Transforming payment choices by doubling fees on the Illinois Tollway

Gene Amromin, Carrie Jankowski, and Richard D. Porter

Introduction and summary

New technologies, such as electronic payments, offer the possibility of innovative remedies to congestion problems facing cities throughout the United States. However, the implementation of such remedies involves a number of difficult economic and political challenges. Indeed, successful implementation of technology-based policies depends critically on devising optimal pricing schemes taking into account network adoption dynamics. It also depends on consumer acceptance of the technology itself. Notably, prompting the switch to electronic payments raises many of the same challenges as the more radical congestion relief initiatives, such as variable pricing and transition to private ownership of roads. In this article, we study the effectiveness of a particular application of pricing incentives, in conjunction with a mass-marketing campaign, to foster adoption of electronic toll collection in Illinois.[1]

The first stage in this process came on January 1, 2005, when the Illinois State Toll Highway Authority (also known as the Illinois Tollway)[2] doubled the toll for cash payers but kept it unchanged (at $0.40 at most toll plazas) for electronic payers. We use data provided by the Illinois Tollway to show that the resulting substantial change in *relative* prices generated a large aggregate response, even though the increase in toll costs constituted a rather small change in overall commuting costs. We also argue that the large relative price change allowed the Illinois Tollway to resolve a difficult coordination problem of convincing motorists to adopt electronic payment in exchange for benefits, such as open road tolling,[3] that could be realized only if enough other motorists were also convinced. Moreover, we analyze the relative importance of price, income, and fixed participation costs in consumer choice of a particular payment mechanism. By doing so, we show that the aggregate effect of the price change masks interesting heterogeneity in motorists' responses. Whereas higher cash tolls served as a key factor in influencing lower-income households to adopt the electronic payment option (the "cost" channel), affluent households responded more to the decline in the fixed costs of acquiring the electronic payment instrument (the "marketing" channel). We also show that social network effects played a significant role in propagating the adoption of electronic payment on the toll road system. The results in our article can be helpful in designing effective ways to implement various congestion relief policies.

To frame our discussion, we first describe the evolution of the Illinois Tollway's electronic payment option—a radio frequency identification device (RFID)—brand-named I-PASS. Then, we take a closer look at the composition of payment choices by time of day and type of drivers, using hourly traffic data on Illinois Tollway payment. We find that even prior to the toll pricing change, I-PASS payments had the strongest appeal for drivers using toll roads on a regular basis and doing so in periods with the highest congestion. We further find that following the toll price change, *all* groups of drivers increased their I-PASS usage by roughly the same amount. To build intuition for further investigation, we next sketch out a simple model of payment choice, which points to the central role of fixed participation costs and drivers' income.[4]

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We also describe the construction of the data for evaluating the model's predictions, and then we present simple univariate summaries of the data in the form of tables and maps. After this, we provide 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.

Evolution of the payment choices on the Illinois Tollway

The current environment in the Chicago area provides one of the most fitting situations to analyze the use of electronic payments technology to reduce congestion. Not only is Chicago the third most congested urban area in the U.S.,[5] but it also has a long-standing economic reliance on transportation that derives from its geographic location at the nexus of the country's transportation networks. The very establishment of the city owed much to the desire to link the water routes of the Great Lakes and the Mississippi River. Waterways yielded to rail by the end of the nineteenth century, and in the 1950s and 1960s, the Chicago area was transformed for a third time with the growth of the federally sponsored interstate highway system and the construction of the Illinois Tollway, which spread out from Chicago to adjoining states.[6]

Until the 1990s, the payment options on the roads overseen by Illinois Tollway seemed incongruous with the remarkably efficient transportation network that has kept Chicago on the country's economic forefront. All vehicles were required to come to a full stop at toll plazas and pay either by handing cash to an attendant (manual lane) or by throwing exact change into a collection bucket (exact change lane). Especially in comparison with other states' tollway configurations, the Illinois Tollway's manual lanes seemed to be a throwback to an older patronage age. For their part, exact change buckets were based on a relatively old technology, which could be readily compromised by fraudsters.

To combat fraud and improve efficiency, in 1993 the Illinois Tollway introduced an electronic payment option called the I-PASS. Cars equipped with an I-PASS RFID transponder have the correct toll amount deducted electronically upon passing through specially equipped toll gates. Over the past decade, RFID technology has improved enough to allow I-PASS payments to be processed on vehicles traveling at highway speeds. In 2004, the Illinois Tollway unveiled plans to reduce road congestion by eliminating toll collection plazas. To implement this plan, the Illinois Tollway had to convince a critical mass of motorists to switch to electronic payments. Although the problem at hand looked simple enough, it faced most of the challenges of more radical reforms, such as variable pricing and transition to private ownership of roads.

These challenges could be broken into three categories: optimal pricing choice, heterogeneity in drivers' preferences, and coordination problems and network externalities. In tackling these issues, the Illinois Tollway needed to answer three questions. First, absent a politically unsustainable choice of mandating electronic payments, what pricing incentives would be necessary to effect the desired level of change? Not all motorists value the same driving attributes equally. Thus, they might respond to different aspects of pricing arrangements, such as higher cost of non-electronic payments or easier acquisition of payment transponders. Second, what strategy could address these heterogeneous preferences? And third, what role do social networks play in a driver's decision to switch? Being the only I-PASS user is worthless, since "no-stop" tolling lanes would never be put in place in such a case. On the other hand, learning that others have made the switch to electronic payments increases the attractiveness of such a choice by making the necessary road reconfiguration more likely.[7]

In an attempt to address these problems, the Illinois Tollway doubled the toll for cash payers on January 1, 2005, but kept it unchanged (at $0.40 at most toll plazas) for electronic payers, the I-PASS clients. By drastically changing the relative prices of these two forms of payment in this natural experiment, the Illinois Tollway sought to achieve an outsized increase in usage of I-PASS over a short period. In advance of the price change, the toll road authority undertook a substantial advertising 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.

