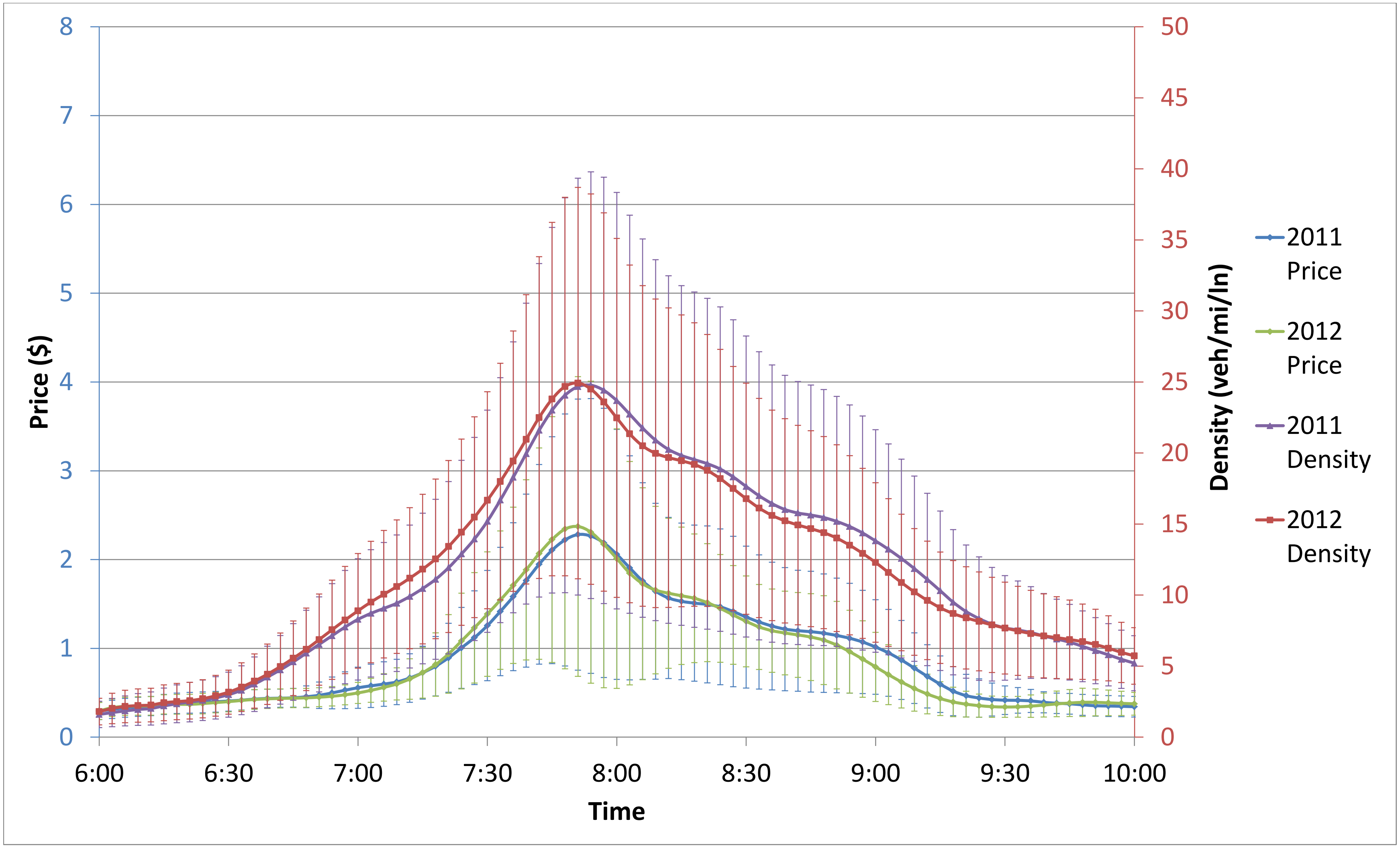
Figure 10 reveals that the MnPASS lanes saw a consistent increase in density throughout the peak period during the field experiment. Although less than the price increase, density at nearly every time segment during the analyzed periods was higher. This led to the positive elasticity results displayed in Tables 10 and 11.

Figure 10: 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
Plaza 1003, between Hwy 169 and Louisiana Ave on EB I-394; Weekdays only

Figure 11: I-394 Control: November 2011 & 2012



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 9 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. Average general purpose lane speeds are included as another measure of change between the periods. Elasticity was calculated using both density and S_{MnPASS} as a measure of demand. Table 10 shows the elasticity values calculated from the weighted averages in Table 9. Results in Table 11 include the mean, median and standard deviation of elasticity values for every three minutes between 7:00-9:00.

