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EVALUATING CONGESTION PRICING IMPACTS UNDER PEAK SPREADING

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ABSTRACT

The paper involves an econometric analysis of congestion pricing at the bridges and tunnels operated by the Port Authority of New York and New Jersey (PANYNJ). Using a fixed effects model, we pool all facilities to evaluate the impacts of the congestion pricing structure in effect since March 2001. We find significant impacts for autos, but need to confront a counter-intuitive finding: cash paying vehicles, who do not benefit from off-peak discounts, are also estimated to be impacted. Using a unique data set on queueing at the facilities, we are able to control for "peak spreading", and find the pricing effect greatly reduced. By further controlling for endogeneity with an instrumental variables estimator, we find that the price effect on cash paying vehicles entirely disappears.

These results confirm the hypothesis that congestion pricing has had an important impact on conditions at the PANYNJ facilities. Taking a weighted average of the changes by crossing for autos, it is estimated that value pricing led to a shift in EZ-Pass-using vehicles from the morning peak equal to 6.5% and in the evening peak 2.2%. Note that this result is heavily influenced by patterns at the George Washington Bridge, which accounts for over 50 percent of EZ-Pass-using autos.

I. INTRODUCTION

The rationale for congestion (or value) pricing is by now well known and described in various sources such as Vickrey (1969), Keeler and Small (1977) and Hau (1992). Essentially, congestion pricing is proposed as a remedy for a classic market failure, where users of a congested facility are not accounting for the costs they impose on the facility. In the case of roads, individual drivers may consider their personal travel costs, including time spent traveling and operational costs, before deciding whether or not to make a trip; however, they do not take into account the added cost their trip places on other drivers, and the resulting equilibrium use of the facility will be sub-optimal. By applying a congestion charge or tax, the individual would face a cost which would be closer to the true marginal cost of using the facility, and the resulting equilibrium would reflect an efficiency gain.

The applications of congestion pricing have been “second best” schemes which do not charge all users the exact marginal costs they impose on the system (Verhoef, 2005). Rather, existing programs have been limited to specific facilities or geographic areas, rather than being imposed on entire networks. The unifying objective has typically been to alter usage of congested facilities by charging a higher price during the hours of peak traffic volume.

The present paper reports an extensive evaluation of such a program, the congestion pricing initiative at six bridges and tunnels operated by the Port Authority of New York and New Jersey (PANYNJ). The PANYNJ facilities include the Holland and Lincoln tunnels as well as the George Washington, Bayonne, and Goethals bridges and the Outerbridge Crossing. These are crucial links in the New York City region’s road network, providing the primary road access to the central business district from New Jersey and points west. Not surprisingly, the facilities are subject to very high volumes and varying degrees of congestion. As expansion of capacity is not, for the most part, an option in the foreseeable future, pricing was seen as one potential remedy.

The PANYNJ instituted congestion pricing in March 2001, arguably one of the most significant efforts at pricing road capacity in the United States to date. Previously, the toll imposed on motorists traveling into New York was set at a constant dollar amount undifferentiated by time of day. With the introduction of congestion pricing, drivers now receive a toll discount of one dollar for using electronic tolling through E-ZPass to pay the toll. In addition, E-ZPass users receive an additional incentive for traveling during off-peak hours as opposed to during peak hours. In short, motorists using electronic toll collection pay two dollars less for traveling during off-peak hours over the standard six dollar cash toll rate

The issue we examine here is the degree to which the introduction of congestion pricing at the PANYNJ facilities has been successful in shifting users to off-peak travel periods. Beyond an evaluation of the specific impacts of pricing at PANYNJ facilities, our analysis is of general interest to proponents of congestion pricing. Underlying the entire rationale for congestion pricing is the notion that a congestion charge will lead to a reduction in peak period traffic. However, absent a comprehensive “first-best” charging scheme users are imposed a charge which is typically only a rough approximation of an external congestion cost. Whether users respond to any significant degree is an entirely empirical question which needs to account for the characteristics of demand. It is clear that the more inelastic the demand at any facility, the less

effective a given congestion charge will be in meeting the objective of reducing peak period congestion.

Our analysis adds to a growing body of work evaluating the impacts of tolls on motorist travel demand, in particular assessing the impacts of differential tolling in response to congestion. The analysis is distinct from the literature in its consideration of congestion and its influence on travel behavior. Specifically, we incorporate measures of congestion in our econometric model to control for its influence on shifts from peak to off-peak travel. Controlling for the phenomenon of *peak spreading* arguably removes a source of potential bias present in earlier studies.