Commuters and other travelers responded to the doubling of cash tolls by quickly switching to electronic payment in large numbers. Electronic toll share soared past 70 percent within a month of the new pricing regime going into effect.[8] By the end of January 2005, about 1.9 million commuters had electronic payment devices—more than double the figure in June 2003 when the transponders were first sold online. As the number of electronic payers shot up, the Illinois Tollway proceeded with its plans to add no-stop tolling lanes.[9]

While the toll hike for cash payers represented a 100 percent increase in toll outlays, the increase represented a considerably smaller percentage rise in the overall cost of commuting. Taking into account the full cost of operating a vehicle and a measure of the value of time spent in the commute, we estimate that higher cash tolls raised the overall commuting costs by more than 3 percentage points for only 10 percent of all Illinois Tollway drivers.[10] The question then becomes how such a relatively small boost in *overall* costs could induce such a large consumer response. As we mentioned previously, the large aggregate increase in I-PASS usage masks interesting heterogeneity in consumer payment choices, which we examine in the following section. As we explain later, the Illinois Tollway's multipronged approach to inducing more efficient payment on its toll roads helped achieve this large aggregate increase among its heterogeneous consumer base.

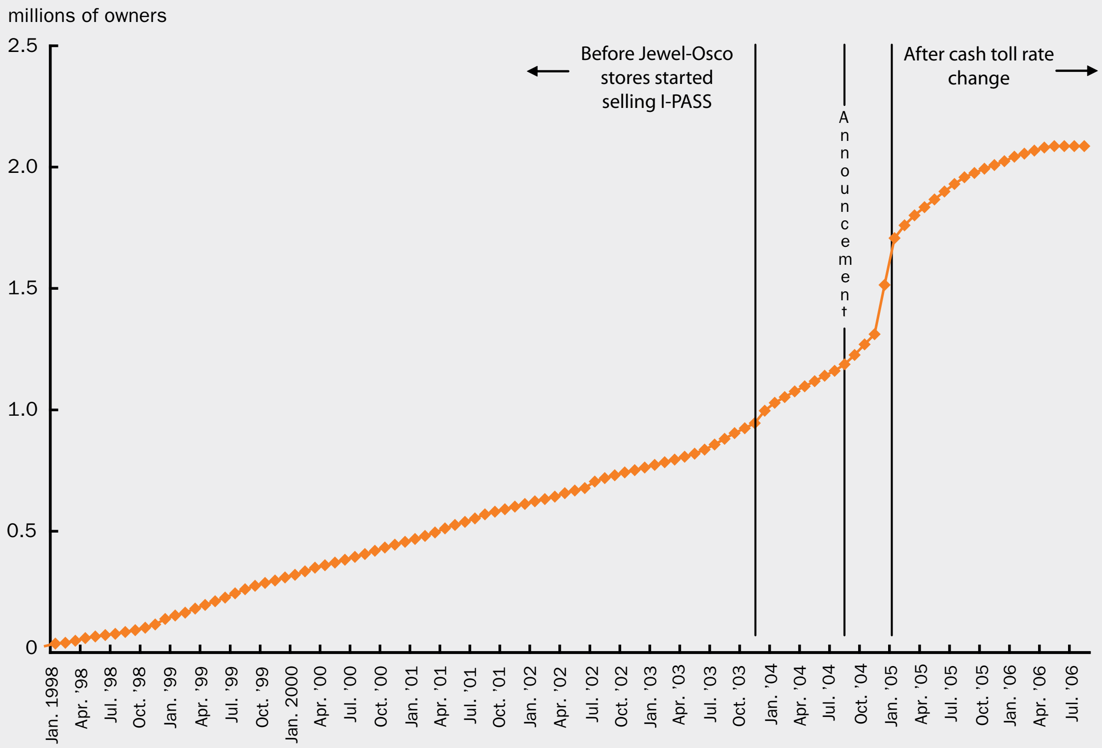
The toll pricing change and its aggregate effects

Doubling the cash toll rates on January 1, 2005, produced an immediate and dramatic response in both the overall share of tolls paid electronically and in the number of I-PASS owners. As shown in figure 1, in slightly more than four months between the announcement of the impending price change and the commencement of the new regime on January 1, 2005, more than 500,000 I-PASS transponders were purchased. About 80 percent of these new accounts were originated in November and December of 2004. The pace of I-PASS ownership growth remained brisk for nearly a year, before leveling off in December 2005.

The relative advantages of different payment methods fluctuate by time of day (for example, the level of congestion) and travel purpose (for example, the importance of arriving at a destination on time). Presumably, a more efficient and convenient electronic payment holds the greatest appeal for rush-hour commuters. We are able to identify such commuters from a special survey of driver preferences, administered in November 2003.[11] Figure 2 confirms that the Illinois 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 p.m. and 6 p.m.