The third field experiment saw statistically significant increases in price and density both between the baseline and field experiment. The control period only saw a significant change in S_{MnPASS} between 2011 and 2012. There was no statistically significant change in the average GP speed. The net values were all positive, resulting in positive elasticity values in Table 11. 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 10. This consistency led to steady elasticity results and the small standard deviation values. Another indication of consistency are the similar mean and median values.

Table 9: 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
GP_{speed}	91.5	93.8	2.5	0.9	1.6
(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
GP_{speed}	90.1	89.3	-0.9	2.2	-3.1
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
GP_{speed}	87.6	85.8	-2.1	-0.8	-1.3
(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
GP_{speed}	91.9	88.0	-4.24	-4.04	0.20

** Significant at 0.05 significance level*
Time of Day: 7:00-9:00
Density in units veh/mi/ln
Speed in km/h
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 10: 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 11: 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

Loop detector data were used to determine the total number of MnPASS lanes users (HOV + SOV) along the two corridors. Counts were gathered for the critical plaza(s) on each corridor using loop detector 5453 for eastbound I-394 and 5460 for westbound. On I-35W, loop detectors 525 and 6792 in the northbound direction were used and 1000 and 1008 in the southbound direction. The transponder logs record the starting and ending plaza for paying SOVs, along with their starting time and paid toll. The assumption was made that drivers do not exit the MnPASS lane between their starting and ending plaza. Therefore, a paying SOV is counted at each plaza between their starting and ending plaza. If the critical plaza lies between the starting and ending plaza, the vehicle is counted as a paying SOV. Cross-referencing these two data sources, independent counts for SOV and HOV can be determined. SOV in this case excludes "business account" which are those accounts with more than two transponders.

Vehicle counts from the field experiment as well as the baseline period were gathered. The tolls paid by SOVs were used to find the average price paid for each period. The changes in price and SOV vehicle counts were used to determine the elasticity to price of paying SOVs. Elasticity for HOVs as well as total elasticity were also calculated.

One month before each field experiment were compared to the same period in 2011. The pricing plan used during the two periods was the same and also matched the prices during the baseline period. Elasticity results were calculated using the net change in price and vehicle counts, subtracting any changes occurring between 2011 and 2012 in the control period.

Elasticity for SOVs and HOVs follows the same format as Equation 5, where demand is replaced with flow (veh/hour).

HOV and SOV vehicle counts for the MnPASS lanes during the three field experiments were measured at the respective critical plazas. SOV counts are for "individual accounts" and exclude "business accounts" or those with more than two transponders tied to one account. The values are converted to flow (vehicles/hours) and are displayed in Table 12. Average prices can be found in Table 9.

Using the change in vehicle flow and the average price change between the two periods, elasticity values were calculated and are displayed below in Table 12.

Table 12: Vehicle Flow and Elasticity

Flow in Vehicles/Hour (Q)						
	Baseline (B)	Field (E)	% Change	Control % Change	Net % Change	Elasticity
(1) Plaza 1003						
Total HOT	1083	1111	2.581	1.211	1.370	0.4086
HOV	665	636	-4.458	-8.391	3.673	1.095
SOV	416	475	14.29	16.62	-2.333	-0.6958
(2) Plaza 3005						
Total HOT	1043	1167	11.96	16.75	-4.791	0.0828
HOV	738	808	9.606	11.09	-1.481	0.0256
SOV	305	359	17.66	32.64	-14.97	0.2587
Plaza 3012						
Total HOT	905	1071	18.30	19.33	-1.033	0.0365
HOV	678	789	16.40	16.19	0.2101	-0.0074
SOV	227	281	23.96	25.84	-1.882	0.0664
(3) Plaza 1003						
Total HOT	817	821	0.4092	-4.108	4.517	0.1091
HOV	442	412	-6.779	-9.412	2.633	0.0636
SOV	375	409	8.867	4.519	4.348	0.1071

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: November2011 and 2012

Results of vehicle flow for the three field experiments tend to validate earlier results, with a few exceptions. Both field experiments on I-394 saw a total net increase in flow. Previous results showed net increases in density and S_{MnPASS} during these experiments.

Results from the third field experiment were the most consistent with net increases in SOV and HOV flow. These increases corresponded with an increase in price. These led to the positive elasticity values in Table 12.