II. EXISTING CONGESTION PRICING PROGRAMS AND IMPACTS

Congestion pricing programs worldwide have been shown to impact traveler behavior in both the short run and the long run. Short-term impacts include adjustments to time of travel, mode choice, and trip frequency, with changes in route choice predominating when there exists a free highway alternative. Long-term adjustments include not only trip-making decisions but decisions as to automobile ownership and residence location as well (Evans et al, 2003). Our review is selective and focuses primarily on traffic impacts in terms of elasticity measures.

Singapore has been successful with its areawide congestion pricing program. Singapore's Area Licensing Scheme (ALS) was an innovative experiment introduced thirty years ago. Under ALS travelers are charged a fee, which varies by time of day, to enter the restricted zone in the central area of the city. Estimates of the initial response to the program produced a midpoint arc price elasticity that was quite high at -2.95, reflecting the response of previously untolled travelers to the new fee. The response to later increases in the fee was more in line with the experience of other programs, with an elasticity estimate of -0.33 (Evans et al, 2003).

Congestion pricing programs that charge a toll for use of specific highway lanes offering premium or express service have been implemented in California and Texas. The pricing mechanism varies by program, but generally involves higher tolls during peak hours. The State Road 91 Express Lanes (91X) congestion pricing program in Orange County, California features pricing that varies by time of day and day of week given by a published schedule with discounts for high occupancy vehicles with 3 or more occupants (HOV 3+). The estimated price elasticity for use of the 91X lanes during the six hour period of heaviest use is approximately -0.7 to -0.8, while the price elasticity during only the one hour period of heaviest use (the peak of the peak) is approximately -0.9 to -1.0 (Sullivan, 2000).

In Lee County, Florida, a variable pricing project is underway on two toll bridges linking the cities of Cape Coral and Ft. Myers. A 50 percent discount on the toll is given to bridge travelers who use transponders for traveling during the discounted shoulders of the peak periods. The bridges do not typically suffer from congestion, and travelers have gained little travel time advantages from traveling during off-peak periods (Evans et al, 2003). Estimates of response to the differential pricing find log arc elasticities for both bridges are lowest in the evening post-peak period and highest in the morning pre-peak period, ranging from -0.04 to -0.24 for the Midpoint Bridge and -0.02 to -0.14 for the Cape Coral Bridge. These elasticities represent the change in traffic during the shoulder of the peak periods relative to the variable pricing toll.

Driver response to variable pricing has decreased over time, indicating that the long run elasticity is smaller in magnitude than the short run elasticity (Evans et al, 2003), (Burris et al, 2000), and (Burris et al, 2004).

The PANYNJ program was initially evaluated a few years after its introduction. Holguín-Veras et al (2005) focus specifically on E-ZPass users of the facilities and find that short run pre-peak price elasticities tend to be greater than short run post-peak elasticities for most PANYNJ facilities during both weekday mornings and evenings and on weekends; thus travelers are more willing to shift their travel to pre-peak periods in order to take advantage of the discounts. Short term pre-peak elasticities with respect to the toll are in the range of -0.32 to -1.97 on weekday mornings, -0.65 to -1.27 on weekday evenings, and -0.88 to -1.68 on weekends. Post-peak elasticities range from -0.61 to -1.04 on weekday mornings, -0.40 to -1.07 on weekday evenings, and -0.55 to -1.39 on weekends. Commercial vehicles are found to be more inelastic to toll levels than passenger cars in both the short run and the long run, which is consistent with previous studies. The long run elasticity for passenger cars ranges from approximately -0.5 to -1.3, while the long run elasticity for trucks ranges from approximately -0.2 to -0.8. It is important to keep in mind that these pure toll elasticities are computed for E-ZPass users only. One would expect to see lower elasticity values when looking at the entire population of Port Authority facility crossings, some of whom cannot take advantage of the off-peak toll discount as they are paying cash.

In general, there is support for the proposition that congestion pricing has significant impacts on the time of day motorists choose to travel and on the level of congestion on the roadways. A major shortcoming in this literature, however, is the possibility that congestion pricing is not the cause of the shift in travel time. As alluded to previously, peak spreading is a phenomenon in which motorists shift the time of day they choose to travel in order to avoid peak congestion, and this could be influencing the results of these studies. For example, Muriello and Jiji (2004), using only a couple years of data available at the time of their analysis, find that the shift from morning peak to pre-peak travel time at PANYNJ crossings appears to be correlated with congestion levels, and there is no statistically significant change in evening traffic levels. This raises the possibility that, without explicit controls for congestion, researchers cannot be sure that their results do indeed capture congestion pricing and not peak spreading.

