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Transforming Payment Choices by Doubling Fees on the Illinois Tollway

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Abstract

Rising traffic congestion and the need to improve operational efficiency prompted the Illinois Tollway Authority to unveil plans to reconfigure its road network for “stop-free” electronic toll collection. Committing to an extensive construction program would have required the Tollway to ensure that enough drivers had electronic payment devices (branded as I-PASS). Conversely, without reconfigured toll gates the drivers would have had less reason to own an I-PASS. To resolve this potentially thorny chicken-and-egg problem, the Tollway put in place a new I-PASS distribution network and then dramatically raised the price for cash toll payments.

This paper focuses on consumer response to the change in relative prices. Using tollway traffic data, we document a substantial aggregate increase in electronic toll payments. The propensity to pay electronically rose uniformly throughout the day, reflecting the effectiveness of the Tollway’s actions in modifying behavior of both commuters and leisure drivers. However, not all drivers appear to have responded to the price change *per se*. To analyze the relative importance of price, income, and fixed participation costs we use the Census tract level data on employment and residential location to construct a ZIP-code measure of the likelihood of commuting to work via the tollway. Conditional on this measure, we show that the adoption of electronic payments among lower-income households was indeed influenced by the price change. In contrast, high- and medium-income households responded to lower fixed costs of obtaining I-PASS at conveniently located supermarkets. Finally, we document the role of social network relationships, as changes in I-PASS ownership for all income groups were strongly affected by I-PASS use among neighbors and co-workers.

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By Gene Amromin, Carrie Jankowski and Richard D. Porter[1]

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1. Introduction

Historically, an important part of Chicago's economic strength derives from its role as the country's transportation center, which first began in the 19th century with water routes spanning south to the Mississippi and east to the Great Lakes and Erie canal. Rail soon outstripped water so that by the World's Columbian Exposition in 1893, 1,000 trains entered and left Chicago daily.[2] Eventually, roads overtook rail and the Chicago area was transformed for a third time in the 1950s with the growth of the Federally-sponsored interstate highway system. In the 1960s, road builders improved this with the construction of tollways spreading out from Chicago to adjoining states.[3]

At one level, the payment options on the Illinois Tollway seem incongruous with the remarkably efficient transportation network that put Chicago on the economic map for over a century and a half. Instead of receiving one toll ticket for the entire state and paying the appropriate amount at one set of gates at the other end, as was done in Ohio and historically in Indiana, Illinois had a confusing array of toll plaza barriers extending around the outskirts of Chicago. All vehicles were required to come to a full stop at these plazas and pass through either manual lanes or exact-change-only lanes. The manual lanes on the tollway, in particular, seem to be a throwback to an older patronage age, with little regard for transportation efficiency.

But the exact-change lanes had one efficient payment option that neighboring states lacked. Unlike neighboring tollways in which long distance interstate travelers tended to jam up the road, the Illinois Tollway is primarily a regional commuter roadway that criss-crosses the northeastern part of the state connecting Chicago with a dozen economically linked counties.

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[2] Larson [2003, p.11]

[3] The tollway is located in the Northern part of the state with spokes going north, west and south from Chicago.

Exact-change drivers could pass through the toll barriers reasonably quickly—hardly ever needing to stop for more than a few seconds, which is a more efficient way of getting commuters through toll plazas than it would be if Illinois had adopted a "two-gate" collection system.

But exact-change "hoppers" represent relatively old technology, which can be readily compromised by fraudsters. To combat fraud and improve efficiency, in 1993 the Illinois Tollway Authority introduced a modern electronic payment option – a radio frequency identification device (RFID), brand-named I-PASS, which got rid of the need to stop to pay tolls. Cars equipped with an I-PASS transponder had the correct toll amount deducted electronically upon passing a specially-equipped toll gate. Over the next decade, RFID technology improved enough to allow I-PASS payments while traveling at near full highway speeds. Such "open-road tolling" is believed to be effective in reducing the congestion that often occurs in the vicinity of toll plazas.[4] However, it requires a significant capital expenditure on the part of the Tollway Authority, as well as a critical mass of motorists positioned to undertake toll transactions electronically.

On January 1st of this year, the Illinois Tollway Authority doubled the price for cash payers but left it fixed (at 40¢ at most toll plazas) for electronic payers, the I-PASS clients. By skewing the fee structure on the tollway to encourage electronic payment in this natural experiment, the authority sought to achieve an outsized increase in I-PASS over a short period. In advance of the price change, the authority undertook a substantial public awareness campaign, which emphasized both the cost advantages of I-PASS payments under the new pricing structure and the ease of acquiring and using the transponder. In this paper, we analyze the effect of these actions on payment choices of tollway drivers. Specifically, we look at the relative importance of price, income, and fixed participation costs in consumer choice of a particular payment mechanism.[5]

Commuters and other travelers responded to this toll doubling by quickly switching to electronic payment in large numbers. The share of I-PASS payers had plateaued at around 45%

[4] Under the full implementation of "open-road tolling", cars unable to pay electronically are diverted to an off-road payment ramp and subsequently have to merge back onto the tollway. Tollway bill boards currently advertise that that open-road tolling will become the standard in 2006. Of course, regardless of the structure of payment gates, traffic on a roadway can slow substantially if the number of vehicles on the roadway exceeds its capacity.

[5] Although IPASS may ultimately be a payment mechanism through which congestion pricing is implemented, it is not used for this purpose at present for passenger cars, though it is for trucks. Hence, our study has a different focus than other recent work in this area (e.g. Small *et. al.* [2005]), which obtains estimates of commuter value-of-time.

for the first half of 2004 and then began to rise steadily when the program was announced in late summer and subsequently approved in early fall.[6] It exceeded 50%, on average, in November and then shot up to over 72% by early February, with a nearly a 17 percentage point increase occurring in January, the first month in which commuters faced the new prices. By the end of January 2005 over 1.9 million commuters had electronic payment devices, nearly double that in June 2003 when the transponders were first sold online. As the number of electronic payers shot up, the authority was able to add non-stop lanes to accommodate the stream of new electronic payers, bestowing an immediate benefit on I-PASS motorists: faster commutes.

While the toll hike for cash payers represented a 100% increase in toll outlays, the increase represents a considerably smaller percentage rise in the overall cost of commuting – perhaps no more than three percent for the group most affected, taking into account all the relevant economic factors: the tolls paid, the full cost of operating a vehicle, as well as a measure of the value of time spent in the commute.[7] The question then becomes how such a relatively small boost in overall costs could induce such a large consumer response?

What is critical to recognize is that the boost in I-PASS ownership finessed a potentially troublesome chicken-and-egg problem facing the Tollway. The Tollway could not rapidly bring on line several I-PASS-only lanes around toll plazas unless they had enough demand from commuters to make use of them. If possible, it needed to have a reasonably balanced (and not mismatched) pattern of lanes types and payer types at particular toll plazas. Otherwise, if there was an excess demand for particular dedicated lanes at toll plazas, congestion could *increase*, thwarting the open-road tolling initiative.

The large aggregate increase in I-PASS usage masks interesting heterogeneity in consumer payments choice. In the next section, we take a closer look at the composition of payment choices by time of day and type of drivers, using hourly traffic data on tollway payment. We find that even prior to the pricing change, I-PASS payments had the strongest appeal for drivers using tollways on the regular basis and doing so in periods with highest congestion. We further find that following the toll change, *all* groups of drivers increased their I-PASS usage by roughly the same amount. To build intuition for further investigation, we sketch

[6] Governor Blagojevich unveiled the plan on August 25, 2004 and the Board of Directors for the tollway approved it on September 30, 2004. We interpret the slight dip in July as reflecting a higher level of out-of-state vacationers who do not generally have an I-PASS device.

[7] The computation of these costs is described in detail in section 4.

out a simple model of payment choice in Section 3, which points to the central role of fixed participation costs and commuter income. The following section describes construction of the data for evaluating model's predictions, while section 5 presents simple univariate summaries of the data, in the form of tables and maps. Section 6 provides an econometric analysis of I-PASS demand at the aggregated zip code level, both before and after the price change. In particular, we focus on the importance of two key features of the new pricing regime – a change in relative prices and easier acquisition of I-PASS information – for different income groups. We find that the higher cash tolls served as a major factor in pushing less affluent drivers toward I-PASS (the "cost" channel), while the increase in more affluent groups came primarily from less-frequent toll drivers who were influenced by the ability to acquire an I-PASS easily (the "marketing" channel) and the convenience benefits accruing from I-PASS ownership given their residential location. Section 7 concludes by outlining the broad welfare implications of the toll pricing change.

2. The toll pricing change and its aggregate effects

Around forty years ago, Kelvin Lancaster [1966] proposed that the demand for a particular good or service be decomposed into the demand for the underlying characteristics emitted by the item. For most transactions, the part played by the payment does not affect the enjoyment of the services derived from consumption. However, the form of payment does matter on the Illinois Tollway since under ideal circumstances a motorist in an I-PASS lane proceeds through the toll plaza at highway speeds, which is both more convenient and faster than the other payment options.[8] Consequently, we will treat the payment choice in the context of a standard transportation model of modal choice, where payment choice is isomorphic with lane choice.

The announcement of the price doubling and public awareness campaign produced a immediate increase in the volume of I-PASS sales, which averaged around 35,000 per month prior to the announcement, ramped up to about 55,000 in the fall and then jumped to a record

[8] I-PASS payers have additional choices as they approach plaza gates. They are free to choose any gate, which will automatically register their payment electronically. Ordinarily, the I-PASS gate will be the fastest but they have the option of choosing another gate when it is seemingly going to be faster. Finally, stopping at toll plazas introduces extra costs on brake linings as well as an additional set of hazards in criss-crossing lanes entering and leaving the plazas. There are other aspects of the Lancaster setup that are relevant such as anonymity, record keeping, and the like that we will discuss below more formally.

level of nearly 330,000 in December, Figure 1. After the spurt at the end of 2004 and early 2005, sales have continued to be somewhat higher, averaging about 66.5% more per month from March to August than in the previous year before the announcement—which suggests a continuing elevated but lagged response to the toll change. The doubling of cash toll rates on January 1, 2005 also produced an immediate and dramatic response in the overall share of tolls paid electronically, which went from about 45% of motorists using I-PASS prior to the price announcement to over 70% in a short interval, Figure 2.[9]

<INSERT FIGURE 1>

<INSERT FIGURE 2>

The relative advantages of different payment methods fluctuate by time of day (e.g. congestion) and travel purpose (e.g. whether one needs to arrive at a destination on time). Presumably, the appeal of a more efficient and convenient electronic payment is greatest for rush-hour commuters. We are able to identify travel purpose from a one-time survey of driver preferences, administered in November, 2003.[10] Figure 2 confirms that the tollway is used almost exclusively by drivers commuting to work during the early morning hours, and that such drivers also dictate traffic volumes in the evening rush between 4 and 6 p.m.

<INSERT FIGURE 2>

Figure 3 depicts the share of I-PASS transactions by time of day, with two series representing payment compositions before and after the pricing change.[11] Both series have two distinct humps corresponding to peak times, effectively mirroring the fraction of toll drivers that are commuting to/from work. This result confirms the basic intuition that even in the absence of price differences (e.g. before the 2005 price hike), electronic payment was embraced by frequent

[9] There is slight dip down by the end-month shown (June), which appears to be a summer time seasonal and not a structural dip. As summer approaches, the number of transient visitors to Chicago increases and overall I-PASS usage declines a little, a pattern that is evident in 2004 as well.

[10] The Tollway conducted the Origin-and-Destination Survey along toll plazas on I-88, with survey instrument handed out to motorists paying cash tolls or mailed out to I-PASS users. The response rates for two groups were 24% and 76%, respectively. In addition to questions on trip purpose, drivers were asked about the origin and destination of their travel, their zip code of residence, frequency of toll trips, and participation in the I-PASS program.

[11] The x-axis shows the beginning time for successive one-hour intervals. Averages for subintervals during the day are shown in Table 1. To limit the effects of weekend or vacation visitors to Chicago, this figure displays the results for a midweek day, Wednesday, for two months with limited vacation activity, March-April 2004 and March-April 2005.

toll users that put a relatively higher premium on convenience and potential improvement in travel times.

<INSERT FIGURE 3>

Interestingly, we find that after the price change went into effect, the *increase* in I-PASS usage rates was nearly identical for motorists using the toll system during rush hours or in mid-day, or late night/early morning. The upward shift in I-PASS usage is remarkably parallel over the whole day so that the difference in shares for the same hour over the two periods is about flat across the 24-hour day. Namely, in the morning and evening rush hours, the percentage point increase is virtually identical (24.7), which is only a few tenths higher than the mid-day increase, see Table 1. This finding suggests that to a first approximation, commuters, as well as shoppers and leisure drivers responded similarly to the change in tolls even though the tollway benefits bestowed on them tended to favor the commuters unequivocally.[12]

<INSERT TABLE 1>

To look more closely at the factors influencing the payment decisions of such disparate groups of drivers we need two things: (a) a simple model of payment choice to build intuition and inform subsequent analysis of disaggregated data and (b) a description of data used to identify cost, intensity, and, most importantly, viability of tollway usage. These subjects are taken up in turn in the following sections.

3. A simple model of payment choice

While we believe we have exposed the principal forces governing I-PASS decisions, we do have more information on some facets of the choice, e.g., the likely composition of tollway users on the basis of location of residence and employment than we do for other tollway users such as occasional or one-time users. Given this uneven treatment, we view the simple model that we sketch below as throwing some light on the relevant variables of interest in a tentative and exploratory modeling exercise rather than as offering us a definitive specification that deserves to be rigorously confronted with the full range of data that we have.

[12] An average toll of $1.40 for a commuter would double and cumulate to $672 over a 48-week work year. For a one-day–a-week or one day-a-month toll users the respective cumulative cash tolls would be either $134.40 or $33.60, again assuming a 48-week year. Even the *savings* from a one-day-a month driver ($16.80) would be sufficient to cover the fixed outlays associated with having $10 tied up with a transponder and $25 tied on average up in tolls held on the transponder at say a 4% nominal interest rate, or an opportunity cost total of $1.40.