FIGURE 1

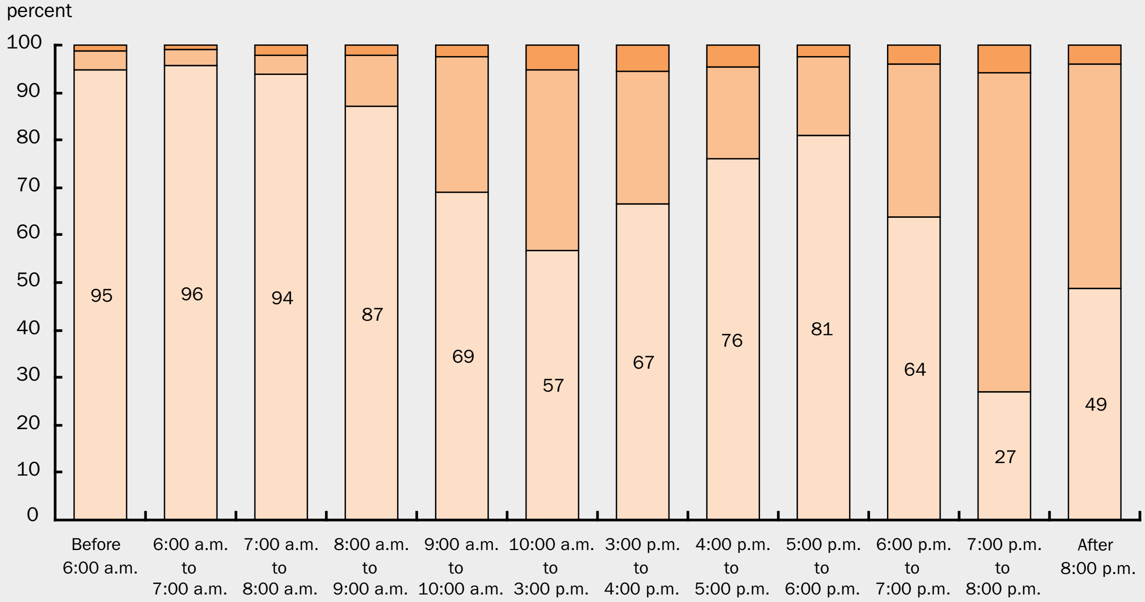
Monthly I-PASS ownership



Notes: Data reflect only passenger vehicles without trailers. Drivers could start purchasing I-PASS transponders at Jewel-Osco stores in November 2003. In August 2004, the Illinois State Toll Highway Authority announced that tolls would be doubled for cash payers but kept unchanged (at $0.40 at most toll plazas) for electronic payers (I-PASS owners) starting in January 2005.
Source: Illinois State Toll Highway Authority.

FIGURE 2

Composition of trip purposes among I-PASS users, by time of day



Notes: Data were collected by the Illinois State Toll Highway Authority through its origin–destination survey that was mailed out to I-PASS users. In addition to questions on trip purpose, drivers were asked about the origin and destination of their travel, zip code of residence, frequency of toll trips, and participation in the I-PASS program.
Source: Illinois State Toll Highway Authority.

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. Both series have two distinct humps corresponding to peak times, effectively mirroring the fraction of tollway drivers that are commuting to and from work. This result confirms the basic intuition that even in the absence of price differences (for example, before the 2005 price hike for cash payment), electronic payment was embraced by frequent toll road users who put a relatively higher premium on convenience and potential improvement in travel times.

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 road system during rush hours, at midday, or throughout late night/early morning times. The upward shift in I-PASS usage is remarkably parallel over the entire day,

FIGURE 3

Average share of I-PASS transactions, by time of day

Notes: Data reflect only passenger vehicles without trailers. To limit the effects of weekend or vacation visitors to Chicago, this figure displays the results for Wednesdays during two months with limited vacation activity, March and April, in 2004 and 2005.
Source: Illinois State Toll Highway Authority.

with about a 25 percentage point increase in electronic toll shares under the new pricing regime. This finding suggests that to a first approximation, commuters, as well as shoppers and leisure drivers, responded similarly to the change in toll prices, even though the Illinois Tollway benefits bestowed upon them tended to favor the commuters unequivocally.[12]

To look more closely at the factors influencing the payment decisions of such disparate groups of drivers we need two things: first, a simple model of payment choice to build our intuition and inform subsequent analysis of disaggregated data and, second, 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.

A simple model of payment choice

Around 40 years ago, Lancaster (1966) proposed that the demand for a particular good or service be decomposed into the demand for the underlying characteristics of the item. For most transactions, the part played by the payment does not affect the enjoyment from the consumption of goods or services. This is not the case, however, on the Illinois Tollway, where a motorist paying electronically may potentially proceed through the toll plaza at highway speeds—a process that is both more convenient and faster than the other payment options.[13] 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.

We use the simple model sketched out here as a useful device to build intuition for the empirical investigation, rather than to identify a specific expression for uncovering structural parameters of interest (for example, the relative value of goods and leisure). Although it is necessarily stylized, the model highlights the trade-offs made by drivers in choosing an appropriate payment method for their Illinois Tollway transactions.