III. THE PRICING MODEL

Our analysis benefits from several more years of data than available to Holguin-Veras et al. and Muriello and Jiji, consisting of quarterly traffic volumes by hour at each of the six Port Authority interstate crossing facilities. The vehicle crossings are aggregated into four vehicle types: autos, light trucks, heavy trucks, and buses. We have further aggregated the data into peak, shoulder of the peak, and off-peak crossing times consistent with the Port Authority's definitions. This will allow us to analyze shifts in the time of travel over time. The final step in preparing the data for analysis is to separate motorists using E-ZPass transponders to pay the toll versus motorists paying with cash. This will allow us to compare shifts in travel times of those drivers who may take advantage of congestion pricing versus those who do not receive the toll discount for using E-ZPass.

We begin our analysis with a model of the pure toll effects on traffic volumes at the six PANYNJ crossing facilities, irrespective of time of day, in order to identify price responsiveness by users. We apply an Ordinary Least Squares (OLS) regression of aggregate crossings for each of our four vehicle types on lagged crossings, seasonal dummy variables, business cycle effects, and the real value of the toll. Our regressions take the form

$$\ln(\text{Volume}_{v,t}) = \alpha + \beta \ln(\text{Toll}_{v,t}) + \delta \ln(\text{LAGS}) + \phi \text{SEASONAL} + \gamma \ln(\text{BIZ}) + u_t \quad (1)$$

where

- v represents vehicle type (Auto, Light Truck, Heavy Truck, or Bus)
- $\text{Volume}_{v,t}$ is the volume of crossings of vehicle type v ,
- $\text{Toll}_{v,t}$ is the toll in real dollars paid by vehicle type v ,
- LAGS is a $tx4$ matrix of lagged volume,
- SEASONAL is a txk_1 matrix of k_1 seasonal dummy variables,
- and BIZ is a txk_2 matrix of k_2 business cycle variables.

As there are no true substitutes to the PANYNJ crossings for travel into New York City from points to the west and south, we expect the coefficient on the toll to be quite small. However, it is important for us to show that demand for the crossings is not perfectly inelastic with respect to the toll. A perfectly inelastic demand curve would fail to shift travel time choices with the implementation of congestion pricing.

Once price responsiveness to the toll has been established, we explore the effects of congestion pricing using a model focusing on time-of-day shares and toll differentials (the Pricing Model). For each vehicle type and payment method, we compute shares of crossings at each of the six PANYNJ facilities by time of day and day of week. We follow Matas and Raymond (2003) in using a fixed effects model to control for heterogeneity in each of the facilities' markets (such as unobserved differences in travel patterns and trip purpose at each of the crossing facilities). Our equations take the form

$$\ln(\text{Share}_{v,p,i,t} / \text{Share}_{v,p,j,t}) = \alpha + \beta \ln(\text{TollRatio}_{v,p,ij,t}) + \phi \text{SEASONAL} + \lambda \Omega + u_t \quad (2)$$

where

- p represents the payment method of the motorists (E-ZPass, Cash, or all motorists)
- i represents the time of day (Peak, Shoulder of the Peak, Off-Peak, etc.),
- $\text{Share}_{v,p,i,t}$ is the share of crossings of vehicle type v , using payment method p , crossing the facility at time of day i
- $\text{TollRatio}_{v,p,ij,t}$ is the ratio of the toll in the two time periods,
- and Ω is a $tx6$ matrix of fixed effects associated with the PANYNJ facilities.

Our data covers a time period that captures five quarters before and seventeen quarters after the implementation of congestion pricing. This complete data set allows us to capture the effects of the congestion pricing toll with respect to traffic patterns before the change in the toll structure.

For each vehicle type, we run estimate the model to capture shifts in traffic patterns due to congestion pricing from the peak to the shoulder of the peak and from the peak to the off-peak.

We run separate regressions for motorists using E-ZPass and motorists paying in cash, as well as a total market regression of both E-ZPass users and non-E-ZPass users combined. We expect to see the greatest response to the toll in the regression of E-ZPass users alone, as those are the motorists who are able to take advantage of the congestion pricing toll discount. With EZ-Pass users being the only motorists eligible to receive the toll discount associated with the congestion pricing mechanism, the distinction between EZ-Pass and non-EZ-Pass motorists is essentially a distinction between a treatment group and a control group.