Assume that drivers' preferences, U, are defined over consumption of goods and services, G, and leisure, L. This gives us:

$$U = U(G, L) \tag{1}$$

$$L = T - H - t_i(N, D) \tag{2}$$

$$G = V + w \cdot H - N \cdot c_i + F + a(w, E) \tag{3}$$

where T is the total time available, H is hours worked, w is the hourly wage rate, N is the number of toll plazas passed, V is the initial net worth, c is the toll cost per plaza, and F and a are the one-time deposit and the costs of learning and installing a particular payment system. Unlike Train and McFadden (1978), we treat that the number of hours spent working as exogenous since each agent's occupational choice is divorced from his or her optimal transportation decision (and even more so from the decision to pay tolls using an I-PASS transponder or cash).[13]

If occupation and thus both w and H, are taken as exogenous, the optimization takes place over a finite set of time and cost pairs $\{t_k, c_k\}$, representing the k^{th} alternate toll payment type, c_k, with associated total travel time, t_k. Since both G and L are assumed to be normal goods, the optimal modal choice will be independent of the specific preference choice only if there exists a pair $\{t_k, c_k\}$ such that

$$(t_k \le t_j)\ and\ (c_k < c_j)\ or\ (t_k < t_j)\ and\ (c_k \le c_j)\ for\ all\ j \ne k \tag{*}$$

Otherwise, the optimal choice will depend on the relative curvature of the utility function with respect to the two arguments.

To build intuition for the tradeoff, assume for the moment that the relationship between total commuting costs c and time spent in commute t is given by a continuous function $c(t)$, with $c'(t) < 0$. In this case, the decision variable of the household is t and the FOCs take a familiar form:

$$U_G \cdot G_t + U_L \cdot L_t = 0, \tag{4}$$

where F_x denotes the partial derivative of some function $F()$ with respect to x. Using general specifications for G and L from (2) and (3) yields:

[13] The assumption of work hours as a perfectly flexible decision variable of households has received less and less empirical support in work in the labor supply literature. For two recent examples see Altonji and Usui [2005] and Aaronson and French [2004].

$$-N \cdot c'(t) \cdot U_G - N \cdot U_L = 0, or$$

$$U_L = -c'(t^*) \cdot U_G \text{ at some optimum travel choice } t^*. \tag{5}$$

One thing to note is that an interior solution does not exist if $c'(t) \geq 0$. Restating this intuitively, we have that an interior solution does not exist if more time in commute is associated with equal or higher commuting costs. But since the first of this year, it is this condition that now holds on the Illinois tollway for cash payers (who pay more and ironically receive less value, namely a longer period in transit). Equation (5) simply says that the marginal gains in leisure from shortening the commute (weighted by the marginal utility of leisure itself) must be equal to the negative of the marginal cost in terms of consumption goods associated with this choice (again weighted by the marginal utility of consumption). Although in our application for the tollway $c(t)$ is not differentiable, it is easy to reason from (5) to obtain the necessary intuition. Each competing commuting choice involves some increment in cost and time spent, Δc and Δt. If gains in leisure valued at U_L are smaller in absolute terms than losses in consumption valued at U_C, i.e. if (5) holds as a negative inequality (≤), then the choice that generates such (Δc, Δt) is rejected.

The tradeoff in (5) is easy to generalize to other aspects of payment choice, where a particular payment alternative provides more benefit(s), e.g. faster service, greater reliability, easier use, greater convenience, better dispute resolution, at an additional cost(s). The choice then becomes one between a cheaper but less attractive payment mechanism and a costlier but more desirable one. For example, very affluent New Yorkers were willing to pay a twenty-five percent premium in excess of first class fares on competing commercial airlines to fly on the Concorde from New York to Paris in order to arrive in less than half the time.

For Illinois tollway drivers this marginal tradeoff was never as dramatic. Even prior to the toll change, the convenience of I-PASS and the possibility for faster travel it offered were counterbalanced by the carry cost of the $10 I-PASS deposit and the carry cost on the outstanding balance. Following the change in the relative toll prices, *electronic toll payments via I-PASS offered both a cheaper and faster (more reliable, easier) way to travel*, clearly satisfying condition (*) above. As such, it should have been the preferred payment choice for virtually all motorists, making the less-than-universal adoption of I-PASS somewhat mystifying.[14]

Clearly, the leading candidate for explaining this puzzle is the existence of fixed participation costs, which can preclude (or perhaps delay) the adoption of a dominant payment mechanism. These costs derive from having to acquire new information and skills, and have been shown to play a role in explaining other consumer choices, such as non-participation in equity markets, see Heaton and Lucas [1997] and Vissing-Jorgensen [2002]. As the relative price advantage of I-PASS increased, the threshold level of participation costs must have fallen, drawing more drivers towards I-PASS. Also, as mentioned earlier, the public awareness campaign that accompanied the pricing change, along with information spillovers from earlier I-PASS users, have likely combined to decrease the cost of information acquisition.[15]

The simple framework in (5) can be mapped to the data by assuming a particular preference specification, as illustrated in the Appendix A. More generically, one can obtain the following set of hypotheses for empirical testing.

1. As wages (or income) increase, the ratio of U_L to U_G increases, especially if the number of hours spent at work is an increasing function of income. As a consequence, drivers with higher wages are more likely to use I-PASS.
2. Higher education likely reduces the fixed costs of an I-PASS purchase, which makes better educated drivers more likely to use electronic payment. This could include both greater willingness to learn something new and lower overall acquisition time to obtain full participation. The same logic should hold for all other characteristics that reduce participation or learning costs, such as proximity to I-PASS retail outlets, advertising, and neighborhood spillover effects.

[14] Of course, one could assume that the cash payers are transient drivers, who view their tollway trips as a one-time events. At the peak of the morning rush hour after the price hike, the fraction of cash payers (15.6%) seems too large for that to be the end of the story. We suspect that there are a significant number of infrequent tollway users who do not view I-PASS as a vital option for them even though in reality it could be, see Appendix D. Some might not be aware of the price difference between I-PASS and cash. If they are aware, undoubtedly the price hike pulled some these "reluctant users" into the I-PASS camp. To the extent that I-PASS users typically pass through toll plazas more quickly, it would have been apparent after January 1 that that they were paying twice as much and enjoying it less, undoubtedly a powerful inducement for some to switch to I-PASS.

[15] Another disadvantage of I-PASS is the potential loss of privacy, which distinguishes it from cash; see Appendix D. Some motorists place very high value on their anonymity, which can be modeled through their preferences. While we acknowledge the relative prevalence of such tastes, we do not seek to qualify them empirically.

3. As commuting distances get longer (higher N), the cost difference between cash and I-PASS toll payments matters more, again making longer distance (higher N) drivers more likely to purchase I-PASS. Moreover, higher N drivers are also more sensitive to time spent in commute (Nt_T), which also pushes them towards using I-PASS.

In sum, the demand function for I-PASS ownership may be written in the following reduced form: *prob*(I-PASS use) = *f*(income or wages, tollway travel factors, participation costs), where tollway travel factors include cost, distance, time, and congestion characteristics of toll trips; and participation costs encompass both the ease of learning and ease of acquisition of an I-PASS transponder.

3.1 Some accounting

Before taking a look at the data, it is useful to set out some accounting identities. The overall I-PASS demand in some geographic unit (say, zip code) with population p derives from demands by different groups, such workers, retirees, and students. As will be described in greater detail below, we have data on everyday commuting choices of workers, which include the origin and destination of the commute, mode of transportation chosen, and time spent in commute. Since a great deal is known about worker commutes, we are able to measure many of the components of the I-PASS demand function including, importantly, the likelihood of using the tollway itself for commuting.[16] In contrast, there is very little information about travel patterns of other demographic groups, which leads to the following decomposition:

$$\frac{i}{p} \equiv \frac{(i^{d,t}_{worker} + i^{d,f}_{worker} + i^{nd,t}_{worker} + i^{nd,f}_{worker})}{p} + \frac{(i_{retiree} + i_{student} + i_{other})}{p}$$

Here, i denotes the number of I-PASS accounts and the superscript for different worker groups denotes the current commute mode (d = driving, nd = public transport, etc.) and feasibility of tollway use (t = potential toll user, f = likely freeway user). Since the easiest way to transform the probability of I-PASS ownership to an aggregate measure is by expressing it as a fraction of a group, we end up with:

$$\frac{i}{p} = (\frac{i^{d,t}}{n^{d,t}}) * (\frac{n^{d,t}}{p}) + (\frac{i^{nd,t}}{n^{nd,t}}) * (\frac{n^{nd,t}}{p}) + (\frac{Freeway\ users + Unknown}{p}) =$$

[16] The algorithm for gauging the likelihood of tollway commute is described in more detail in the following section and in the Appendix B.

$$= f^{d}()*(\frac{n^{d,t}}{p}) + f^{nd}()*(\frac{n^{nd,t}}{p}) + (\frac{Freeway\ users + Unknown}{p}) \qquad (6)$$

Here, f(·) represents a generic demand function of I-PASS ownership from the preceding section. If workers who potentially use the tollway daily to drive to work $(n^{d,t})$ have the same I-PASS demand function as workers who may only do this occasionally $(n^{nd,t})$, the weight on the common demand function becomes $(\frac{n^{d,t} + n^{nd,t}}{p})$. In the subsequent regressions we look at both of these possibilities.

4. Data construction

The data that we analyzed in this study were obtained primarily from two sources: the Illinois Tollway Authority and the 2000 United States Census. From the former, we received I-PASS ownership by zip code and I-PASS usage and lane configurations by plaza. We also gathered public information about toll costs, plaza locations, and exit specifications (on and off ramp directions) from their website. From the later, we used economic and demographic information by zip code of residence as well as journey to work data by census tract of residence to census tract of work.[17] We then merged all of these data into a single, unique dataset of economic, demographic, and geographic information by zip code of residence, described in more detail below.[18]

4.1 I-PASS use and registration data

The dataset on I-PASS ownership details the total number of accounts and transponders by unique zip code. This information was provided for two time periods, August 2004 and February 2005. These dates were chosen because they fall right before the announcement of the Congestion-Relief Plan and shortly after the rate change went into effect, respectively. The number of accounts and transponders are sums of individual accounts, as opposed to corporate accounts, for zip codes of residence.

[17] The zip code data is actually by the census defined geographic area called Zip Code Tabulation Area (ZCTA). These areas cover basically the same geography as zip codes with some differences. For a description of ZCTAs see http://www.census.gov/geo/ZCTA/zcta.html. For simplicity, we will call ZCTAs zip codes for the duration of the paper.

[18] Stata programs used in constructing this dataset are available upon request.

We also have hourly data on I-PASS, exact-change and manual lane tollway transactions for the 114 toll plazas on the tollway from January 1, 2004 to June 30, 2005, a total of over 1.5 million observations.[19] Embedded in this data is the type of payment with which the transaction was made, as well as the specific lane configuration of each plaza (that is, how many I-PASS only, exact-change, and manual lanes are present at the plaza).[20] With this information we hope to assess the impact of the price change and changes in lane configurations on congestion in future work.[21]

4.2 Zip code level data from the 2000 U.S. Census

Similar to the I-PASS ownership information, the Census provides economic and demographic data at the level of zip code of residence. Among numerous other variables, included in this dataset are variables describing income, education, length of residency, and population for all zip codes in the U.S. Specifically, we chose the following variables as regressors in our model: the population of people 16 years or older, household median income, the number of households in ten different income groups, the length of residency in the U.S., and the fraction of the population 25 years and older with college or advanced degrees. We felt that the population of those sixteen years or older was representative of those people that could have I-PASS accounts, because they are of working, and more importantly, of driving age. All household variables were normalized by this number. We then matched the Census data to our I-PASS ownership data to create a larger dataset of I-PASS ownership by zip code of residence plus all population related economic and demographic data that we thought could be influential in deciding to obtain an I-PASS.

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[19] We consider plazas that serve different directions as separate plazas even though they have the same reference number according to the Tollway Authority. Plaza 3 in both directions is excluded due to data problems that cannot be resolved at this time.

[20] Remember an I-PASS payment can be made in any lane at a plaza, not just the I-PASS only lanes.

[21] We find the zip code information easier to model than the potentially much richer hourly I-PASS usage information. This plaza-level information is geographically dispersed and captures variations in congestion patterns that we are able to infer to some degree. The difficulty with the latter is connecting it to our basic commuter information organized at the zip code level for I-PASS ownership together with income and demographic information. For isolated plazas in remote areas, it may be easier to say something since the residency of the tollway users may be easier to pinpoint. For closer-in plazas, this matching becomes more difficult with the information we have in hand. Thus our focus, thus far, has been on the more limited I-PASS information at the zip code level.

Beyond the conventional variables likely to influence the decision to get I-PASS, we were also interested in determining whether the convenience of getting I-PASS and exposure to information about it were influential. We felt that the distance to points of sale for I-PASS transponders, primarily a chain of grocery stores (Jewel), and the degree to which one's neighbors were getting on the "I-PASS bandwagon" would be representative. In the first case, we simply calculated the straight geospatial distance between all zip codes and Jewel stores selling I-PASS. Using the zip code I-PASS ownership information, we were also able to determine the I-PASS ownership makeup of neighboring zip codes. We believe that there are potential spillover effects of neighboring zip codes' decisions, even if it is simply a source of introduction. Therefore, we used the population figures from the census to calculate the population weighted average of the number of I-PASS transponders per person of those zip codes within five miles of each zip code.

4.3 Census tract data on daily commuting choices

The Census provides even greater detail in their Census Transportation and Planning Package (CTPP) on demographic and economic variables that relate to workers and their commutes to work. Specifically, Part III of this survey, called Journey-to-Work, provides data by pairing place of residence and place of work. From this data, we know how many workers make a given commute, how long it takes, what form of transportation they use, and what their income is.[22]

The Census provides this detailed information at the census *tract* level, a geographical definition that is much smaller in size than a zip code. Aggregating these data to the zip code level (as described in Appendix B) provided us with data on how many workers commute from their zip code of residence to each of the other zip codes in our geography.