With this caveat in mind, assume that drivers' preferences, U, are defined over consumption of goods and services, G, and leisure, L. This gives us:

1) $U = U(G, L)$,

2) $L = T - H - N \times t_k(D) - 1_{ipass}\, t^F(d, E)$,

3) $G = V + w \times H - N \times c_k(D) - 1_{ipass}\, c^F$,

where T is the total time available, H is hours worked, N is the number of tollway trips per unit of time, and $t_k(D)$ is the amount of time spent on a trip of length D using payment method k. Note that 1_{ipass} is an indicator function set equal to 1 if the individual purchases an I-PASS and that $t^F(d, E)$ is the time required to do so given the physical distance to the nearest retail outlet, d, and the ease of acquiring necessary information, E. Turning to equation 3, V measures household wealth, w is the hourly wage rate, $c_k(D)$ are toll outlays per D-mile-long trip using payment method k, and c^F is the monetary cost of acquiring an I-PASS. We assume that c^F consists only of deposit and carry costs and thus is identical for all households as long as they face the same set of market interest rates. Unlike Train and McFadden (1978), we treat 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).[14]

To build intuition for the trade-off, assume for the moment that the higher commuting costs are associated with shorter times spent in commute (for example, tollway travel is faster than travel on smaller and more congested freeways). In other words, $(\Delta c/\Delta t) < 0$. In this case, a driver would prefer the payment and time combination k to some alternative k' if

4) $U_L \geq -(\Delta c / \Delta t) \times U_G$,

where, $\Delta c = c_k(D) - c_{k'}(D)$, $\Delta t = t_k(D) - t_{k'}(D)$, and U_L and U_G are evaluated at consumption and leisure levels associated with choice k. Equation 4 simply says that the marginal gains in leisure from shortening the commute (weighted by the marginal utility of leisure itself) must be greater than the marginal cost in terms of consumption goods associated with this choice (again weighted by the marginal utility of consumption).

The trade-off in equation 4 is easy to generalize to other aspects of payment choice, where a particular payment alternative provides greater benefits (for example, faster service, greater reliability, easier use, greater convenience, or better dispute resolution) at additional cost. 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 25 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 trade-off was never as dramatic. Even prior to the toll price change, the convenience of I-PASS and the possibility for faster travel it offered were counterbalanced by the carry cost of the $10 I-PASS deposit and of the outstanding transponder balance. Following the change in the relative toll prices, electronic toll payments offered both a cheaper *and* faster (more reliable, easier) way to travel. Restating this in terms of equation 4, switching to I-PASS generates a positive marginal "trade-off" ($\Delta c/\Delta t > 0$) which means that the optimal solution to this problem is one where all motorists pay electronically. This clearly isn't the case in the real world.[15]

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. Intuitively, high participation costs may make the *overall* utility of having a transponder lower than that of continuing to pay cash tolls, even though *at the margin*, electronic payments are preferred by all. 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 nonparticipation 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 toward I-PASS. Also, as mentioned earlier, the advertising campaign that accompanied the pricing change, along with information spillovers from those who adopted I-PASS earlier, have likely combined to decrease the cost of information acquisition.[16]

The simple framework in equation 4 can be mapped to the data by assuming a particular preference specification, as illustrated in appendix 1. More generically, one can infer that electronic toll payment is most beneficial for households that obtain the greatest gains in leisure from paying electronically and those that incur the smallest losses in consumption from I-PASS acquisition. These observations lead to the following set of hypotheses for empirical testing.

- As wages (or wealth) increase, the relative loss of consumption from bearing the fixed cost of purchasing an I-PASS (c^F) is smaller. This is especially true if the number of hours spent at work is an increasing function of income, at least over some range. As a consequence, drivers with higher income and/or wealth are more likely to use I-PASS.
- Lower fixed costs of learning about and acquiring the I-PASS increase the likelihood of electronic toll payment. To the extent education or English fluency proxy for the ease of acquiring information, we would expect better educated nonimmigrant households to be more likely to own I-PASS. The same logic should hold for all other characteristics that reduce participation or learning costs, such as proximity to I-PASS retail outlets and informational spillover effects from neighbors or coworkers.
- As commuting distances get longer (higher N), the cost difference between cash and I-PASS toll payments matters more, again making drivers who travel longer distances more likely to purchase I-PASS. Moreover, drivers with higher N are also more sensitive to time spent in their commute, $t_k(D)$, which also pushes them toward 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 road trips and where participation costs encompass both the ease of learning about and the ease of acquisition of an I-PASS transponder.

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 as workers, retirees, and students. As described later, 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 on the commute. Consequently, we are able to measure many of the components of the I-PASS demand function for workers, including the likelihood of using the tollway for commuting.[17] In contrast, there is very little information about travel patterns of other types of drivers (for example, students and retirees), which leads to the following decomposition:

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

Here, i denotes the number of I-PASS accounts owned by different driver segments. Those commuting to work are further described by their current commute mode (d = driving, nd = public transport or other options, such as walking) and feasibility of tollway use (t = likely tollway user, f = likely freeway user). Since the easiest way to transform the probability of

I-PASS ownership to an empirically observable aggregate measure is by expressing it as a fraction of a group, we end up with:

$$5)\quad \frac{i}{p} = \left(\frac{i^{d,t}}{n^{d,t}}\right)\times\left(\frac{n^{d,t}}{p}\right) + \left(\frac{i^{nd,t}}{n^{nd,t}}\right)\times\left(\frac{n^{nd,t}}{p}\right) + \left(\frac{i^{leisure}}{n^{f}+n^{other}}\right)\left(\frac{n^{f}+n^{other}}{p}\right)$$

$$= f^{work}()\times\left(\frac{n^{d,t}}{p}\right) + f^{work}()\times\left(\frac{n^{nd,t}}{p}\right) + f^{leisure}()\left(\frac{n^{f}+n^{other}}{p}\right).$$