Any toll responsiveness from motorists paying the toll in cash should not be interpreted as a result of congestion pricing because these users do not receive a toll discount and hence are not provided a direct incentive to shift their travel times. At most, one could arguably expect a shift in cash paying motorists from the shoulders and off-peak periods back into the peak as a result of increased congestion from E-ZPass motorists shifting out of the peak periods, which would appear as a *positive* toll elasticity in our regressions.

The final step in our analysis is to confirm that the behavioral responses we are seeing are indeed due to congestion pricing and not instead a result of peak spreading. Essentially, this involves defining a wider measure of the travel cost of using a PANYNJ facility. This measure would include not only monetary costs but congestion costs as well.

We are lucky to benefit from such a measure: The PANYNJ produces biannual reports on congestion at their crossing facilities. In these reports, observed minutes of delay obtained from aerial photographs of the facilities and their surrounding access roads are presented. In essence, the aerial observations, differentiated for peak and off-peak periods, are reporting queue delays at the approaches to the facilities, which are much more meaningful indices of congestion than simple volumes at the crossings, for example. From these reports, we may extract these measures of traffic delay approaching the facilities during the morning and evening peak and shoulder of the peak periods. Adding this delay variable to our congestion pricing model will allow us to determine whether our results are due to the pricing mechanism or peak spreading. Our congestion model takes two forms:

$$\ln(\text{Share}_{v,p,i,t} / \text{Share}_{v,p,j,t}) = \alpha + \beta \ln(\text{TollRatio}_{v,p,ij,t}) + \lambda \ln(\text{Delay}_{i,t} / \text{Delay}_{j,t}) + \phi \text{SEASONAL} + \lambda \Omega + u_t \quad (3)$$

$$\ln(\text{Share}_{v,p,i,t} / \text{Share}_{v,p,j,t}) = \alpha + \beta \ln(\text{TollRatio}_{v,p,ij,t}) + \lambda \ln(\text{Delay}_{i,t}) + \phi \text{SEASONAL} + \lambda \Omega + u_t \quad (4)$$

Equation 3 models the effects of the ratio of delay in each of our two study periods i and j to the shift in traffic volume between these two periods. Equation 4, on the other hand, simply models the effect of delay in period i on the shift in traffic out of period i into period j . A negative and statistically significance coefficient on delay implies that peak spreading is occurring. While peak spreading may occur in concert with significant toll effects, our model will show that congestion pricing does in fact create incentive for drivers to alter their behavior.

IV. EMPIRICAL RESULTS FROM THE PRICING MODEL

In our model of pure toll effects, the coefficient on the toll for each vehicle type, presented in Table 1, is quite small, as we would expect, but highly significant. As shown, the elasticity estimates for cars, light trucks and heavy trucks are all highly significant at the one percent level and similar in magnitude at -0.04, while the toll effect for buses is not significant.

TABLE 1: “PURE” TOLL EFFECTS

Vehicle Type	Toll Coefficient	Standard Error	R Squared
Auto	-0.04***	0.01	0.99
Light Truck	-0.04***	0.01	0.97
Heavy Truck	-0.04***	0.01	0.97
Bus	-0.003	0.02	0.99

*** 1% Significance Level

** 5% Significance Level

* 10% Significance Level

These elasticities show that while demand for use of the PANYNJ crossing facilities is quite inelastic, it is not perfectly inelastic. Thus, pricing schemes should have an affect on traffic volume at the Port Authority interstate crossing facilities. We explore this issue in detail using our Pricing Model, which focuses on changes in time-of-day volumes in response to toll differentials. We find that responses to congestion pricing for each of the four vehicle types are strongest in the submarket for autos. In particular, we analyze the change in the shares of crossings in the peak and several non-peak periods, including *Shoulder 1* (the one hour shoulder around the peak periods), *Shoulder 2* (the two hour shoulder around the peaks), *Off-Peak* (all non-peak and non-shoulder hours), and *Total Off-Peak* (all non-peak hours). Each regression was run for both week and weekend crossings and for all three payment submarkets (*E-ZPass*, *Cash*, and *E-ZPass & Cash* combined)