Although this summary is sufficient to compute the weighted averages of commuting times, we needed to determine whether it would be reasonable for a commuter to take the tollway to work. To do this we employed a simple model of tollway choice (also described in Appendix B). In essence, each origin-destination pair of zip codes (say A and B) was judged to be "potentially" suitable for tollway travel if a trip from A to B via tollway was not

[22] We used the travel time for those that drive alone to work since it seems to be the purest measure of the travel time between the origin and destination. The travel time for those that carpool, for example, could include several stops and would not be representative of the actual commute.

"excessively" longer than "as a crow flies" route. With this binary variable in hand, we were able to impute the approximate daily commuting distance for each of our 656,600 origin-destination pairs.

4.4 Total commuting costs and value of time imputation

Next, we turned to estimation of tollway commuters' toll expenditures, total commuting costs, and their ratio. Because we had the actual coordinates of all toll collection points, we could determine which toll booths a commuter going on a certain tollway route will encounter. Therefore, we summed the toll costs corresponding to the toll booths passed through along the route, including those at the entry and exit points.[23] These costs turn out to be just a small part of a commuter's costs in making this trip, however.

Total commuting costs encompass the costs of gas and insurance, depreciation, and, importantly, the value of time spent in commute. While the direct monetary costs of car ownership are easy to calibrate (e.g. one can rely on estimates provided by the American Automobile Association or Edmunds.com), choosing a proper measure for the value of time is trickier. We chose to impute these values on the basis of estimates from Small et.al [2005], who estimate value of time as a function of household income and commute distance using a dataset of actual and hypothetical choice of commuters in Southern California in congestion pricing setting. This approach allows us to maintain heterogeneity in value-of-time measures that clearly exists in the population while relying on state-of-the-art econometric technique applied to a unique data set.[24] Specifically, for each origin-destination pair we find how much a commuter would pay to obtain a marginal reduction in the time spent commuting. We obtain the following expression for the value of time, v from Small et. al. [2005]:

$$v = \frac{\tau_1 d + \tau_2 d^2 + \tau_3 d^3}{\xi_1 + \xi_2 D_{medium\ income} + \xi_3 D_{high\ income}}$$

where d is the one-way commuting distance and D_x denotes a dummy variable for income group x, and where we use their parameter estimates of the τ's and the ξ's.

[23] Reversing the commute, we calculated the tolls costs on the return trip. Summing these up, we had the toll costs for the roundtrip commute.

[24] Clearly, using estimated coefficients to impute some of our explanatory variables means that we will have to account for the imputation error when drawing statistical inferences, an exercise that we have do not do in this draft.

As the next step, we compute the total commuting cost (TC) using:

$$TC = v * t(A,B) + d(A,B) * c + (F + v * C) + tolls$$

where *d(A,B)* and *t(A,B)* are estimated distance and time spent commuting between zip codes A and B, *c* is the per mile cost of operating a vehicle (assumed for simplicity to be the Federal government's reimbursement rate), *F* is the transponder deposit ($10), and *C* is setup time for obtaining I-PASS, which potentially varies with education and income levels.[25] *TC* is computed on the annualized basis for each (A, B) pair, and we consequently form *tolls* / *TC* ratios and aggregate them to zip code level.

Figure 4 shows the distribution of the *toll* / *TC* ratio across multiple destinations in two of the zip codes that are located close to the tollway. In both of them about 45 % of all drivers are classified as likely toll users, though the median income in one of the zip codes is about twice the level of the other. As shown in the figure, the distribution of *toll* / *TC* ratio is skewed to the right for both zip codes, with the mode for the "affluent" zip in the 1-2 percent range, and the mode for the "less affluent" zip in the 3-4 percent range.

Table 2 provides the descriptive summary of the *toll* / *TC* ratio at the aggregated level, that is, across all zip codes. The table shows commuting costs for the likely toll drivers after the pricing change under two payment choices: I-PASS and cash tolls. Even after the doubling of cash tolls, the overall toll outlays constitute a fairly marginal part of the overall commuting expense for the vast majority of tollway commuters. Yet, they remain the most explicit component of commuting costs.

<INSERT FIGURE 4 AND TABLE 2>

At this point, we have all of the variables of interest relating to the commuting patterns of workers likely to use the tollway in our sample. Because all of our other data is at the level of zip code of residence, we need to aggregate our specific worker commuting path variables to be representative of all workers in that zip code. To do this, we form weights by taking the number of workers unique to each origin-destination pairing over the sum of all workers starting at the

[25] By introspection the full setup time to obtain an I-PASS transponder can not be that large. For most I-PASS users it (1) involves going to the service desk at Jewel grocery store chain and buying a transponder, (2) setting up an account with the tollway authority by phone or internet, and (3) affixing the transponder to the windshield of the car. For these calculations, we assume a one-hour setup time, which seems to us to be at the upper end of the plausible range of the time to complete the purchase, registration, and installation of a transponder. We expect that many commuters would be able to complete these tasks in considerably less time. Such a higher estimate accommodates commuters who have a significant distaste for learning about a new payment media beyond the time involved.

zip code of origin, calculated separately for all workers, workers likely to use the tollway, and workers unlikely to use it. These weights are applied to all variables unique to each commute to get weighted-average variables representative of the entire zip code of origin.

In the end, we are left with a dataset that includes: the zip code of residence; I-PASS ownership; neighbors' I-PASS ownership; distance to the nearest Jewel store; total population variables for income, education, and length of U.S. residency; separate worker and driver variables for income, travel time, and distance to work for tollway and non-tollway commuters; and tollway worker and driver data for toll costs, value of time, and total commuting costs.

5. A first look at the data

5.1 Geographical Representation of the Data

Due to the geographical nature of both the toll roads and the zip code information on I-PASS ownership, a first pass at analyzing our data is best accomplished with a visual look at the primary variables in a map of the region. In order to focus on the main body of close-in commuters, we center the maps on the seven counties surrounding and including Chicago: Cook, DuPage, Kane, Kendall, Lake, McHenry, and Will. All six maps are conditioned at the level of zip code of residence. Since we are most interested in the geographic penetration of I-PASS, the first map (Map 1) exhibits I-PASS ownership in August 2004. The zip codes are shaded from lighter to darker representing *increasing* I-PASS ownership per person.[26] Map 2 updates Map 1 to account for I-PASS ownership in February 2005, in effect, showing the geographic effects of the price change when compared with Map 1. The next three maps (Map 3, Map 4, and Map 5) display the average tollway commuter's income, distance to work, and value of time, respectively, shaded from lighter to darker as the variable *increases* in magnitude. In general, darker shading represents an *increased* likelihood of getting I-PASS. The last map (Map 6) shows distance from the center point of a zip code to the closest Jewel store where I-PASS transponders can be purchased. In this case, we shaded the zip codes from lighter to darker as the distance *decreases*.[27]

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[26] In some cases the Tollway Authority was not able to filter out I-PASS accounts as commercial if the registrant gave a business address but applied under his/her own name. Therefore, there are highly commercial zip codes that have too many I-PASS accounts per person to be plausible for personal use (a ratio of above one per person). These zip codes are colored light yellow and indicated as 'other' in the legend and should be ignored in the analysis.

[27] Although this is the opposite of what we did for the commuter distance map, it is consistent with the idea that as the shading gets darker, there is an increasing expectation of I-PASS penetration.

In the first map (Map 1) August 2004 I-PASS ownership first becomes significant around where most of the tolls roads converge, which is about 15 miles from the downtown Chicago area. I-PASS ownership per person remains mostly above 0.15, fanning out with the toll roads as they move farther from Chicago. At about 20 to 30 miles out there are pockets of increased I-PASS ownership along all of the tollways. The largest pocket of dark area (high concentration of I-PASS accounts) surrounds the intersection of I-88 with I-355. This higher density could partially reflect the history of I-PASS, since I-PASS was first introduced on I-355 in 1993 and then expanded onto I-88 in 1994, while most other areas did not have this payment option until around 1997. It is interesting to note, however, that I-294 also received I-PASS technology in 1994, but I-PASS ownership is not as concentrated in this area. In general, we do not see a drop-off in the ownership rates along the tollways until you move about 40 miles away from Chicago and at least 15 miles away from a toll road.

<INSERT MAP 1>

After the Tollway Authority's implementation of the price change, the entire I-PASS ownership map (Map 2) for February 2005 is significantly darker than that for August 2004 (Map1), representing increased I-PASS penetration between these periods. The February map presents a similar pattern to August; however, the lighter areas (the middle range) and darker areas (the high range) both appear to have significantly spread out, shrinking the lowest range. Because many areas of light shading became medium and many areas of medium became dark, Map 2 conveys the sense that I-PASS uptake took place somewhat evenly across the close-in region between these two periods. The fairly uniform geographic "deepening" of I-PASS ownership dovetails with the parallel rise in I-PASS usage across commuter types, depicted earlier in Figure 3.

<INSERT MAP 2>

In Map 3, tollway commuter income is broken into three nearly equal income groups: the lightest shading representing those with an average income of less than or equal to \$60,000; the middle shading over \$60,000 but less than or equal to \$80,000; and the darkest shading showing those with an average income above \$80,000.[28] As one might expect, with only a few exceptions the higher income zip codes tend to fall very near to the tollway system. Given the income

[28] The income groups represent nearly equal numbers of zip codes in our entire 40-mile-from-the-tollway sample. Since the map is centered on a smaller area, the income grouping appears biased towards the higher income groups.

makeup displayed in this map, one can assume that there is a premium for living closer to the tollway system since it serves as a gateway for mobility within this region. Initially, one would therefore expect to see higher I-PASS ownership in these areas, both due to the ability to afford the deposit and the proximity and likely frequent use of the tollway. Looking back at Map 1, this is clearly the case, as I-PASS ownership above 0.15 per person is registered almost exclusively in areas where income is greater than $80,000, our highest income group. This concentration of high income and I-PASS ownership suggests that before the price hike income was the main determining factor in the decision to own an I-PASS. Furthermore, the lower income of the area around the southern and northern parts of I-294 compared to that around I-355/I-88 might help to explain why I-PASS ownership is lower there even though they have had a lengthy exposure to the technology. Interestingly, by February, I-PASS ownership shows less of a dependence on income. Map 2, for instance, looks remarkably similar to Map 3, reflecting the idea that there was a pick up in I-PASS ownership rates across all three income groups.

<INSERT MAP 3>

The next map (Map 4) is displays three nearly equal distance-to-work areas for three types of tollway residents: close-in, inner suburbs, and outer suburbs. On the one hand, one might expect that the farther a commuter has to drive to work, the more likely they would want to live near the tollway. On the other hand, living near the tollway typically reduces a commuter's distance to work. It is also important to note that the city of Chicago is one of the main destinations for commuters in the displayed region. Consequently, the distance from each zip code to Chicago seems to be the dominant force behind the layout of the shading, with those areas closer to the city being lighter than those farther away.[29] One might have expected that the likelihood of getting an I-PASS for a tollway commuter would increase with distance to work, simply because a commuter is likely to pass through more tolls. This map suggests, however, the distance variable may be insignificant or even negative, at least in this subset of our sample. This relationship holds because many tollway commuters who live right along the closer-in tollways have relatively short commutes to work and associated higher levels of I-PASS ownership.

<INSERT MAP 4>

[29] Shading in the city is darker because those areas are commuting to places other than Chicago if they are using the tollway and are relatively far from the tollway itself.

Since our value of time calculation is strictly based on two factors, income and distance to work, we in essence meld Maps 3 and 4 together to produce Map 5. Consequently, we tend to have the highest values of time (darkest) where both distance and income are highest (darkest) on the respective maps and the lowest value of time where income and distance are lowest (lightest). The areas with opposing variables tend to fall mostly in the middle range, but sometimes are pulled in the direction of the income variable, given the structure of the ratio of distance to income defining the empirical value of time that we are using. Overall, this map tends to have the most patchwork elements of the six maps shown. There is some sense of higher values of times along the tollway starting about 30 miles out of the city, where high income commuters still value the geography's proximity to the city and the distance to work (with Chicago as the likely destination) is reasonably long.[30] Because the relationship between income and residency near the tollway appears quite strong, it is reasonable to expect the value of time to display a small positive correlation with I-PASS penetration or at the very least be more significant than distance to work.

<INSERT MAP 5>

The final map (Map 6) shows that almost every zip code in this close-in sample has a Jewel store that sells I-PASS within seven miles or less of its center point. This dispersion indicates that commuters in these zip codes would likely not have to go far out of their way to buy a transponder. It is likely that in this close-in subset, the distance to Jewel is not much of a deciding factor in getting I-PASS since everyone has at least one store within a relatively short distance. In the full sample, however, the distance to the closest Jewel store continues to increase the farther the zip code is from Chicago. It is conceivable that the convenience of being near a Jewel store is more significant in those farther-out areas.

<INSERT MAP 6>

5.2 Correlation structure

We can conduct a preliminary empirical evaluation of I-PASS acquisition by looking at the correlations (the ρ's) between the level of I-PASS accounts in both August 2004 and February 2005 and the *differences* in I-PASS account concentrations by zip code between these dates with various economic, demographic, and geographic characteristics. We would expect the

[30] The north side of the region shows a high value of time even closer in to the city, where the distance to work is relatively small but the income must be quite large.

difference in the I-PASS uptake rate to be negatively correlated with membership in a group judged to be most likely to already have I-PASS by August 2004 (i.e. higher wage earners, better educated households, and households with longer commutes). In other words, areas with high concentrations of early I-PASS adopters would experience the smallest increase in their I-PASS concentrations following the price change on January 1, 2005. We also examine indirectly the population of new I-PASS owners following the pricing change. They are the inframarginal group for which the time advantages of I-PASS ownership did not outweigh the costs in the old regime, but who switched and moved to the I-PASS margin, after the new regime became evident.