Here, n denotes the total number of people in a given group and $f(\cdot)$ represents a generic demand function of I-PASS ownership from the preceding section. For workers who could potentially use the tollway for their daily commute, f is a function of their known commute characteristics: toll costs, travel time, and congestion. If f is linear, as will be assumed for empirical analysis, each of these commuter-specific arguments should be multiplied by $(n^{d,t}+n^{nd,t})/p$.[18] Other determinants of tollway demand would be common to *all* drivers—those using the tollway to commute to work or for leisure—and would thus receive a full weight of 1. These determinants would include the distance to the tollway from the place of residence, distance to I-PASS retail outlet, measures of income, and education level, among others.

Data construction

The data that we analyzed for this article were obtained primarily from two sources: the Illinois State Toll Highway Authority and the U.S. Census Bureau (specifically, the 2000 U.S. Census). From the former, we received data on 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 (the onramp and offramp directions) from the Illinois Tollway website. From the latter, we received and used zip-code-level economic and demographic information, as well as journey-to-work data linking census tract of residence with census tract of work.[19] We then merged all of these data into a single data set of economic, demographic, and geographic information by zip code of residence, described in more detail later.[20]

I-PASS ownership data

The data set on I-PASS ownership details the total number of accounts and transponders by zip code. This information was provided for two time periods, August 2004 and February 2005, which were chosen because they fall right before the announcement of the Illinois Tollway's 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.

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

Similar to the I-PASS ownership information, the U.S. Census provides economic and demographic data at the level of zip code of residence. Among numerous other variables, included in this data set are variables describing income, education, length of residency, and population. Specifically, we chose the following variables as regressors in our model: the population of people 16 years and older, household median income, the number of households in five 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 16 years and older was representative of those people who could have I-PASS accounts because they are of working age and, more importantly, of driving age. All household variables were normalized by this number.

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 matter. To capture the former, we computed the distance from each zip code to the nearest point of sale for I-PASS transponders—a chain of grocery stores (Jewel-Osco) and the Illinois Tollway headquarters. We used the degree to which one's neighbors and coworkers were getting on the "I-PASS bandwagon" as measures of information spillovers or network effects. For each zip code, we constructed a population-weighted average of I-PASS ownership rates in "adjacent" zip codes (those within a 5-mile radius from the zip code center). We followed a similar approach to compute I-PASS ownership rates among coworkers, using census-tract-level data on work and residential location, described in the following section.

U.S. Census tract data on daily commuting choices

The U.S. Census provides detailed demographic and economic variables that relate to workers and their commutes to work in the Census Transportation and Planning Package (CTPP)—a special tabulation of responses to the Census long form questionnaire, mailed to one in six U.S. households. Specifically, the "Journey-to-Work" part of the CTPP provides data by pairing place of residence and place of work. For each origin–destination pair, we know the number of workers making the commute, the length of time in the commute, the form of transportation they use, and their income.[21]

The U.S. Census provides this detailed information at the level of census tract, 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 2) allowed us to estimate 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 2). In essence, each origin–destination pair of zip codes (say, A and B) was judged to be "potentially" suitable for tollway travel on the basis of two simple metrics: whether an online trip-planning software (MapQuest) recommended the tollway for all or part of the trip, and whether a trip from A to B via tollway was "excessively" longer than a straight-line route ("as the crow flies"). Using this methodology, we were able to impute whether a commute between each of our 656,600 origin–destination pairs would involve the tollway, as well as the approximate daily commuting distance.

At this point, we have all of the variables of interest relating to the commuting patterns of workers in our sample. Because all of our other data are at the level of zip code of *residence*, we need to aggregate our specific commuting path variables of workers residing in a given zip code across all *destinations*. To do this, we form weights by taking the number of workers unique to each origin–destination pair over the sum of all workers at the zip code of origin. These weights are calculated separately for all workers, workers likely to use the tollway, and workers unlikely to use it. They are then are used to compute measures of commute characteristics representative of the entire zip code of origin.

In the end, we are left with a data set that includes: the zip code of residence; I-PASS ownership; neighbors' I-PASS ownership; coworkers' I-PASS ownership; the smaller of the distance to the nearest Jewel-Osco store or the Illinois Tollway headquarters; distribution of income, educational attainment, and length of U.S. residency within a zip code; separate estimates of travel time and distance to work for tollway and non-tollway commuters; and estimated tollway commuter toll costs.

A first look at the data

Here, we take an initial look at the data with the simple bivariate contrasts. We do this by focusing on the data's geographic representation. We also examine the data's correlation structure, noting the relationships between the level of I-PASS ownership and various economic, demographic, and geographic characteristics at the zip code level, in both August 2004 and February 2005—the dates falling right before the Illinois Tollway officially announced its congestion relief plan and shortly after the toll rate change took place, respectively. We find median household income to be a key factor in the decision to own an I-PASS and, therefore, provide summary statistics by income groups.