TABLE 2: PRICING MODEL TOLL COEFFICIENTS FOR AUTOS

AUTOS	Week			Weekend		
	EZPass + Cash	EZPass	Cash	EZPass + Cash	EZPass	Cash
Peak/Total Off-Peak	-0.09**	-0.16*	-0.09**	0.02	0.02	-0.04
Peak/Shoulder1	-0.09***	-0.21***	-0.07***	-0.05***	-0.21***	0.05***
Peak/Shoulder2	-0.09***	-0.19***	-0.06**	-0.05***	-0.14***	-0.05***
Peak/Off-Peak	-0.08	-0.23**	-0.12**	0.05	0.06	-0.04

*** 1% Significance Level

** 5% Significance Level

*10% Significance Level

As can be seen in Table 2, E-ZPass motorists are shifting out of the peak periods in response to the congestion pricing toll during the week. Additionally, our model shows that they are shifting

from the peak into each of the off-peak periods fairly equally. The toll elasticity of autos using E-ZPass during the week does not vary much across off-peak alternatives. Cash users also seem to be responding to the congestion toll by shifting out of the peak during the week. This seems counterintuitive, as motorists paying cash do not receive the toll discount during off-peak periods. This response may instead be due to peak shifting, which we examine further in our congestion model.

We further refine our analysis to examine the effects of congestion pricing on the morning and evening periods separately. We can separate the crossing data into morning and evening peak periods and one hour shoulder periods both before and after each peak. The results from the Pricing Model run on these four dependent variables are presented in Table 3.

In general, there is a larger response of motorists shifting to the pre-peak rather than post-peak period both in the morning and in the evening. Congestion pricing has the largest effect on E-ZPass motorist crossings during the morning. Drivers are shifting their travel to the pre-peak hour in response to the toll discount with an elasticity of -0.54. With the exception of the share of evening peak to evening before peak crossings, cash drivers do not exhibit significant responses to the congestion pricing toll.

**TABLE 3: PRICING MODEL TOLL COEFFICIENTS FOR AUTOS:
MORNING AND EVENING SHARES**

AUTOS	Week		
	EZPass + Cash	EZPass	Cash
Morning Peak/Morning Before Peak	-0.19**	-0.54***	-0.16
Morning Peak/Morning After Peak	-0.06***	-0.14**	-0.04
Evening Peak/Evening Before Peak	-0.07***	-0.14***	-0.08***
Evening Peak/Evening After Peak	0.0002	-0.07*	-0.01

*** 1% Significance Level

** 5% Significance Level

* 10% Significance Level

On weekends, motorists are not as responsive to the toll discount. We see strong responses of both E-ZPass and cash paying motorists between the peak and shoulder periods, but not in the other off-peak submarkets. This may be because the peak period on weekends runs from noon to 8:00pm, a significant portion of the day. Motorists traveling during the middle of the peak may not find the incentive to switch to the off-peak to be strong enough to motivate changing their travel plans. The elasticity of cash paying drivers switching to the one-hour shoulder is positive on weekends. This may be the reverse effect of motorists moving back into the peak because of reduced congestion from E-ZPass users taking advantage of the toll discount during the off-peak.

The markets for light trucks, heavy trucks, and buses do not show as strong results as autos, and therefore we do not find it meaningful to discuss these results in detail here. One reason for the lack of response to congestion pricing of these motorists, including those using E-ZPass transponders, is the lack of flexibility in travel times (Vilain and Wolfrom, 2000). Commercial

vehicles must make deliveries during specific windows. If the specified delivery window does not fall during an off-peak period, the driver will have little ability to alter his schedule to take advantage of the off-peak discount. Most buses follow a set schedule according to rider demand, and thus would not respond to congestion pricing either. Furthermore, the cost of the toll is very small compared to the operating costs of commercial vehicles and buses. The congestion pricing discount is not large enough, in relation to total operating costs, to elicit changes in motorist behavior.

V. CONGESTION MODEL AND RESULTS

The negative toll elasticities in our model of cash paying autos lead us to believe that peak spreading may be taking place, as there would be no pecuniary reason for these motorists to shift their travel time due to their ineligibility for the toll discount. In order to control for this, we now introduce congestion explicitly into our model. Our congestion variable takes the form described previously, namely minutes of delay at each of the crossings as reported by the PANYNJ (*Annual Report of Interstate Toll Delay*). We note that the Bayonne Bridge crossing is not monitored due to a lack of frequent congestion at that facility.

In order to incorporate delay into our model, we must make some adjustments to the Pricing Model. Besides removing the Bayonne Bridge crossing from our model, we also adjust our model to be consistent with the Port Authority's biannual congestion data. Congestion data is collected during the second and fourth quarters of each year and is reported hourly between 6:00 am and 10:00 am and between 3:00 pm and 7:00 pm. From this data we extract morning and evening delay in the peak and in each one hour shoulder period. Delay data is not available for the one hour morning pre-peak shoulder occurring at 5:00 am. This leads us to modify the structure of our crossing data for consistency.