<INSERT TABLE 3>

Table 3 presents simple pairwise correlations built up from our basic information at the zip code level. It is apparent that I-PASS ownership is extremely persistent, with near-perfect correlation at the zip level between August and February. As with the maps, the most notable feature of the correlation structure is the central role played by household income. Not only does income have a strong positive relationship with I-PASS ownership, it is also strongly correlated with a number of key variables such as education, likelihood of tollway use, and imputed value of time. Median income had a stronger correlation for I-PASS ownership in August ($\rho = 0.65$) than after the announcement of the price change ($\rho = 0.54$). I-PASS penetration by August 2004 is strongly correlated with the fraction of workers in a zip code that potentially would take the tollway to work, if they were to drive ($\rho = 0.76$). It is informative that this relationship is somewhat weaker for *changes* in I-PASS ownership over the period from August to February. This finding suggests that under the new price regime, I-PASS ownership was somewhat less tied to strictly work-related travel, leaving us with the inference that leisure and convenience purposes contributed relatively more to the payment choice after the toll doubling.

The negative correlations between distance (and similarly for travel time and toll costs) with both the August and the change variable for I-PASS ownership may be surprising at first glance. It should be noted, however, that distance has a relatively strong negative correlation with the fraction of all workers that could use the tollway to get to work (ρ = -0.66) and median income ($\rho = -0.30$). On most commutes, the distance variable includes not only the distance spent on the tollway but also the distance in getting to the tollway or in getting from the tollway to work. It therefore appears likely that longer tollway distances are generally associated with zip codes that are actually quite far from the tollway and, hence, there is less demand for workers to use the tollway for work purposes (which translates into a smaller demand for I-PASS). Next, because the median income and distance variables have a significant negative correlation it suggests that lower income drivers are the ones making the longer distance commutes and were less likely to get I-PASS, especially initially.

Comparing the correlations of both periods' average share of I-PASS-only lanes for potential tollway users suggests that there has been relatively little supply effect in play. The negative correlations of the earlier period between I-PASS lane ratios and transponders ($\rho = -0.30$) can be explained by the fact that I-PASS lanes were first added to mainline plazas, which had lower *relative* use of I-PASS in August 2004 due to the diversity of users at these plazas.[31] Between periods, the I-PASS lane ratios for August 2004 and February 2005 have a slight negative correlation ($\rho = -0.08$) with each other, as most of the plazas that received IPASS lanes in July 2004 or earlier did not gain any by January 2005, while most of the plazas that had no IPASS lanes in July 2004 received at least one by January 2005.[32]

5.3 Summary tables by income groups

Given the primary importance of income, we next present summary statistics of the key variables in the I-PASS ownership decision broken out by income group. Specifically, we compare characteristics of zip codes that had median household incomes below \$60,000, between \$60,000 and \$80,000, and above \$80,000. As shown in Table 4, these three income subgroups respectively account for 152, 271, and 139 zip codes each with populations of 2.6, 3.4, and 2.4 million residents aged 16 and above, respectively. There are few surprises in this table: wealthier zip codes have substantially higher education levels, and their residents are somewhat more likely to drive to work.

Table 5 presents the driving habits of different income groups in somewhat starker terms. Although the higher income groups have a somewhat higher propensity to drive to work, the

[31] Mainline plazas are not entry or exit points but rather through points where tolls are collected. Plazas at on and off ramps are more likely to serve users from the distinct areas where they are located, whereas mainline plazas would likely have users from any area geographically preceding it, thus, a more diverse population. It is also likely that mainline plazas see a higher rate of longer distance, incidental travelers than on and off plazas.

[32] Around 70% of those plazas with no I-PASS lanes in July 2004, received at least one by January. Only 25% of those with at least one I-PASS lane in July 2004 received one more by January 2005. Overall, most plazas did not increase or decrease their total number of lanes.

breakdown between likely tollway and freeway travel is quite different. Among high-income zip residents, nearly 30 % would likely find it advantageous to commute to work via tollways (again, the likelihood is determined by their residential location and work destination vis-à-vis the toll road network). In contrast, the toll road choice would be appealing to only 11 % of lower-income zip residents. This difference reflects the strategic choice that many high income tollway users opt to live in neighborhoods close to the tollway and convenient for their workday commute.

<INSERT TABLES 4-5>

The upper panel of Table 6 lays out the distance traveled on a commute for these various income subgroups on the assumption that they use the toll roads. To derive these estimates from one zip code to another in the Chicago area, we sum the actual distance along the toll road to the straight line distance outside the toll road connecting the two zip codes.[33] Remarkably, our mapping of the tollway and census information suggests that the median driver in the lowest income group travels over 60 miles per day, while that in the 90th percentile of driving distance for that income group goes nearly 145 miles per day just to get to work and back! The disparities in total toll payments across income groups (the middle panel) are most pronounced at the tails of the distribution, as more drivers in the lower third of the income distribution tend to travel further to work and automatically hit more tolls. The bottom panel maps out the value of time across these income segments. As expected, the value of time per minute traveled increase as income increases but in a nonlinear fashion.

<INSERT TABLE 6>

Table 7 combines cost information from the tolls outlays we computed for the various zip pairs, commuting distance based on the current Federal Government rate of 40 cents a mile, and the estimated value of time.[34] Drivers in the high income group with the highest value of time have the shortest overall shorter commuting distances, which acts to even out overall costs at

[33] Here, as elsewhere in this paper, distance is measured from the centroid of the zip code to the centroid of the zip code.

[34] Small et al, [2005]. The government rate is a conservative estimate with the current American Automobile Association mileage rate now around 15 cents higher. Of the costs, depreciation is by far the largest, especially in the early part of a vehicles' life cycle. See Appendix A for a breakdown of these costs and more details on the assumptions underlying these cost calculations for a typical mid-sized car housed in downtown Chicago.

least roughly across the cost distribution, leaving a relatively flat spread across the income groups.

We now can combine both the implicit (the value of time) and explicit costs (depreciation, financing, fuel, insurance, maintenance, repairs, taxes & fees, and tolls), to determine the ratio of toll costs to total costs of driving. Table 8 summarizes this information on the assumption that the motorist possesses an I-PASS account. Even for the highest percentile shown in the table, the 90th, toll costs for the low income group constitute no more than 3.8% of total commuting costs.

Of course, tollway motorists who choose not to acquire an I-PASS transponder confront higher costs than those who do, compare Table 8 with Table 9. But the biggest difference between entries in these last two tables, which reflects the additional relative burden in percentage terms of the new toll structure on those who choose not to participate, is relatively small – just over 3%.

<INSERT TABLES 7 – 9 HERE>

Table 10 allows us to compare I-PASS ownership before and after the change in the price for cash tolls across income groups for five different population slices: the adult population, the number of workers, the number of motorists, the number of workers who would be likely to use the toll roads, and the number of motorists who would be likely to use the toll roads.[35] The results for these five (different) denominators basically parallel each other and thus for convenience we will focus on the likely toll road commuters. In August, 2004 before the increase in cash tolls, I-PASS penetration was quite high among the middle and high income groups with 81.3% and 116.6% of likely toll road commuters having I-PASS respectively. The low income group had somewhat less participation with only about 40% having an I-PASS account.

The dramatic relative price change on January 1 and public awareness campaign were sufficient to boost percentages across the income groups with I-PASS penetration among likely tollway drivers reaching almost 90 % of likely tollway users for the low-income group and exceeding 100 % in the more affluent neighborhoods. The results suggest that even in the lowest income zip codes, I-PASS ownership was basically sufficient to cover almost all likely toll

[35] Some workers live in an area where taking the tollway to work is an option. However, they report that they currently use some alternative transport medium such as light rail, train, or bus.

commuters (i.e. those that drive to work on the daily basis) after the price change. In contrast, there are many, many more I-PASS holders in the more affluent neighborhoods following the price change, suggesting the appeal of the electronic payments choice even for the occasional toll drivers in those areas. We interpret this as demonstrating that convenience of having an I-PASS transponder was an important consideration for them.

<INSERT TABLE 10>

5.4 Interpretation

These tables and maps loosely appear to tell the following story. Prior to the change in toll pricing structure, residents of higher-income zip codes (particularly those lying close to the tollway network) accounted for the lion's share of I-PASS accounts. These consumers used the tollway frequently, and thus had higher values for convenience and faster travel times, even in the absence of cost savings. Once the relative prices changed, I-PASS usage rates rose for consumers of all types. For drivers residing in low-income zip codes, the number of post-change I-PASS accounts nearly matched the number of likely commuters, while for higher income zip codes such accounts far surpassed the population likely to use them for daily work commute.

The questions that cannot be resolved with the simple bivariate contrasts presented in this section are: (1) did variables associated with the daily toll commute – distance, cost, and congestion – affect the payments choice either before or after the pricing change, and (2) whether different aspects of the pricing change – higher cash toll payments and exposure to advertising – had a differential effect on the payments choice of different income groups. These questions can only be entertained in a multivariate regression framework, which is the subject we now turn to.

6. Regression analysis of I-PASS ownership

6.1 The econometric model and variable selection

Since our dependent variable is expressed as a proportion of a zip code that owns I-PASS transponders, we naturally use a grouped logit estimator. Assuming that the proportion of I-PASS accounts to population 16 years or older, $(i/p)_z$, follows a logistic distribution (i.e. $(i/p)_z = \Lambda(\beta X_z)$, where Λ is the appropriate CDF, allows us to restate it as a log odds ratio, which is linear in the matrix of regressors X. The resulting regression specification takes the form:

$$\ln[(i/p)_z - (1-i/p)_z] = \beta X_z + \varepsilon_z \tag{7}$$

which is estimated by weighted least squares to account for heteroskedasticity induced by aggregating the data over geographic units with different characteristics. The weights are given by $[p_z \Lambda(\beta X_z)(1-\Lambda(\beta X_z))]^{1/2}$, where p_z is population in zip z, and $\Lambda(\beta X_z)$ is based on first-stage (OLS) estimates of β.

Based on the preceding discussion, the vector of explanatory variables X is broken into several subsets. The first group of regressors captures the proportion of households in a given zip code that fall into various annual income categories, \$15K-\$35K, \$35K-\$75K, \$75K-\$150K, and above \$150K, with households whose income is less than \$15K per year constituting the omitted category. The next subset is meant to capture the ease of learning about and acquiring I-PASS that stems from general education and familiarity with existing institutions and technology. It consists of the share of zip code's population with college degrees or higher, and of the share made up by recent immigrants. The following subset is also focused on gauging costs of participation in the I-PASS program and it includes the distance to the nearest I-PASS retail outlet, as well as the measure of I-PASS penetration in neighboring zip codes. All of these variables are applicable to the entire population of a zip code, and so they can be thought of as capturing a common component of I-PASS demand among all groups in (6).

The final subset of explanatory variables consists of the arguments of the I-PASS demand function for likely toll users that commute to work daily, as outlined in section 3.1. These variables are available only for workers, and hence would be applicable to the I-PASS demand function of commuters only.[36] Specifically, these variables include weighted averages of commuting time for likely toll drivers, of their estimated toll costs (estimated either in absolute terms or as a share of total commuting costs), and of the share of I-PASS-only lanes encountered along the commute route. While the last variable can be thought of as a measure of congestion, it also likely reflects the supply side of the I-PASS infrastructure. As suggested by equation (6), each of these regressors is multiplied by the share of likely toll commuters (n^t / p) to account for the fact that they capture only a part of total I-PASS demand.

[36] For commuters judged likely not to use tollways, the imputed cost and tollway congestion variables would be zero. Thus, their I-PASS demand would derive from characteristics unrelated to their work commute, similar to retirees, students, etc.

The model above is used to analyze the tollway payments choice under the "old", non-price-differentiated regime, as well as the choice to acquire the I-PASS after the pricing change went into effect. The null hypotheses outlined in section 3 form our benchmark for evaluating estimated regression coefficients.

6.2 The case of identical marginal prices for cash and I-PASS– August, 2004

The dependent variable in this case is defined as the number of I-PASS transponders registered in a given zip code in August 2004 normalized by the number of residents aged 16 and above in that zip code. We will refer to this variable as "I-PASS ownership rate". Table 11 presents the results from estimating (7) on the joint Census-Tollway Authority dataset.[37]

The first column shows the "base case" specification. We find strong positive effects of income on I-PASS ownership, as higher shares of zip code population in each income range above \$35K are associated with higher I-PASS penetration rates in August, 2004. We further find that zip codes with higher education levels have higher I-PASS penetration rates, even as we control for direct effects of income. Although this finding lends some support to the hypothesis of learning costs, we do not find any relationship for the share of population made up by recent immigrants for whom such costs would presumably be higher due to a number of language and institutional knowledge barriers. Still, other variables meant to gauge participation costs come in very strongly. In particular, all else equal, I-PASS penetration rates are higher for those living closer to I-PASS retail outlets (Jewel grocery stores) and those living "close" to zip codes with high I-PASS ownership. The latter result may reflect information spillovers from one's neighbors, but since our "neighborhood" variable is somewhat crude and is measured contemporaneously, we do not focus on it heavily.[38]

[37] Most of the explanatory variables are time-invariant, i.e. they are taken from the 2000 Census and are thus common to regressions explaining I-PASS ownership at either of the two dates for which we have data (August 2004 and February 2005). The few of the variables that could be obtained separately for 2004 and 2005 include: the share of I-PASS-only lanes along a commute route and I-PASS ownership at neighboring zip codes. Note that the first of these variables combines time-invariant origin-destination data from the Census with time-specific data from the Tollway Authority that reflects current lane configuration.

[38] One way to check for the importance of simultaneity is to run a regression for February, 2005 I-PASS ownership using August, 2004 "neighborhood ownership rates" as a control. This regression (not shown). produces effectively the same results, which is not surprising given the very high autocorrelation (0.98) in I-PASS penetration rates. Also, omitting the neighborhood I-PASS rates altogether does not have a qualitative effect on any of the estimated coefficients.