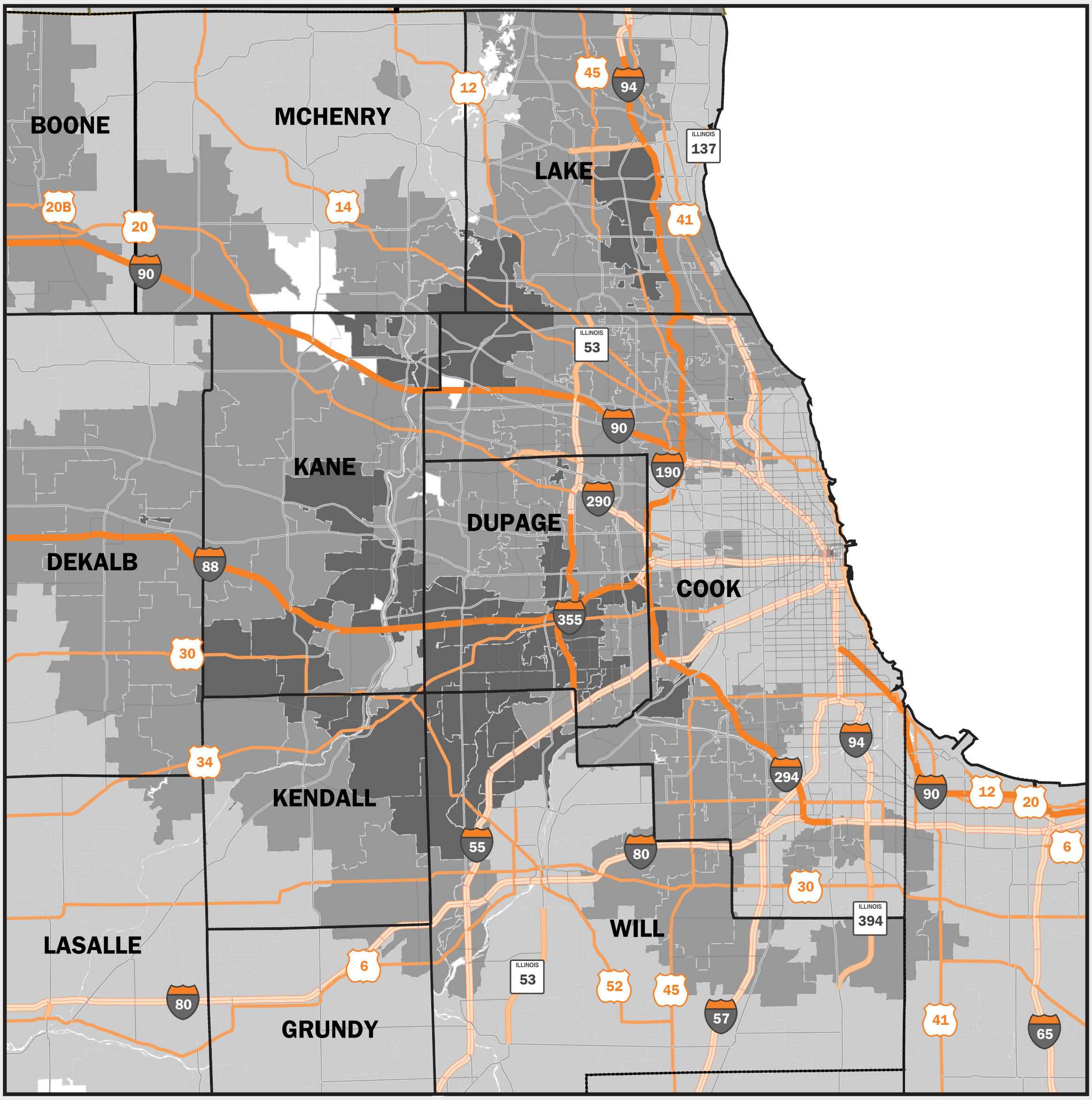
Geographic representation

Because of 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 maps. In order to focus on the main body of commuters who live close to the city, we center the maps on the seven counties that include the City of Chicago and surround it: Cook, DuPage, Kane, Kendall, Lake, McHenry, and Will. All maps present information at the zip code level. Since we are most interested in the geographic penetration of I-PASS, figure 4 exhibits the ratio of I-PASS transponders to the adult population in August 2004. The zip codes are shaded from light gray to dark gray, representing *increasing* I-PASS ownership rates.[22] Figure 5 presents the same information in February 2005, highlighting geographic distribution of the effects of the toll price change on I-PASS ownership.

As shown in figure 4, by August 2004, I-PASS ownership rates reached significant levels around the area where most of the tolls roads converge, which is about 15 miles from the downtown Chicago area. I-PASS rates remained mostly above 15 percent in zip codes along the toll roads as they move out farther from Chicago. At about 20 miles to 30 miles outside the city center, there are pockets of even higher I-PASS ownership along all of the toll roads. The largest pocket of dark gray area surrounds the intersection of I-88 with I-355. This higher density could partially reflect the history of I-PASS, which was first introduced on I-355 in 1993 and then expanded onto I-88 in 1994. In contrast, most other areas did not have the electronic payment option until 1997. It is interesting to