We must also check for strong serial correlation between the toll and the delay, which could confound estimates of their relative influence. We define delay at any crossing as serially correlated with the toll if the correlation between delay and the toll is greater than the correlation between delay and the dependent variable for that crossing. Any crossings for which we find serial correlation are removed from the model.

Finally, we also need to consider the issue of endogeneity in the model. In particular, we can expect that the measure of congestion by period is endogenously determined with demand for crossings in any particular period as well as with the "supply" of capacity. While we can make the claim that the toll component of travel costs is determined exogenously, we cannot do so for congestion, leading to a classic issue of simultaneity bias (Greene, 2003). A test of endogeneity (in this case the Hausmann test) tended to confirm the hypothesis that congestion levels were indeed endogenous.

In order to correct for this problem, we run a second set of estimates of the Congestion Model that incorporates delay using Instrumental Variables (IV). The IV estimation attempts to neutralize the potential effect of endogeneity by finding an instrument or set of instruments that will act as a form of surrogate for the endogenous variable. We find that the E-ZPass participation rate and the New Jersey CMSA population together meet the usual standards for

being a satisfactory instrument as they are highly correlated with our measures of delay but uncorrelated with the error terms. The E-ZPass participation rate is negatively correlated with delay in that when participation in the electronic tolling program increases, delay approaching the toll plaza decreases. New Jersey CMSA population is positively correlated with delay in that when population increases, the volume of traffic from New Jersey into New York increases as well. A Wald test performed on the coefficients verifies that E-ZPass participation and NJ CMSA population are jointly significant in modeling delay. We use a standard Two-Stage Least Squares (TSLS) estimation with IV that controls for the endogeneity. These results are reported along with the OLS estimates in Tables 4 and 5.

We first examine our Congestion Model in the market of autos using E-ZPass. We may expect to see some response to congestion in this market, but it should not greatly affect our toll coefficient. The results from this model are presented in Table 4. As we can see, there is no significant response to delay in the shares of crossings by Auto motorists using E-ZPass. On the other hand, this model confirms that these motorists are significantly altering their travel behavior in response to the toll. The elasticity with respect to the toll for the evening periods is larger in absolute value than that in the pricing model. These results verify that E-ZPass motorists are in fact responding to the toll and that the perceived responses are not instead due to peak spreading.

**TABLE 4: RESULTS FOR ESTIMATES OF PEAK SPREADING
EFFECTS FOR E-ZPASS USERS**

E-ZPASS AUTOS	Week	
OLS estimates:	Toll Coefficient	Delay Coefficient
Morning Peak/Morning After Peak	-0.13 [*]	0.01
Evening Peak/Evening Before Peak	-0.29 ^{**}	0.02
Evening Peak/Evening After Peak	-0.16 ^{**}	0.004
IV estimates:	Toll Coefficient	Delay Coefficient
Morning Peak/Morning After Peak	-0.13 ^{**}	-0.0003
Evening Peak/Evening Before Peak	-0.20 ^{**}	-0.04
Evening Peak/Evening After Peak	-0.17 ^{**}	0.04

*** 1% Significance Level

** 5% Significance Level

* 10% Significance Level

We now turn to our congestion model for motorists paying the toll in cash. These motorists should be more inclined to exhibit peak spreading since they do not receive the off-peak toll discount; however our model shows otherwise. As seen in Table 5, these motorists are generally not responding to either the toll or the delay. One significant response to tolls (evening peak to evening before peak) loses its significance entirely when the IV regression is used, while the other shows a positive response to the toll. A quick look at the average shares during the shoulders, controlling for seasonal variations, confirms that there is little movement of cash paying motorists into the shoulder periods.

**TABLE 5: RESULTS FOR ESTIMATES OF PEAK SPREADING
EFFECTS FOR CASH USERS**

CASH AUTOS	Week	
OLS estimates:	Toll Coefficient	Delay Coefficient
Morning Peak/Morning After Peak	0.06	0.01
Evening Peak/Evening Before Peak	-0.11***	0.01*
Evening Peak/Evening After Peak	0.02	-0.005
IV estimates:		
Morning Peak/Morning After Peak	0.11***	0.03
Evening Peak/Evening Before Peak	-0.07	-0.06
Evening Peak/Evening After Peak	0.02	-0.03

*** 1% Significance Level

** 5% Significance Level

* 10% Significance Level

VI. FACILITY SPECIFIC MODELS AND RESULTS

So far, our analysis has assumed that the response to changes in the relative toll is equal across facilities. This may not be the case. In order to determine any facility-specific effects of the Port Authority's Value Pricing Program, we create a model that includes a facility-specific toll effect¹. This allows the effect of the toll to be analyzed for each crossing independently.