The changes in HOV flow are assumed to be existing HOVs on the corridor, which previously used the GP lanes. It is believed the HOVs, like the SOVs, interpreted price as a signal of downstream congestion and therefore, had additional incentive to use the MnPASS lanes when the toll was higher (even though the lanes are always free for HOVs). Previously, moving left to the MnPASS lanes may have provided insufficient benefit to some HOVs, which were using the corridor for a short trip.

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 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. Drivers must make a quick decision whether to use the MnPASS lanes and the posted price acts as one important factor. Other intangibles also influence a user's lane choice decision. In any case, drivers are consuming different goods when the toll varies, because time savings is not constant. These different goods represent different demand curves and not movement along one downward sloping demand curve Beggs (2010). Therefore, although price is higher, quantity consumed is also higher.

7 Acknowledgments

We would like to thank Carlos Carrion, John Hourdos, Chris Iverson, Brian Kary, the Minnesota Traffic Observatory, the MnPASS Technical Advisory Panel, Andrew Owen, Tim Phillips, and Mike Solomonson for their contributions to this paper. Any errors are solely the responsibility of the authors.

References

Beggs, J. (2010). On the Hunt for the Elusive Upward Sloping Demand Curve. http://www.economistsdoitwithmodels.com/2010/04/05/on-the-hunt-for-the-elusive-upward-sloping-demand-curve.

Brownstone, D., Ghosh, A., Golob, T. F., Kazimi, C., and Van Amelsfort, D. (2003). Drivers' willingness-to-pay to reduce travel time: evidence from the San Diego I-15 congestion pricing project. *Transportation Research Part A: Policy and Practice*, 37(4):373–387.

Brownstone, D. and Small, K. A. (2005). Valuing time and reliability: assessing the evidence from road pricing demonstrations. *Transportation Research Part A: Policy and Practice*, 39(4):279–293.

Buckeye, K. R. and Munnich, L. W. (2004). Value pricing outreach and education: key steps in reaching high-occupancy toll lane consensus in Minnesota. *Transportation Research Record: Journal of the Transportation Research Board*, 1864(1):16–21.

Burris, M., Nelson, S., Kelly, P., Gupta, P., and Cho, Y. (2012). Willingness to Pay for High-Occupancy Toll Lanes. *Transportation Research Record: Journal of the Transportation Research Board*, 2297(1):47–55.

Burris, M. W. (2003). Application of variable tolls on congested toll road. *Journal of transportation engineering*, 129(4):354–361.

Burris, M. W. and Figueroa, C. F. (2010). Analysis of traveler characteristics by mode choice in HOT corridors. In *Journal of the Transportation Research Forum*, volume 45.

Burris, M. W. and Pendyala, R. M. (2002). Discrete choice models of traveler participation in differential time of day pricing programs. *Transport Policy*, 9(3):241–251.

Burris, M. W., Sadabadi, K. F., Mattingly, S. P., Mahlawat, M., Li, J., Rasmidatta, I., and Saroosh, A. (2007). Reaction to the managed lane concept by various groups of travelers. *Transportation Research Record: Journal of the Transportation Research Board*, 1996(1):74–82.

Burris, M. W., Ungemah, D. H., Mahlawat, M., and Pannu, M. S. (2009). Investigating the impact of tolls on high-occupancy-vehicle lanes using managed lanes. *Transportation Research Record: Journal of the Transportation Research Board*, 2099(1):113–122.

Burris, M. W. and Xu, L. (2006). Potential single-occupancy vehicle demand for high-occupancy vehicle lanes: Results from stated-preference survey of travelers in high-occupancy toll corridors. *Transportation Research Record: Journal of the Transportation Research Board*, 1960(1):108–118.

Cambridge Systematics (2010). MnPASS System Study. http://www.mnpass.org/pdfs/MnPassSystemStudy2.pdf.

Carrion, C. and Levinson, D. (2012a). Uncovering the influence of commuters' perception on the reliability ratio. (000108).

Carrion, C. and Levinson, D. (2012b). Value of travel time reliability: A review of current evidence. *Transportation research part A: policy and practice*, 46(4):720–741.

Chum, G. L. and Burris, M. W. (2008). Potential Mode Shift from Transit to Single-Occupancy Vehicles on a High-Occupancy Toll Lane. *Transportation Research Record: Journal of the Transportation Research Board*, 2072(1):10–19.

Dahlgren, J. (2002). High-occupancy/toll lanes: where should they be implemented? *Transportation Research Part A: Policy and Practice*, 36(3):239–255.

Devarasetty, P. C., Burris, M., and Douglass Shaw, W. (2012). The value of travel time and reliability-evidence from a stated preference survey and actual usage. *Transportation Research Part A: Policy and Practice*, 46(8):1227–1240.