FIGURE 4

Ratio of I-PASS transponders to adult population, by zip code, August 2004



I-PASS per adult

0.00 to 0.15 | 0.15 to 0.35 | 0.35 to 1.00

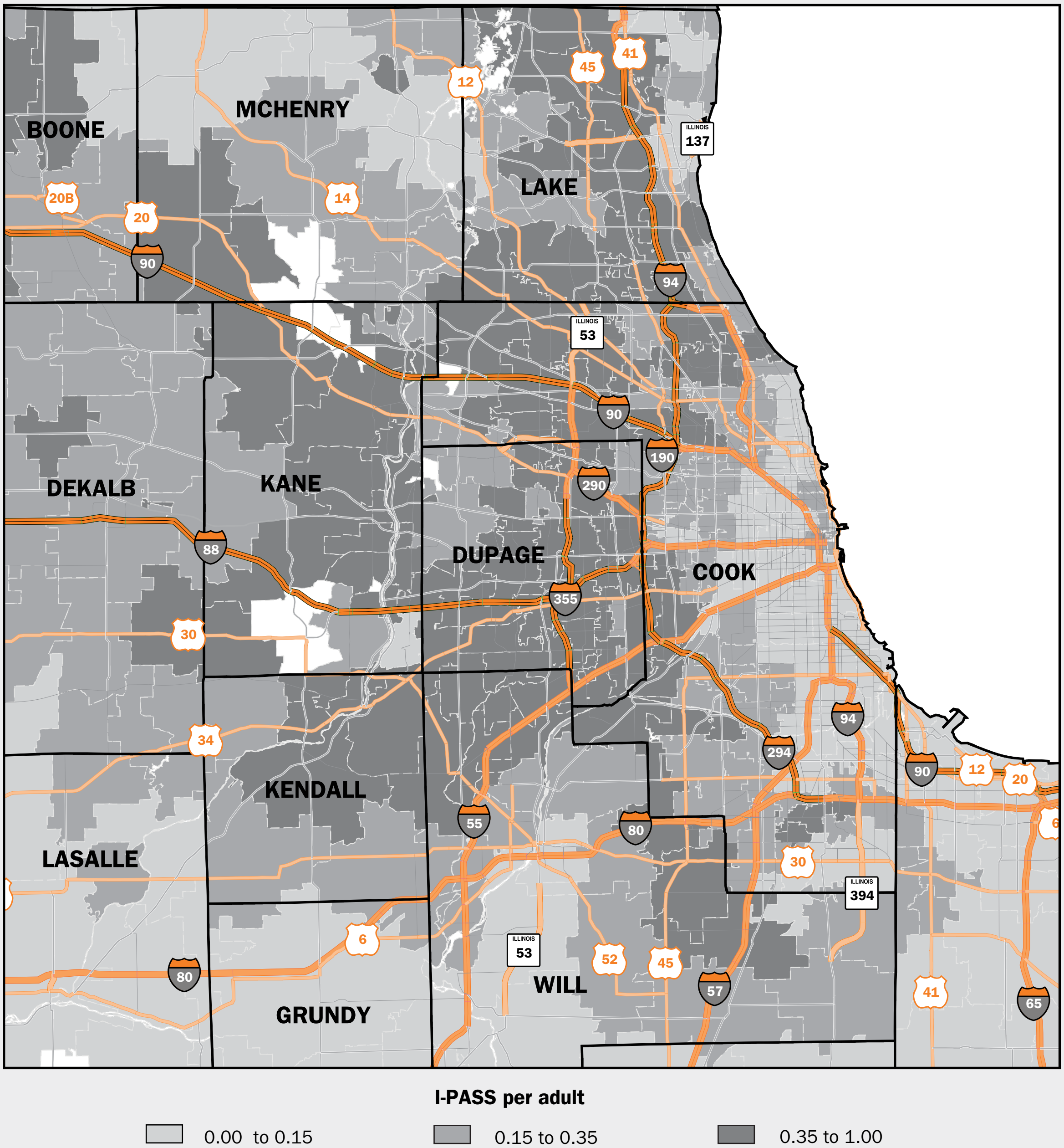
Notes: The adult population includes everyone aged 16 years and older. For an explanation of white areas, see note 22.
Sources: Authors' calculations based on data from the Illinois State Toll Highway Authority and U.S. Census Bureau, 2000 U.S. Census.

note, however, that although I-294 also received I-PASS technology in 1994, I-PASS ownership is not as concentrated in this area. In general, we do not observe a drop-off in the ownership rates along the tollway until reaching locations about 40 miles away from Chicago and at least 15 miles away from the toll road itself.

Figure 5 is significantly darker than figure 4, indicating increased I-PASS penetration by February 2005, after the rise in cash toll prices. The February 2005 map presents a similar pattern to that in the August 2004 map; however, the areas of medium gray (the middle range) and dark gray (the high