The model examines the effect of the value pricing toll and seasonal dummy variables on the share of crossings in each time period. The share of crossings in any given time period may be related to the share of crossings in the other time periods. This leads us to construct a model of Seemingly Unrelated Regressions (SUR). Estimating the SUR system jointly provides more efficient estimates than estimating each equation separately (Russell and MacKinnon, 1993). Given the limited number of observations in the delay data, the measure of congestion is not included in the SUR models so as to preserve degrees of freedom which are reduced by the crossing specific toll.

For autos, the system is estimated for morning peak, evening peak, and total off-peak periods jointly. The crossing specific toll coefficients are presented in Table 6 for each time period. While the results generally conform to expectations, they contain several puzzling results, namely that Bayonne and Goethals bridges show an increase in peak period shares in the morning and the Holland Tunnel exhibits an increased evening peak period share. The Holland Tunnel evening peak trend may well reflect a delayed result of disruptions related to the September 11, 2001 attacks, with pronounced increases in evening peak period shares in the first and second quarters of 2002. The Goethals and Bayonne bridges also exhibit sharp increases in

¹ The effect on cash-paying users is not examined here due to the lack of significant results in the previous models.

morning peaks in early 2002 through 2003, which account for the positive coefficients reported in Table 6.

TABLE 6: TOLL COEFFICIENTS FOR AUTOS

Crossing Facility	Morning Peak Toll Coefficient	Evening Peak Toll Coefficient	Off-Peak Toll Coefficient
Bayonne Bridge	0.37 ^{***}	-0.25 ^{***}	0.07 ^{***}
Goethals Bridge	0.22 ^{***}	-0.48 ^{***}	0.12 ^{***}
Holland Tunnel	-0.11	0.23 ^{***}	0.01
Lincoln Tunnel	-0.34 ^{**}	-0.27 ^{***}	0.11 ^{**}
Outerbridge Crossing	-0.07	-0.18 ^{***}	0.04
George Washington Bridge	-0.40 ^{***}	-0.16 ^{***}	0.10 ^{***}

**** 1% Significance Level*

*** 5% Significance Level*

** 10% Significance Level*

In the evening peak period, a highly significant negative response to the toll is observed at all crossings. The largest response is seen at the Goethals Bridge, which connects Staten Island and New Jersey. Autos traveling on the Goethals Bridge in the evening peak are generally making a trip from work to home, and thus may have more flexibility in their travel times than motorists at the other crossings.

Highly significant positive responses to toll are observed at four of the six crossings in the off-peak period. The magnitude of the toll coefficients is small in comparison to those in the peak periods, but the off-peak period is much larger than each of the peak periods. Motorists will most likely switch to the shoulders around the peak periods in response to the value pricing toll rather than the middle of the off-peak period. For light trucks, we estimate the system for the peak, off-peak, and overnight periods. The Holland Tunnel is excluded from the analysis due to inconsistencies in the traffic data at that particular crossing. The results of the SUR are presented in Table 7.

A significant and negative response is seen in the peak period at the Goethals Bridge and the George Washington Bridge. This indicates that, at these two crossings, light trucks are shifting out of the peak period. It is unclear, however, whether they are switching into the off-peak or overnight period, as they would receive monetary savings in either period.

The results in the off-peak period are mixed. A significant negative response is observed at the Bayonne Bridge. This indicates that drivers are moving out of the off-peak period at this crossing. These drivers may be switching to the overnight period in order to receive the overnight toll discount. On the other hand, a highly significant and positive response is observed at the Lincoln Tunnel and at the George Washington Bridge. Drivers at these two crossings are

moving into the off-peak period, probably from the peak period in order to receive the toll discount.