For the subset of "tollway travel" variables we find higher I-PASS ownership for residents of zip codes that face longer commutes to work, as well as for those with commuting routes more heavily saturated with I-PASS-only gates. All this lines up well with the hypotheses outlined in section 3. Interestingly, the only "tollway travel" variable not found to affect I-PASS choice in August 2004 is toll costs. Since at that time there was no cost differential between electronic and cash toll payments, toll outlays would not have been expected to play a role in I-PASS acquisition decision.

The base case regression explains a significant amount of variation in I-PASS ownership prior to the pricing change, with the R-squared value of 0.83. Although high R-squared values are not unusual in grouped data settings that suppress within-group variation, the general consistency of estimated coefficients with predictions of a simple economic model is comforting.

All of the significant variables in the "base case" specification are significant at the one percent level or better. However, in order to address their economic significance, we need to obtain estimates of their marginal effects on I-PASS ownership. It is difficult to interpret the magnitude of reported coefficients as marginal effects of X on the probability of I-PASS ownership since the dependent variable is a non-linear function of this probability. One common choice is to report exponentiated coefficients e^{β} as marginal effects for the odds-ratio of I-PASS ownership. However, we choose to estimate these effects at mean values of X by using

$$\frac{\partial E[I-PASS\ rate_z \mid X_z]}{\partial X} = \Lambda(\beta X_z)(1-\Lambda(\beta X_z))\beta$$

The strongest marginal effect derives from zip code concentration in the \$75K-\$150K range. A zip code that consists of 29 % of such households (75th percentile value) is estimated to have a 5% higher I-PASS ownership rate than a zip code in which only 14% of households fall in this income range (25th percentile value). At a first glance, a 5% increase may seem insignificant, but one needs to keep in mind that the unconditional mean of I-PASS ownership as a *fraction of population* over the age of 16 amounted to only 11.9% in August, 2004.[39] Relative to this benchmark, the estimated effects of moving from one end of the interquartile range to the other are as follows: education (+ 1.8 %), commute time (+3.8 %), share of I-PASS-only lanes (+0.8 %), distance to nearest Jewel store (-1.9 %), and share of I-PASS penetration rates in

[39] Recall that the much higher figures of 40-45 percent I-PASS usage prior to the pricing change referred to the share of all *tollway traffic* paying tolls electronically. Clearly, tollway users represent only a small fraction of population over 16.

neighboring zip codes (+1.8 %). Thus, the key variables appear to have economic not just statistical significance.

We also consider some modifications of the base case formulation. As mentioned in section 3.1, likely tollway users that drive to work daily may have a different I-PASS demand function than commuters that may only drive to work on occasion. To entertain this possibility, we use commuter I-PASS demand variables that are defined only for current drivers and weight them by the share of such drivers in the populations $(n^{d,t} / p)$. The demand of commuters that may use tollways only occasionally is proxied by the share of such drivers in the population. The results of this formulation are shown in column (2) of table 11. Both the magnitude and significance level of the estimated coefficients are very similar to the "base case". The share of occasional drivers in the population was not found to have a statistically measurable effect on I-PASS ownership, suggesting a limited role for I-PASS usage by such drivers prior to the pricing change.

Finally, we estimate the base case specification on a subset of zip codes that constitute the "greater Chicago" area. Our definition of "greater Chicago" is rather informal, as it simply encompasses the six counties surrounding Cook County, where the City of Chicago is located. Drivers residing outside of this area may differ on a number of dimensions. Importantly, fewer of them work in or near Chicago and thus they rarely encounter the heavy congestion experienced by urban and suburban drivers. They also have to pass fewer tolls gates on their commute, suggesting a somewhat lower value for electronic toll payment. The results in column (3) of table 11 suggest that the only difference from eliminating these distant zip codes is the disappearance of proximity to Jewel stores as an explanatory factor. Jewel stores are fairly uniformly distributed throughout the "greater Chicago" area and thus proximity to them does not help differentiate zip code demand for I-PASS. This result suggests the possibility that the negative coefficient on distance to a Jewel store in the base case formulation confounds the effects of lower I-PASS demand on part of drivers outside of the "greater Chicago" area with the higher cost of obtaining an I-PASS transponder.

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6.3 The pricing experiment: doubling of cash tolls together with a public awareness campaign

We choose to focus on the change in I-PASS ownership for our analysis of the effects of the pricing change.[40] Given the overriding importance of income in the preceding analysis, we estimate the regressions of change in I-PASS on three distinct income subsamples used in the earlier tables and presented in Map 3. To restate, the new pricing regime had two distinguishing characteristics: a dramatic change in relative prices for cash and electronic payments and a widespread public awareness campaign that presumably lowered participation costs for I-PASS acquisition.[41] We are interested in whether these two effects had different (or any) effects for payments choice in each of the income groups. Given the very high rates of I-PASS participation among residents of wealthy zip codes (see Table 10) prior to the change and the parallel shift in ownership thereafter, we hypothesize that the incremental demand for these zip codes derived from incidental tollway users who were attracted by the convenience of I-PASS use *and* acquisition. In contrast, we would expect the residents of "low-income" zip codes, whose use of I-PASS was much less common prior to the change to be affected by the cost of the cash toll hike.

The regression results, presented in Table 12, help to illuminate these hypotheses. Even though we form the subsamples on the basis of median household income, nearly every zip code contains households in each of the income categories. For all three income groups, the effects of income distribution are quite uneven and typically not statistically significant. Among households in wealthier zip codes, the income distribution is not found to have any effect on the *change* in I-PASS ownership after the price change. For households in low-income zip codes, the coefficient of the fraction in the top income category stands out, largely because there are very few such households (1.5 %) residing in these zips. Also in contrast with the earlier results, there is no evidence of a relationship between education levels and I-PASS ownership for any of the income subsamples.

[40] We also estimated the same three specifications for I-PASS ownership rate in February 2005, following the pricing change. However, given the high autocorrelation in I-PASS ownership and the fact that most of our regressors do not vary with time (since they are derived from the 2000 Census data), the results are very close to those reported in the previous section.

[41] The public awareness campaign made it easy to acquire information about the features of I-PASS accounts and to learn about Tollway Authority plans for changes in lane configurations that favor electronic payments. The campaign also made obvious the large *relative* difference in toll prices, with the words "twice as much" and "double the cost" featuring prominently in media coverage of the impending change

The other variables associated with participation costs are neighborhood effects and proximity to an I-PASS retail outlet. We find strong evidence that I-PASS ownership rates in neighboring zip codes had a positive effect on the increase in I-PASS use. Moreover, the magnitude of this effect is relatively stronger for low- and medium-income zip-codes, suggesting a possibility of stronger informal spillover effects there. Interestingly, the proximity to a Jewel grocery store is estimated to have an effect on the change in I-PASS ownership only in medium- and high-income zip codes.

In contrast, the doubling of cash tolls per se generated a statistically significant response only among residents of low-income zip codes. The comparison of coefficients on "average toll costs" across the three income groups in Table 12 reveals a strong positive effect of toll costs on *incremental* I-PASS ownership for low-income zip codes and virtually no effect for the other two income categories. Neither travel time nor the share of I-PASS-only gates has a consistent effect on incremental I-PASS ownership.

In sum, we find some evidence that, on average, low-income neighborhoods responded to the cost doubling aspect of the toll pricing change while medium- and high-income neighborhoods were affected by the convenience of I-PASS acquisition through heavily advertised retail outlets. This is consistent with the picture presented in summary tables, where the number of I-PASS accounts relative to the number of likely regular tollway users (i.e. commuters) was extremely high in wealthy zip codes even prior to the price change. Consequently, incremental I-PASS use could only have come from more occasional users that responded to the public awareness campaign. This hypothesis receives additional support from the strong positive coefficient on the share of occasional toll users in column 3 (high-income category) and a negative and insignificant coefficient on this regressor in column 1 (low-income category). I-PASS ownership in low-income zip codes also rose to include nearly all regular tollway users, who were apparently held back by high participation costs (whether real or perceived) and who were faced with the prospect of doubling of nominal toll outlays if they continued to shun the electronic payment option.

7. Conclusion

The Illinois Tollway authority had reached a leveling off of usage in its electronic payment system, called I-PASS, in the summer of 2004 before adopting a new toll schedule that penalized cash payment at the beginning of 2005. While in nominal terms the tolls were doubled for cash, as a percent of overall explicit and implicit outlays for autos, the toll hike was relatively small. In fact it was on the order of 3 % or so for the group most affected according to our estimates. Nonetheless, that change induced a very broad spectrum of drivers to switch to electronic payment. Without more detailed information on those who use the tollroads but continue to pay with currency, it is difficult to know how to convert a significant proportion of the remaining drivers to I-PASS, at least without further substantial increase in relative costs.

However, we find that in terms of the likely tollway users, participation among the three different income groups we consider nearly reached or exceeded nearly 100 %. Indeed it exceeded this "full buy-in" level for the more affluent income groups. This latter usage reflects occasional use, which is more important in more affluent neighborhoods in part because they are frequently located relatively near to the tollway. A variety of evidence suggests that income was an important determinant of I-PASS ownership. The regression evidence suggests that cost was a consideration for the low income group but not for the more affluent groups. The latter were influenced by the ease of getting I-PASS. Supply-side availability of I-PASS only affected the middle income group. From a payment perspective, the new toll schedule worked in reducing congestion, though the benefits on that side of the ledger are more forward looking as the Tollway authority completes the lane configurations for open-road tolling. Finally, the changes allowed the authority to eliminate some attendants and the direct costs of handling thousands of dollars of coins daily.

Appendix A: The True Cost to Own a 2006 Chevy Malibu (LT 4dr Sedan (2.2L 4cyl 4A)

According to www.Edmunds.com it costs 45 cents per mile for someone living in zip code 60601 in downtown Chicago near Navy Pier to drive a 2006 Chevy Malibu (LT 4dr Sedan (2.2L 4cyl 4A). The cost per mile is computed by averaging the estimated costs (exclusive of tolls and the value of time) over a five-year period by an average of 15,000 miles driven per year. Adjusting for somewhat higher fuel costs recently or to taking the present value rather than average will have only small effects on these estimates. For example, at a 5 percent discount rate, the cost per mile would be 41.6 cents. If fuel were to double in price, the cost per mile would increase by 9 cents in present value terms. Finally, if a car were five years old, the cost per mile would drop by 8 cents a mile to 37 cents per mile.

COST	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	5-YR TOTAL
Depreciation	$6,483	$1,838	$1,617	$1,433	$1,286	$12,657
Financing	$1,100	$885	$655	$410	$148	$3,198
Insurance	$795	$823	$852	$882	$913	$4,265
Taxes & Fees	$1,438	$78	$78	$78	$78	$1,750
Fuel	$1,472	$1,516	$1,561	$1,608	$1,656	$7,813
Maintenance	$352	$565	$431	$962	$1,082	$3,392
Repairs	$0	$0	$113	$272	$397	$782
Tolls	672	672	672	672	672	$3,360
Yearly Totals	$12,313	$6,377	$5,979	$6,317	$6,232	$37,217

Appendix B. Converting the lane choice model to an econometric model: an illustrative example

To map the simple framework of equation (5) in section 3 to data, one needs to assume a specific functional form for preferences. As an example, we analyze the CES preference specification.[42] Let the I-PASS choice correspond to a cost and time pair $\{t_T, c_T\}$. Suppose that commuting costs c_T consist of a fixed setup cost (F), opportunity or carry cost (O), marginal per plaza cost (m_T), and the number of toll gates taken over the unit of time in our analysis (N). Moreover, assume that setup costs are a function of individual's demographics, such as education level and/or access to low-cost subscription technologies, such as the Internet.

Then for the I-PASS transponder choice T of individual i, equation (3) becomes

$$G_{i,T} = V_i + w_i \cdot H_i - O - F(E_i, w_i) - N_i \cdot m_T \qquad \text{(3T)}$$

where the fixed costs F are a function of education E_i and wages w_i

And for the other two lane choices, the exact-change or attendant lanes, (3) becomes

$$G_{i,e} = V_i + w_i \cdot H_i - N_i \cdot m_T \qquad \text{(3E/A)}$$

It also does not seem unreasonable to assume that for many the time spent at work is an increasing function of wage. For example, salaried employees in at least some professional occupations (e.g. consultants, attorneys, and architects) are more often required to work longer hours or put forth a greater intensity of effort. Under this assumption, and keeping in mind that both w and H are exogenous, we can restate (2) and (3) as

$$L_{i,T} = (24 \cdot 60) - H(w_i) - N_i \cdot t_T \cdot L \qquad \text{(2T)}$$

$$G_{i,T} = V_i + w_i \cdot H_i - O - F(E_i, w_i) - N_i \cdot m_T \qquad \text{(3T)}$$

Let the constant elasticity of substitution (CES) utility be given by:

$$U(G, L) = [G^{-\rho} + h \cdot L^{-\rho}]^{-1/\rho},$$

where h is the relative price of leisure (G is a numeraire), and the elasticity of substitution between consumption and leisure is $1/(1+\rho)$. To introduce uncertainty in this preference framework, assume that h is measured with a multiplicative error ε, which is lognormally

[42] Other preference specifications would produce the same qualitative predictions, but differ in terms of the economic interpretation of the coefficients.

distributed.[43] Using (5), the probability of signing up for an I-PASS, which costs more but saves on travel time, is equivalent to:

$$prob\left(U_L \geq -c'(t)\cdot U_G\right) = prob\left(h\cdot \varepsilon L^{-\rho-1} \geq -c'(t)G^{-\rho-1}\right) =$$
$$prob\left(-\ln(h) + (1+\rho)\ln(L/G) + \ln(-c'(t) \leq \ln\varepsilon\right)$$

Using the expressions for L, G, and $c(t)$ from (2T) and (3T) and approximating $c'(t)$ by Δc, we obtain:

$$prob\left(I - PASS\ chosen\ over\ other\ alternatives\right) =$$
$$prob\begin{pmatrix} -\ln(h) + \ln\left(O + F(E_i, w_i) + N(m_T - m_e)\right) + \\ (1+\rho)\ln\left([(24\cdot 60) - H(w_i) - N_i\cdot t_T]/[V_i + Hw_i - O - F(E_i,w_i) - N_i\cdot m_T]\right) \leq \ln\varepsilon \end{pmatrix} \quad (*T)$$

The discussion above focused on the choice between the I-PASS and a *single* alternative (say, the exact-change toll). Consequently, the binary specification in (*T) can be estimated in a simple logit framework, using an estimator adjusted for grouped data. The major advantage of this approach is that it allows us to simplify the machinery for empirical analysis considerably while still being able to identify parameters of interest.