Doan, J. (2013). I-394 MnPASS Express Lanes. http://www.ibtta.org/files/PDFs/Doan_John.pdf.

Fielding, G. and Klein, D. (1993). High Occupancy/Toll Lanes: Phasing in Conjestion Pricing a Lane at a Time. *Reason Foundation, Policy Study*, (170).

Finkleman, J., Casello, J., and Fu, L. (2011). Empirical evidence from the Greater Toronto Area on the acceptability and impacts of HOT lanes. *Transport Policy*, 18(6):814–824.

Ghosh, A. (2001). *Valuing time and reliability: commuters' mode choice from a real time congestion pricing experiment*. PhD thesis, University of California.

Hirschman, I., McKnight, C., Pucher, J., Paaswell, R. E., and Berechman, J. (1995). Bridge and tunnel toll elasticities in New York. *Transportation*, 22(2):97–113.

Janson, M. and Levinson, D. (2013). HOT or Not: Driver Elasticity to Price on the MnPASS HOT Lanes.

Kall, D. N., Guensler, R. L., Rodgers, M. O., and Pandey, V. S. (2009). Effect of High-Occupancy Toll Lanes on Mass Vehicle Emissions. *Transportation Research Record: Journal of the Transportation Research Board*, 2123(1):88–96.

Konishi, H. and Mun, S.-i. (2010). Carpooling and congestion pricing: HOV and HOT lanes. *Regional Science and Urban Economics*, 40(4):173–186.

Metropolitan Council (2003). Travel Behavior Inventory 2000.

Metropolitan Council (2013). Metro Transit. http://www.metrotransit.org.

Miami Herald (2010). High Tolls Lure Drivers to I-95. http://www.miamiherald.com/2010/03/30/1555970/high-tolls-lure-drivers-to-i-95s.html.

MinnesotaGasPrices.com (2013). Historical Price Charts. http://www.minnesotagasprices.com/retail_price_chart.aspx.

MnDOT (2013a). MnPASS. http://www.mnpass.org.

MnDOT (2013b). Planning and Programming - Benefit/Cost Analysis for Transportation Projects. http://www.dot.state.mn.us/planning/program/appendix_a.html.

Mowday, M. (2006). Equity and High-Occupancy Toll Lanes: Literature review and Minnesotans' perceptions about I-394 High-Occupancy Toll Lanes. In *CD-ROM: Transportation Research Board 85 th Annual Meeting*.

Munnich, L. W. and Buckeye, K. R. (2007). I-394 MnPASS High-Occupancy Toll Lanes: Planning and Operational Issues and Outcomes (Lessons Learned in Year 1). *Transportation Research Record: Journal of the Transportation Research Board*, 1996(1):49–57.

National Research Council (1994). Curbing Gridlock, Peak Period Fees to Relieve Traffic Congestion. *Transportation Research Board, Special Report*, 242.

Odeck, J. and Bråthen, S. (2008). Travel demand elasticities and users attitudes: A case study of Norwegian toll projects. *Transportation Research Part A: Policy and Practice*, 42(1):77–94.

Oum, T. H., Waters, W. G., and Yong, J.-S. (1992). Concepts of price elasticities of transport demand and recent empirical estimates: an interpretative survey. *Journal of Transport Economics and policy*, pages 139–154.

Parthasarathi, P., Hochmair, H., and Levinson, D. (2012). Network structure and travel time perception.

Patil, S., Burris, M., and Douglass Shaw, W. (2011). Travel using managed lanes: An application of a stated choice model for Houston, Texas. *Transport Policy*, 18(4):595–603.

Safirova, E., Gillingham, K., Harrington, W., and Nelson, P. (2003). Are HOT lanes a hot deal? The potential consequences of converting HOV to HOT lanes in Northern Virginia. *RFF Issue Brief*, pages 03–03.

Steimetz, S. S. and Brownstone, D. (2005). Estimating commuters' "value of time" with noisy data: a multiple imputation approach. *Transportation Research Part B: Methodological*, 39(10):865–889.

Transportation Research Board (2000). Highway Capacity Manual.

Turnbull, K. F. (2008). High-Occupancy Toll Lanes and Public Transportation. *Transportation Research Record: Journal of the Transportation Research Board*, 2065(1):36–40.

Wuestefeld, N. H. and Regan III, E. (1981). Impact of rate increases on toll facilities. *Traffic Quarterly*, 35(HS-032 664).

Yan, J. (2002). *Heterogeneity in motorists' preferences for travel time and time reliability: empirical finding from multiple survey data sets and its policy implications*. PhD thesis, University of California.