TABLE 7: TOLL COEFFICIENTS FOR LIGHT TRUCKS

Crossing Facility	Peak Toll Coefficient	Off-Peak Toll Coefficient	Overnight Toll Coefficient
Bayonne Bridge	0.13	-0.27 ^{**}	0.08
Goethals Bridge	-0.24 ^{**}	0.09	0.40 ^{**}
Lincoln Tunnel	-0.22	0.32 ^{***}	-0.14
Outerbridge Crossing	0.15	0.002	-0.09
George Washington Bridge	-0.31 ^{***}	0.13 ^{***}	0.30 ^{**}

*** 1% Significance Level

** 5% Significance Level

* 10% Significance Level

In the overnight period, significant positive responses are seen at the Goethals Bridge and at the George Washington Bridge. This indicates that light trucks are moving out of the peak and off-peak periods and switching to the overnight period in order to receive the value pricing toll discount at these crossing facilities. For Heavy Trucks, the SUR model was again estimated for the peak, off-peak, and overnight periods. The Holland Tunnel crossings were excluded from the analysis because of the restrictions implemented after the terrorist attacks of September 11, 2001 banning heavy trucks from the Holland Tunnel. The results of the estimation are presented in Table 8.

TABLE 8: TOLL COEFFICIENTS FOR HEAVY TRUCKS

Crossing Facility	Peak Toll Coefficient	Off-Peak Toll Coefficient	Overnight Toll Coefficient
Bayonne Bridge	-0.07	-0.08	-0.05
Goethals Bridge	0.03	-0.07	0.06
Lincoln Tunnel	-0.20	-0.07	0.11
Outerbridge Crossing	-0.57 [*]	-0.19	0.32
George Washington Bridge	-0.11	-0.12 ^{**}	0.15 ^{***}

*** 1% Significance Level

** 5% Significance Level

* 10% Significance Level

As can be seen, the only significant response to the value pricing toll in the peak period is a shift out of the peak at the Outerbridge Crossing. In the off-peak, the only significant response is a

shift out of the off-peak (presumably into the overnight) at the George Washington Bridge. In the overnight, there is a corresponding highly significant positive effect of the value pricing toll at the George Washington Bridge, confirming that heavy trucks are in fact moving into the overnight period in response to the toll at this one crossing.

We can then use these results to estimate actual shifts in traffic from the peak. In Table 9 we summarize the implied shifts of traffic out of the peak periods for all of the vehicle types and for each crossing. Only the crossings and vehicle types where the toll effect is statistically significant at least to the 5 percent level, whether negative or positive, are identified. For all other segments, it is assumed that the lack of statistical significance implies no change in patterns due to value pricing. Taking a weighted average of the changes by crossing for autos, it is estimated that value pricing led to a shift in EZ-Pass-using vehicles from the morning peak equal to 6.5% and in the evening peak 2.2%.

TABLE 9: CHANGES IN PEAK PERIOD VOLUMES BY CROSSING AND VEHICLE TYPE

Crossing Facility	Morning Peak Change	Evening Peak Change
Autos:		
Bayonne Bridge	9.2%	-6.2%
Goethals Bridge	5.4%	-12.0%
Holland Tunnel	No change	5.7%
Lincoln Tunnel	-8.5%	-6.8%
Outerbridge Crossing	No change	-4.5%
George Washington Bridge	-10.1%	-1.4%
Light Trucks:		
Bayonne Bridge	No change	-6.7%
Goethals Bridge	-6.0%	No change
Lincoln Tunnel	No change	8.0%
George Washington Bridge	-7.7%	3.2%
Heavy Trucks:		
George Washington Bridge	No change	-3.0%

VII. CONCLUSIONS

Our rich data set and quarterly model have given rise to some very conclusive results regarding the effectiveness of the PANYNJ's congestion pricing program. Through fixed effects, we are able to control for the time indifferent unobserved variables at each crossing. Furthermore, our incorporation of the congestion model into our analysis provides us with an innovative step in controlling for peak spreading previously absent from the literature. Our analysis shows the

absence of significant peak spreading at the PANYNJ interstate crossing facilities; we can thus be confident that the shifts in travel time choices are indeed a result of the Port Authority's congestion pricing toll program.

Our pricing model yields results consistent with previous literature. In line with the 2005 study of E-ZPass users by Holguín-Veras et al and the 2003 study of variable pricing in Lee County, Florida by Evans et al, we find pre-peak elasticities to be greater in magnitude than post-peak elasticities, with the strongest response to the congestion pricing toll in the morning. Additionally, we find little responsiveness to the toll of cash paying vehicles ineligible for the congestion toll discount, a result consistent with other studies (Burris et al, 2004). Finally, the initial counter-intuitive responsiveness to congestion pricing by cash paying motorists that we do find disappear with the use of IV regressions.

NOTES

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