[43] Alternatively, we can assume that G and/or L are measured with error. A prime candidate for measurement errors is participation costs *F*, many of which are implicit.

Appendix C. Constructing zip code measures for daily commutes and toll / freeway choice

The Census provides detailed information on home to work commutes at the census *tract* level, a geographical unit that is much smaller in size than a zip code. Census tracts are not necessarily fully contained in a given zip code but can overlap one or more zip codes. Furthermore, a zip code in our sample generally contains several or parts of several census tracts. These overlaps present the obvious problem of ascertaining how to equate the census tract data to zip code level data.

In order to transform this data from census tract to zip code, we employed the mapping software, Maptitude. From this software we were able to obtain the proportion of each census tract in each of the zip codes that it overlaps. Because we did not know how the worker population is geographically distributed over a given census tract, we made the simplifying assumption that they were evenly distributed.[44] This assumption allowed us to cleanly allocate workers in a given census tract to each of its corresponding zip codes by the proportions of their relationships. Since the data comes in pairs relating to a commute pattern, this allocation must be performed for both the origin and destination census tract/zip code relationship. Once all of the workers of these census tract commute pairs were assigned proportionally to zip code commute pairs, the worker data can be summed up by unique zip code pairs. We then calculated a weighted-average of travel time and income using the proportion that the original worker data, detailed by census tract pairs, makes up of the total worker data, detailed by corresponding zip code pairs. In the end, we know who goes to work where, whether they drive there, how much time it takes, and how much money they earn by zip codes. At this point, we do not know, however, what path they take to get there.

Since the tollway is the focus of our study, we needed to find a way to determine whether it would be reasonable for a commuter to take the tollway to work. We decided to first determine what a tollway trip would entail for each zip code of residence going to all zip codes within our sample. Again, Maptitude was used to assist in this determination. First, we used Maptitude to create a file that contained the longitude and latitude of the center points of all zip codes in our

[44] We applied the following methodology individually for all workers regardless of their means of transportation and for those workers that drive. The difference between these variables allowed us to know who goes between these points but does not drive. It is reasonable to assume that these commuters do drive on occasion and therefore are of interest as incidental driving commuters.

sample. From this file, we were able to determine the distance as the crow flies between all of our zip code pairs and what direction the destination is from the origin.

Next, Mapitude includes a point layer that details the longitude and latitude of all exits on all highways as well as toll plaza points on tollways.[45] Selecting only those that correspond to the Illinois Tollway system, we merged them with information from the Tollway's website detailing which of these points allow a vehicle to get on or off the tollway and in what direction. The above file on zip code geography was matched to the exit file. We then selected the two closest on ramps to each origin zip code and the two closest off ramps to each destination zip code that allowed the commuter to go in the direction of their commute. Next, we summed up the distance from the center point of the origin zip code to the entry point, the distance between all points on the path between the entry and exit points on the tollway, and the distance from the exit point to the center point of the destination zip code, giving us the total distance of the tollway commute. Since we did this for each of the entry-exit point combinations, we determined up to four unique paths.[46] We then picked the shortest commute pattern for each zip pairing using the tollway.

While this allows us to know how a commuter living in one zip code and working in another would travel to work using the tollway, we still did not know whether they were likely to take this path or dive on a more convenient roadways at their disposal. To resolve this unknown, we need a model of tollway versus roadway choice. Clearly, commuters living greater distances from the tollway are less likely to use the tollway as their commuting venue than those living closer. After a variety of trial and error calculations, we decided to exclude zip codes that were more than 40 miles from the toll road. For those driving to work and living within a 40-mile radius, however, it would still not necessarily be economical to use the toll road if the time spent on other non-tollway roads was sufficiently shorter. But distance alone is not the only consideration: More direct routes would entail less driving but would often include more congestion with more stop-and-go driving —and perhaps with motorists encountering a greater number of irritations along the way in the course of numerous daily roundtrip commutes.

[45] In many cases, exits and toll plazas are the same points. There are numerous exits that do not have toll plazas. Also, there are toll plazas at points along the tollway that are not exits, but simply collection points.

[46] In cases where the origin zip code is closest to a tollway that does not intersect with the tollway to which the destination zip code is closest, the commute was deemed impossible given these exit pairings. Therefore, there would not be four unique commuting patterns in these cases. The chance of this occurring is what led us to find up to four commuting possibilities, with the hope of getting at least one possible tollway commuting path. If all four paths are determined impossible, we assumed that the commuter does not take the tollway to get to work.

To account for these possibilities, we settled on a simple geometric metric to determine whether the tollway was a feasible choice or not. If the distance of the straight line (as the crow flies) between the A and B zip centroids, say, $\overrightarrow{AB}_{cf}$, was at least 65 percent of the distance from the center of zip code A to zip code B using the tollway, $\overrightarrow{AB}_{tw}$, that is,

$$\overrightarrow{AB}_{cf} > 0.65 * \overrightarrow{AB}_{tw}$$

then the motorist would use the tollway, otherwise the motorist would not. Said another way, it was assumed that in a populated area like greater Chicagoland, there would be another route between the two points, while likely slower, that would take less than the tollway travel time if the tollway route is more than about 1.5 times the direct distance.

We verified the robustness of this cutoff primarily through the following two methods. First, the Tollway provided us with results of an origin and destination survey that they conducted in November 2003 on a section of the Interstate-88 (I-88) tollway. This survey detailed the purpose of a given trip for the traveler, the zip codes of where each trip started and ended, and the type of vehicle driven. All of those surveyed were either using the tollway on the day of the survey or held IPASS accounts that showed transactions at the plazas of interest on I-88; hence, all were tollway users.[47] We used this information to apply our geometric metric. We looked at all of those surveyed of whom the purpose of their journey was commuting to work driving a passenger vehicle. Of these, less than 15% had a distance ratio (described earlier) of below 65%.[48]

Next, we chose a random sample of 20 out of our distance-zip pairing data from our full sample of 165,600 pairs, 10 with values below 0.65 and 10 with values greater than or equal to 0.65. Using the three main websites that motorists tend to depend on for driving directions on the Internet, Yahoo Maps, MapQuest, and Google Maps, we queried the suggested courses between the pairs. The following table describes the results.

In the table below, a one was recorded if the site suggested driving on an Illinois toll road, 0 if it did not. As the table shows, the results do not perfectly align with where the distance

[47] Supply footnote on survey.

[48] We did not feel it was necessary to choose a distance ratio cutoff that represented more than 85% of the sample, allowing for the idea that there are some drivers who do not make rational choices and are not representative of our entire sample.

ratio falls relative to the 0.65 cutoff ratio we have selected. But the match up is pretty close with three relatively minor exceptions. [49]

Appendix Table C

Zip-A	Zip-B	Crow flies (miles)	Toll distance (miles)	Distance ratio	Yahoo	MapQuest	Google	$\sum$ [50]	
60108	60106	7.36	23.54	0.31	0	0	0	0	
60402	60805	8.85	25.73	0.34	0	0	0	0	
60548	61341	21.93	54.25	0.40	0	0	0	0	
60618	60093	11.27	23.84	0.47	0	0	0	0	
60647	60462	21.64	44.62	0.48	0	0	0	0	
61072	53402	71.85	138.45	0.52	0	0	0	0	
60151	60407	50.52	88.71	0.57	0	0	0	0	
60060	53576	65.96	115.31	0.57	0	0	0	0	
46405	60609	26.12	43.79	0.60	0	0	0	0	
60048	60520	50.97	84.40	0.60	1	1	1	3	**cutoff**
60504	60070	28.70	43.81	0.65	1	1	1	3	
60463	60077	26.05	38.44	0.68	0	0	0	0	
60565	53128	56.84	81.62	0.70	1	1	1	3	
46409	60077	40.48	56.24	0.72	0	0	0	0	
60135	60480	49.17	64.82	0.76	1	1	1	3	
53195	60643	70.76	92.72	0.76	1	1	1	3	
60043	61314	115.59	150.79	0.77	1	1	1	3	
61354	60641	84.18	105.53	0.80	1	1	1	3	
60425	61378	80.95	98.99	0.82	1	1	1	3	
60613	61114	72.67	77.82	0.93	1	1	1	3	

[49] The mapping websites suggested only one observation falling below the 0.65 cutoff ratio, which we would assign exclusively to the roadway, but the maps assign to the tollway. They also found two lying above the cutoff ratio that we would have classified as using the tollway. One of which we have only using the tollway for a minimal portion of their trip.

[50] In some cases the routes suggested by the mapping sites include the Gary tollway, since this is not a tollway in our sample, it is not counted.

Appendix D: Survey Information on reasons why Tollway drivers do not have I-PASS and what would convince them to get it.

In late November and early December of 2004, just before the price hike, surveys were distributed to tollway users at five locations: one plaza each on the North-South and the Tri-State Tollways and three locations around I-55, which lies near to the Tollway. The survey collected information about the origin and destination of a particular trip, purpose of the trip, trip frequency, vehicle occupancy, and vehicle type. Respondents were asked whether they owned I-PASS. Those that did not own I-PASS, were asked two final survey questions: 1) why have you not purchased I-PASS and 2) what would convince you to purchase I-PASS? Respondents were allowed to choose from a provided list of multiple choice answers or substitute their own answer if the multiple choice categories did not represent their own beliefs.[51]

The predominant response to the first question (why have you not purchased I-PASS?) was that the respondent had not (yet) made the effort. One interpretation for this response is that the majority of those surveyed did intend to purchase I-PASS, but were late responders. Recall that the toll price hike was scheduled to go *into effect a few weeks later*. Breaking the responses out into three groups according to frequency of trips per week, those that made more than one trip per week still answered that summoning up the effort to get a transponder was the main inhibitor. While this answer was the second most popular answer for those that traveled less frequently than weekly, they most often answered that they have not purchased an I-PASS because they rarely used the tollway. In over a fifth of overall number of responses, respondents wrote in their own answers. Of these, privacy was by far the most cited reason for the hesitation or refusal to purchase I-PASS.[52]

The majority of the responses to the second question (what would convince you to get an I-PASS?), match up well with the basic findings of our research. Namely, most drivers answered that would purchase I-PASS to avoid paying higher tolls. More importantly, this response held across all motorists in terms of frequency of trips, suggesting that further penetration of I-PASS

[51] In many cases, respondents provided more than one answer. As a result, there were over 50% more responses than there were respondents.

[52] I-PASS records can be subpoenaed in both civil and criminal court proceedings. Some respondents were worried that their individual travel information could be used against them. In particular, they speculated that it could be used to fine them for speeding on the tollway.

was likely to happen across all groups of tollway motorists (at least in terms of frequency of tollway use). Over a fifth of the responses to this second question also added their own written response to this question, which we plan to analyze in subsequent work.

Figure 1: Sales Sources and Volumes

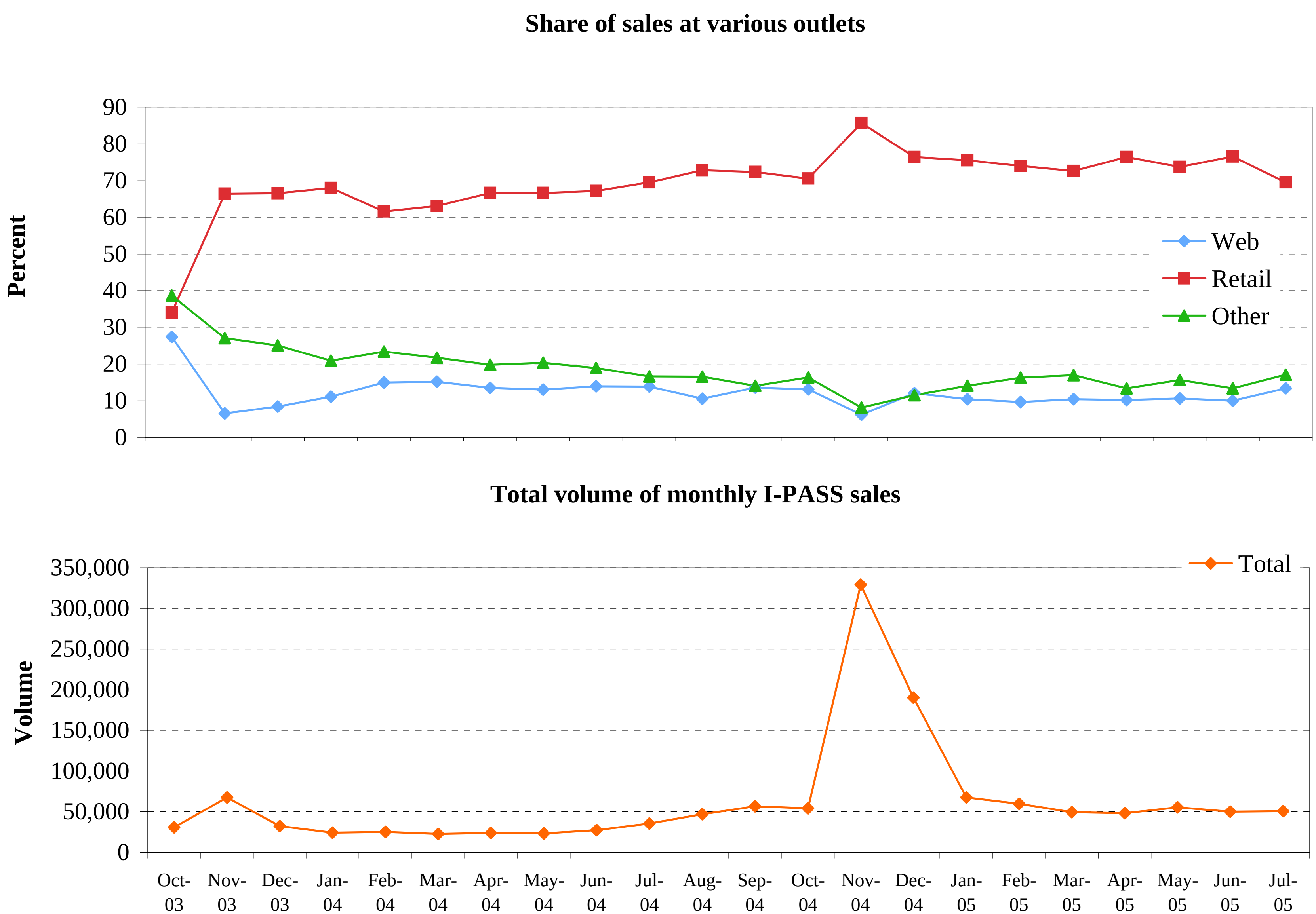
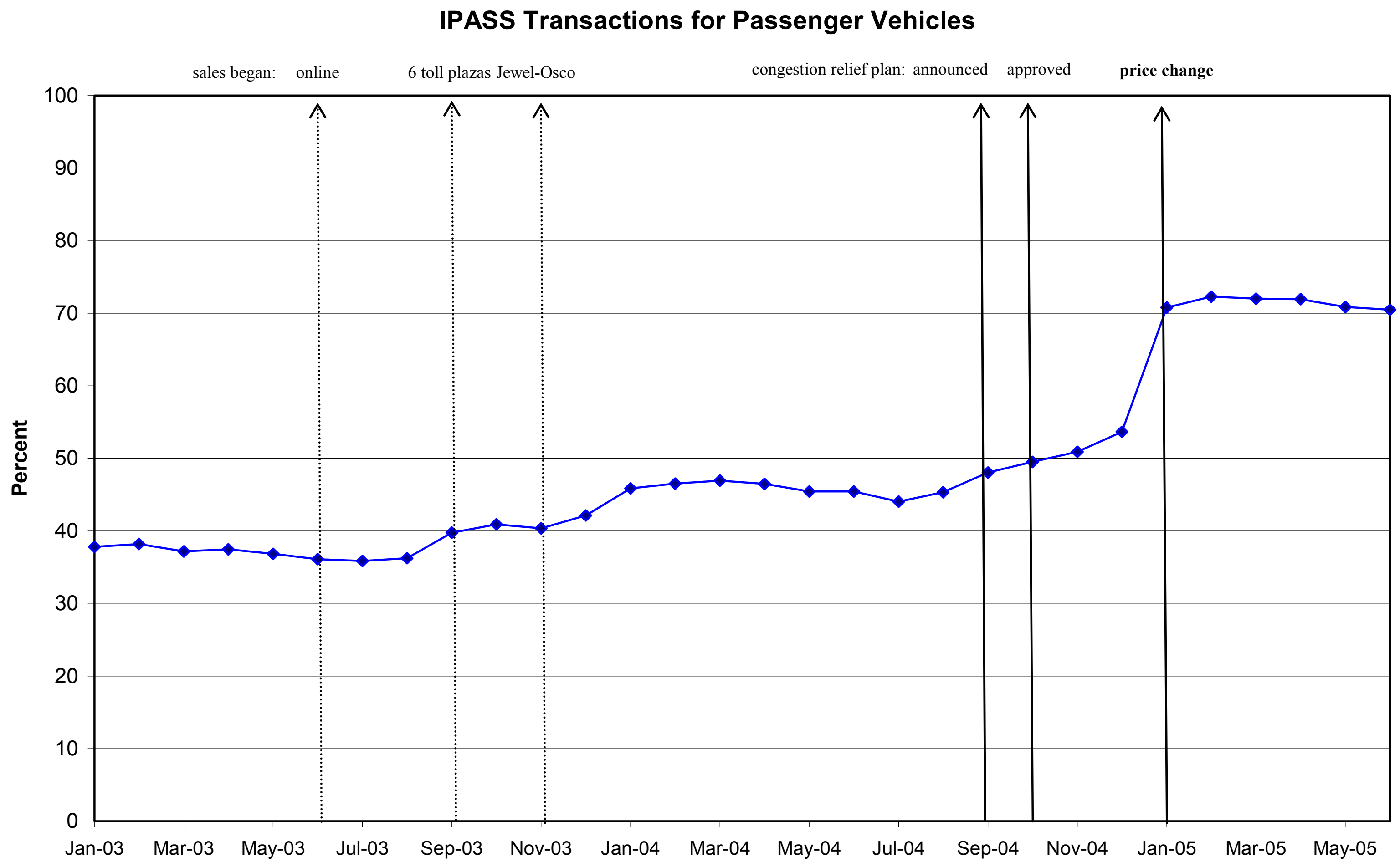


Figure 2: Increase in I-PASS usage, before and after cash toll price increase



Source: *Illinois Tollway Authority*
Notes: 1) Excludes Plaza 3 after 2003 due to measurement issues; 2) Data reflects only passenger vehicles without trailers (class 1)

Figure 3: Composition of trip purpose by time of day (mail-out survey respondents)

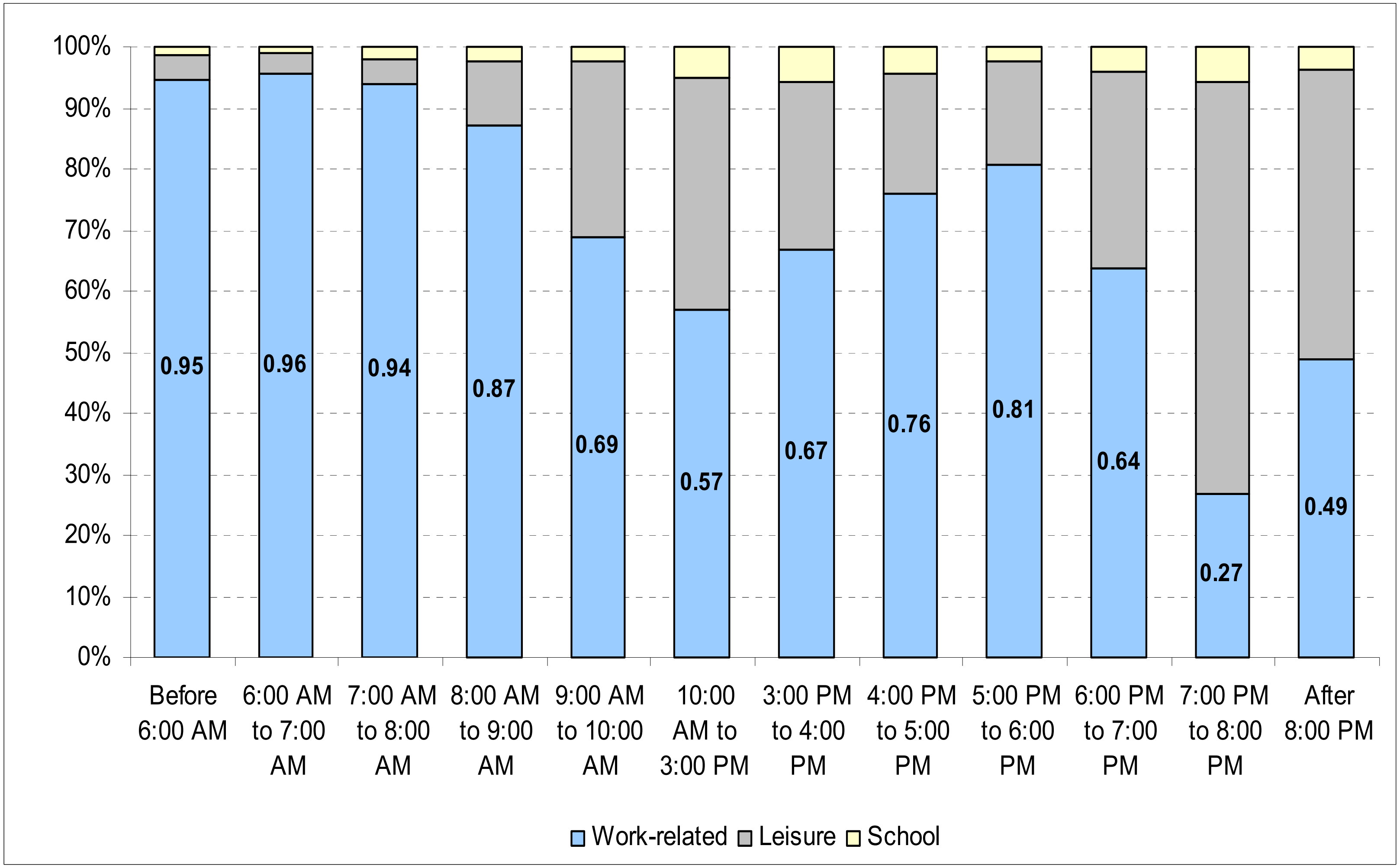
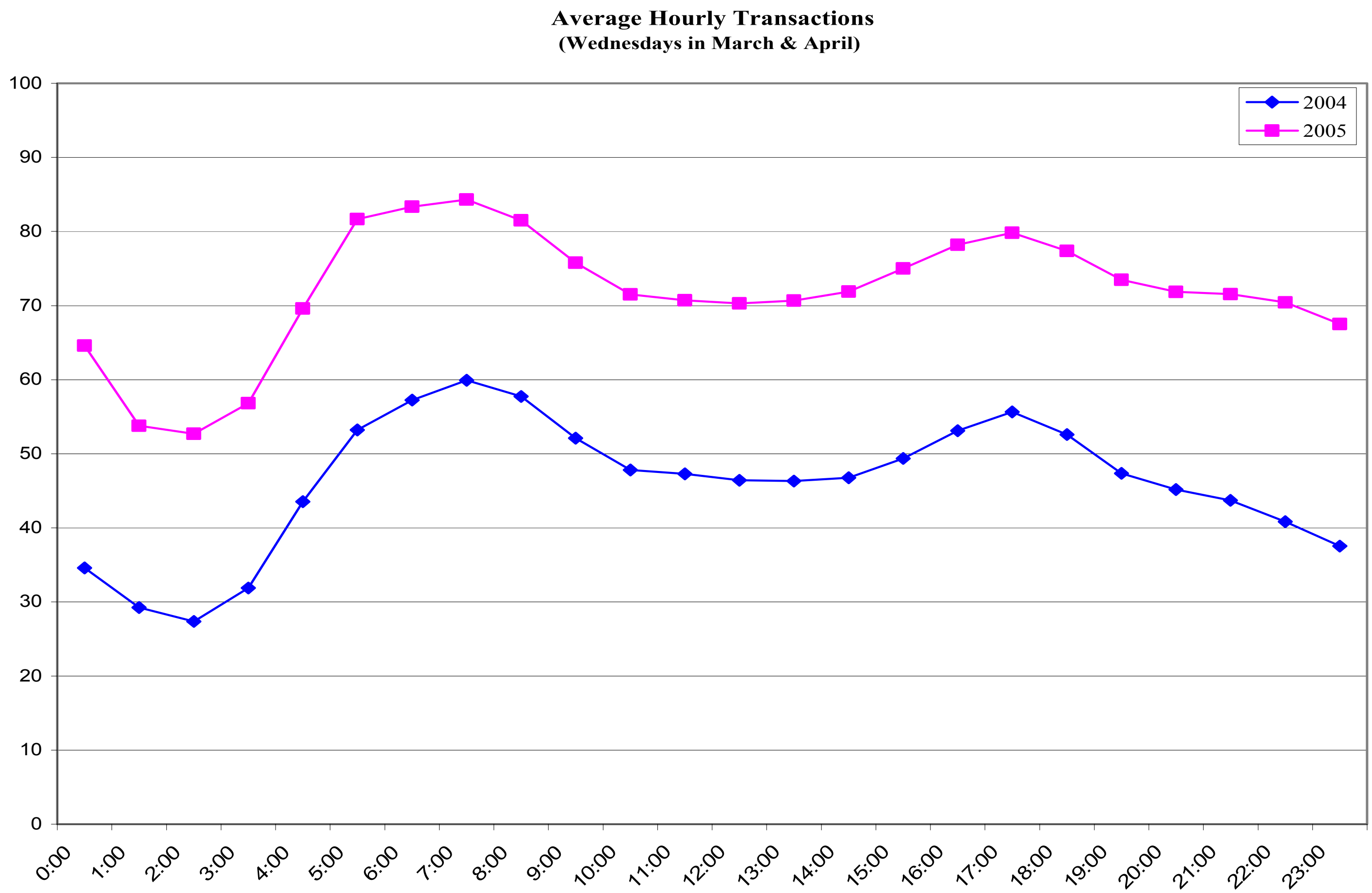
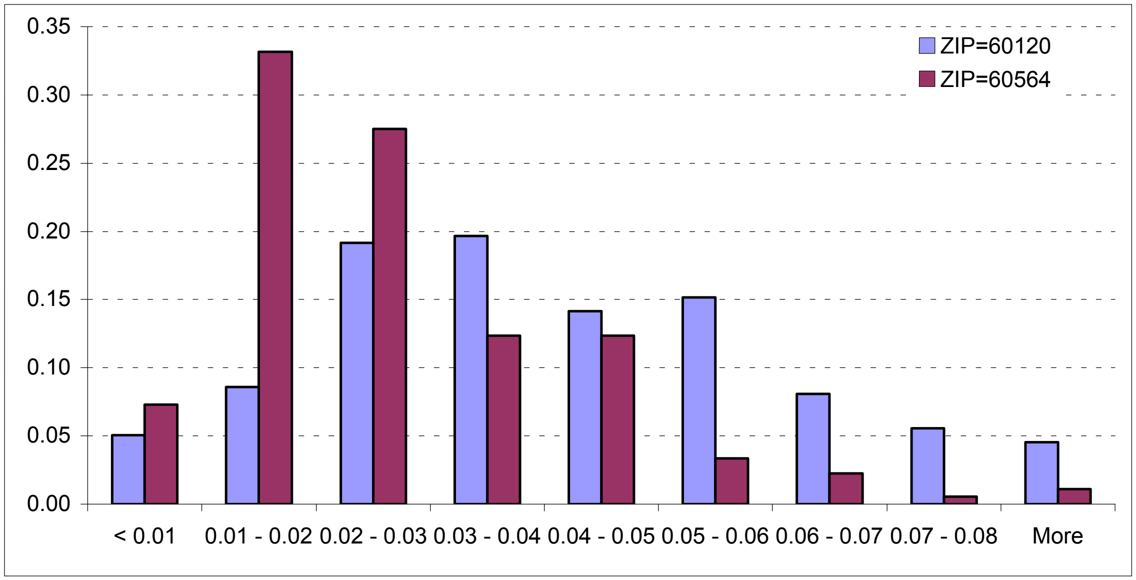


Figure 4: I-PASS usage over twenty-four hour day, 2004 and 2005



Source: *Illinois Tollway Authority*
Notes: 1) Excludes Plaza 3 due to measurement issues; 2) Data reflects only passenger vehicles without trailers (class 1)

Figure 5: Distribution of the (Toll payments / Total commuting cost) ratio within two zip codes (zip 60564 is "affluent", zip code 60120 is less so)



Source: Illinois Tollway Authority.

Table 1: Parallel shift in I-PASS usage following the pricing change

Interval	*Change in I-PASS usage from March-April 2004 to March-April 2005, Wednesday observations, percentage points*
Midnight to 6 AM	27.8
Morning Rush Hour 6 AM to 9 AM	24.7
9 AM to 4 PM	24.4
Evening Rush Hour 4PM to 7PM	24.7
7 PM to midnight	27.6

Table 2. Distribution of commuting costs following the pricing change

toll costs (annual)	10th pct.	25th pct.	median	75th pct.	90th pct.
pay with I-PASS	$ 197	$ 234	$ 303	$ 420	$ 629
pay cash	$ 394	$ 468	$ 606	$ 839	$ 1,258
total commuting costs (annual)					
get I-PASS	$ 9,243	$ 11,777	$ 16,098	$ 19,937	$ 21,612
pay cash	$ 9,379	$ 11,975	$ 16,337	$ 20,374	$ 22,070
share of tolls in total costs (annual)					
get I-PASS	1.2%	1.6%	2.1%	2.6%	3.4%
pay cash	2.4%	3.2%	4.0%	5.1%	6.5%

Table 3: Correlations

	N_1	N_2	ΔN	*Median HH income*	*Fraction with college or more*	*Fraction that are recent immigr-ants (<5yrs in U.S.)*	*Fraction of all workers that could use the tollway to get to work*	*Fraction of all drivers that could use the tollway to get to work*	*Avg. IPASS tolls for workers that are potential toll users*	*Avg.. tollway distance to work for potential toll users*	*Avg. solo drive time on tollway for potential toll users*	*Avg. share of IPASS only lanes on tollway routes for potential toll users (Jul04)*	*Avg. share of IPASS only lanes on tollway routes for potential toll users (Jan05)*	*Avg. imputed value of time*	*Avg. total commute costs in scenario R0 for potential toll drivers*	*Avg. share of total commute costs in scenario R0 contribute d by tolls*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
(1)	1															
(2)	0.98	1														
(3)	0.84	0.93	1													
(4)	0.65	0.64	0.54	1												
(5)	0.61	0.58	0.46	0.73	1											
(6)	0.12	0.14	0.17	-0.06	0.13	1										
(7)	0.78	0.77	0.67	0.43	0.37	0.25	1									
(8)	0.76	0.75	0.66	0.40	0.33	0.25	0.99	1								
(9)	-0.35	-0.36	-0.35	-0.19	-0.26	-0.34	-0.47	-0.47	1							
(10)	-0.52	-0.54	-0.51	-0.30	-0.37	-0.40	-0.66	-0.67	0.83	1						
(11)	-0.38	-0.39	-0.38	-0.14	-0.22	-0.36	-0.50	-0.50	0.48	0.61	1					
(12)	-0.30	-0.30	-0.26	-0.26	-0.21	-0.18	-0.33	-0.33	0.52	0.35	0.22	1				
(13)	0.10	0.09	0.05	0.12	0.13	0.04	0.09	0.09	0.17	0.00	0.02	-0.08	1			
(14)	0.51	0.50	0.43	0.64	0.54	0.03	0.43	0.41	-0.50	-0.61	-0.20	-0.22	0.13	1		
(15)	-0.28	-0.30	-0.31	0.06	-0.11	-0.47	-0.48	-0.49	0.52	0.61	0.84	0.25	0.07	0.09	1	
(16)	0.04	0.04	0.04	-0.11	-0.08	0.08	0.14	0.14	0.45	0.05	0.01	0.44	0.28	-0.27	-0.07	1

Footnotes to correlation table.

(1) N_1 = number of I-PASS accounts in August 2004.

(2) N_2 = number of I-PASS accounts in February 2005.

(3) $\Delta N = N_2 - N_1$

(4) HH = household

(5) All population shares are taken with respect to total population >16 years living in a zip code.

(7) All worker shares are taken with respect to total worker population in a zip code based on the tract-to-tract Census transportation survey

(8) Drivers are defined as workers that currently commute to work by driving either solo or in a carpool.

(9) Potential toll users are those from whom the ratio of straight/tollway distance to work >0.65.

(14)-(15) See (9)

Table 4: Commuting Subgroups

Income group	**Number of (zips)**	**Population > 16 (million)**	**Median income**	***Averages across zip codes in a various income groups*[#]** College or more (%)	**Population > 16 years**	**Workers (number)**	**Drive to work (number)**	**Potentially drive on tollway**
Low	152	2.6	$52,772	13	16,936	8,841	6,554	963
Middle	271	3.4	$70,344	20	12,581	7,938	6,662	1,497
High	139	2.4	$92,118	38	17,053	11,657	9,762	3,433

[#] all reported averages are population-weighted

Table 5: Driving habits

Income group	***Average shares relative to number of workers*[#]** workers (number)	Drive to work	Drive on tollways (percent)	Drive on freeways
Low	8,841	73.7	11.0	62.7
Middle	7,938	84.3	18.9	65.4
High	11,657	83.5	29.2	54.3

[#] all reported averages are population-weighted

Table 6: One-way distance to work, annual toll payments, dollars per year (240 workdays, one round trip each work day), and value of time ($/minute)

Income group	*10th pct*	*25th pct*	*median*	*75th pct*	*90th pct*	*Interquartile range*
One-way distance to work if use tollway (miles)						
Low	21.6	23.6	30.6	36.1	71.9	12.5
Middle	16.7	20.3	26.4	40.3	54.4	20
High	16.6	18.1	21.9	26.7	32.0	8.6
Annual toll payments, dollars per year (240 workdays, one round trip each work day)						
Low	$198	$212	$237	$329	$427	117
Middle	$178	$222	$258	$366	$430	144
High	$180	$202	$244	$294	$340	92
Value of time ($/minute) [a]						
Low	Low	0.25	0.30	0.33	0.35	0.41
Middle	Middle	0.32	0.36	0.41	0.45	0.48
High	High	0.35	0.37	0.44	0.52	0.73

[a] Based on the estimated model of Small et al, op. cit.

Table 7: Overall commuting costs if driving on toll road with an I-PASS, dollars

Income group	*10th pct*	*25th pct*	*Median*	*75th pct*	*90th pct*	*Interquartile range*
Low	8,826	10,039	11,803	14,980	20,852	4,941
Middle	8,445	10,100	13,406	18,563	21,722	8,463
High	9,057	9,998	12,803	16,302	21,226	6,304

Table 8: Ratio of tolls to total commuting costs--if driving on toll road with an I-PASS

Income group	*10th pct*	*25th pct*	*Median*	*75th pct*	*90th pct*
Low	1.7%	1.8%	2.1%	2.3%	2.9%
Middle	1.4%	1.6%	2.1%	2.6%	3.2%
High	1.3%	1.7%	2.1%	2.6%	3.4%

Table 9: Ratio of tolls to total commuting costs if driving on toll road without I-PASS *less* ratio of tolls to total commuting costs if driving on toll road with I-PASS

Income group	*10th pct*	*25th pct*	*Median*	*75th pct*	*90th pct*
Low	1.80%	1.70%	2.00%	2.20%	2.70%
Middle	1.30%	1.60%	1.90%	2.50%	2.90%
High	1.20%	1.70%	2.00%	2.40%	3.10%

Table 10: I-PASS ownership for various population breakdowns, percent [a]

	Population [a]		*Workers*[b]		*Motorists*[c]		*Workers on tolls*[d]		*Motorists on tolls*[e]	
Income Group	**Aug'04**	**Feb'05**	**Aug'04**	**Feb'05**	**Aug'04**	**Feb'05**	**Aug'04**	**Feb'05**	**Aug'04**	**Feb'05**
Low	2.6	5.1	5.0	9.8	6.8	13.2	39.1	76.5	45.9	89.8
Middle	10.9	18.5	17.2	29.4	20.5	35.0	81.3	139.0	91.2	155.8
High	27.1	40.8	39.7	59.8	47.4	71.3	115.5	174.0	134.7	202.9

[a] The population greater than 16 years of age.
[b] Workers as defined by the 2000 census, Transportation Planning Package, Journey to Work.
[c] Motorists as defined by the 2000 census, Transportation Planning Package, Journey to Work.
[d] Workers on tolls defined by 2000 census Transportation Planning Package, Journey to Work and our 0.65 cutoff ratio.
[e] Motorists on tolls defined by 2000 census Transportation Planning Package, Journey to Work and our 0.65 cutoff ratio.

Table 11. I-PASS Usage Prior to the Rate Change - August 2004

Weighted least squares logistic regression on zip-level grouped data – t-statistics are denoted in parentheses below the estimated coefficient

dependent variable: Fraction of zip with IPASS	(1) main	(2) check 1 non-drivers separately	(3) check 2 drop distant ZIPs
Share of HHs with income in 15K-35K range	1.243	1.696	1.252
	(1.0)	(1.4)	(0.8)
Share of HHs with income in 35K-75K range	3.541	3.493	3.729
	(7.7)	(7.6)	(6.2)
Share of HHs with income in 75K-150K range	5.180	4.948	5.645
	(7.4)	(7.0)	(6.1)
Share of HHs with income above 150K	2.076	2.564	2.061
	(3.6)	(4.3)	(2.8)
Fraction of population with college degree +	1.892	1.702	1.931
	(7.8)	(7.0)	(6.3)
Fraction of recent immigrants	-0.041	-0.262	-0.072
	(-0.1)	(-0.8)	(-0.2)
Distance to the nearest Jewel store (in miles)	-0.013	-0.022	0.015
	(-3.4)	(-6.0)	(1.0)
Fraction with IPASS in neighboring ZIPs (Aug04)	1.894	2.231	1.791
	(10.0)	(11.8)	(7.4)
Fraction of occasional# tollway commuters		0.551	
		(0.3)	
Average travel time * Share of likely toll drivers	0.073	0.094	0.055
	(6.9)	(5.3)	(4.0)
Average toll costs * Share of likely toll drivers	-0.562	0.023	4.431
	(-1.1)	(0.0)	(-0.6)
Average share of IPASS only lanes in July04 * Share of likely toll drivers	4.001	3.179	3.179
	(2.6)	(1.2)	(2.3)
Constant	-6.548	-6.381	-6.624
	(-12.0)	(-11.8)	(-9.3)
N	553	553	285
Adjusted R-squared	0.83	0.84	0.82

occasional tollway commuters are those who currently do not drive to work, but who could use tollways should they decide to drive

(2) defines all toll usage variables for those likely toll users that driver to work daily; all other likely users are classified as "incidental tollway commuters"

(3) drops all zip codes outside of the 6 counties bordering Cook County, where the City of Chicago is located

Table 12. Change in I-PASS Usage Following the Change in Cash Tolls

Weighted least squares logistic regression on zip-level grouped data – t-statistics are denoted in parentheses below the estimated coefficient

dependent variable: change in fraction of zip with IPASS	(1) low-income	(2) medium-income	(3) high-income
Share of HHs with income in 15K-35K range	0.298	0.904	-1.196
	(0.13)	(0.52)	(-0.53)
Share of HHs with income in 35K-75K range	2.385	1.345	1.099
	(2.11)	(1.08)	(1.75)
Share of HHs with income in 75K-150K range	4.467	2.775	0.629
	(1.68)	(2.38)	(0.52)
Share of HHs with income above 150K	25.663	2.438	0.545
	(3.73)	(1.12)	(0.63)
Fraction of population with college degree +	0.112	-0.396	0.087
	(0.16)	(-0.84)	(0.21)
Fraction of recent immigrants	0.310	0.367	0.320
	(0.72)	(0.85)	(0.42)
Fraction with IPASS in neighboring ZIPs (Aug04)	2.000	1.676	0.509
	(7.6)	(6.68)	(2.69)
Distance to the nearest Jewel store (in miles)	-0.001	**-0.014**	**-0.032**
	(-0.12)	**(-3.64)**	**(-3.16)**
Fraction of occasional# tollway commuters	-3.573	2.676	**3.203**
	(-0.66)	(1.35)	**(2.23)**
Average toll costs * Share of likely toll drivers	**5.374**	-0.653	-0.627
	(2.32)	(-0.59)	(-0.68)
Average travel time * Share of likely toll drivers	0.004	0.028	0.039
	(0.06)	(1.2)	(1.74)
Average share of IPASS only lanes in July04 * Share of likely toll drivers	2.406	5.858	1.382
	(0.62)	(3.24)	(0.77)
Constant	-6.281	-4.668	-3.055
	(-7.25)	(-4.71)	(-3.24)
N	150	269	138
Adjusted R-squared	0.68	0.66	0.45

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