FIGURE 5

Ratio of I-PASS transponders to adult population, by zip code, February 2005



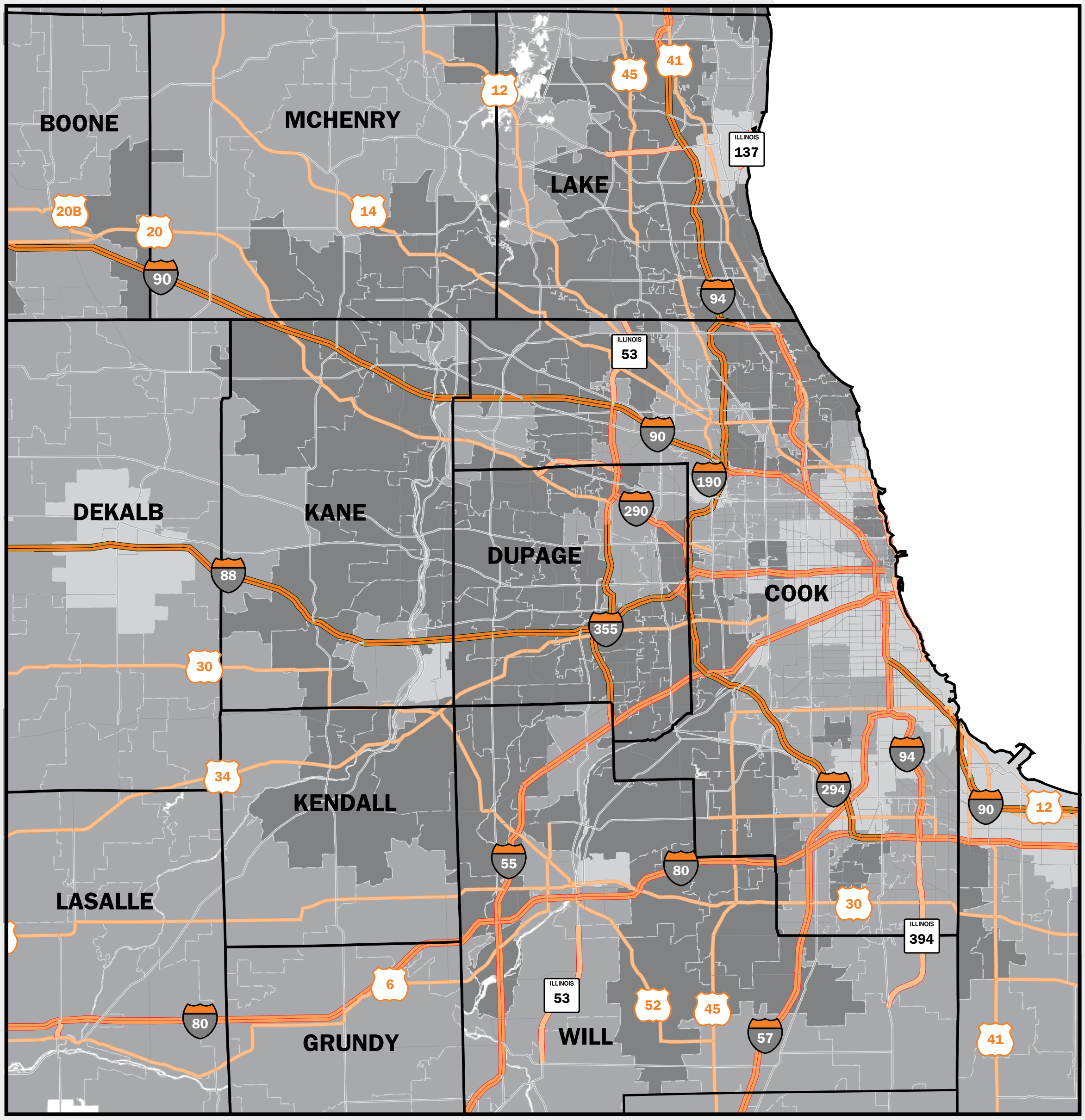
Notes: The adult population includes everyone aged 16 years and older. For an explanation of white areas, see note 22.
Sources: Authors' calculations based on data from the Illinois State Toll Highway Authority and U.S. Census Bureau, 2000 U.S. Census.

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, figure 5 conveys the sense that the increase in I-PASS ownership was fairly evenly spread across this seven-county region over the course of these six months. 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 (p. 25).

In figure 6, the income levels of zip codes in our data sample are broken into three categories on the

FIGURE 6

Median household income, by zip code



Median household income

Below $60,000 — $60,000–$80,000 — Above $80,000

Source: U.S. Census Bureau, 2000 U.S. Census.

basis of income quartiles of working household from the 2000 U.S. Census. The light gray represents zip codes with a median household income below $60,000, and the dark gray corresponds to zip codes with a median household income above $80,000.[23] As one might expect, with only a few exceptions the higher-income zip codes tend to be very close to the tollway system. Given the income makeup displayed in figure 6, 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 because of the ability to afford the setup costs for electronic payment and the proximity and likely frequent use of the tollway itself. Looking back at figure 4, this is clearly the case, as I-PASS ownership rates above 15 percent are registered almost exclusively in areas where median income is greater than $80,000, our highest income group. This concentration of high income *and* high I-PASS ownership suggests that before the price hike for cash payments, income was the main determining factor in the decision to own an I-PASS. Furthermore, this observation might help to explain why I-PASS ownership is lower in those areas around the southern and northern parts of I-294, even though they have been exposed to the technology for a similar length of time as those areas around I-355/I-88. Indeed, the areas around the southern and northern parts of I-294 have relatively lower median household income compared with those around I-355/I-88. Interestingly, by February 2005, I-PASS ownership exhibits less of a dependence on income. Figure 5, for instance, looks remarkably similar to figure 6, reflecting a pickup in I-PASS ownership rates across all three income groups.

Correlation structure

We can conduct a preliminary empirical evaluation of I-PASS acquisition by looking at the correlations between the level of I-PASS accounts and various economic, demographic, and geographic characteristics at the zip code level in both periods—August 2004 and February 2005. We also examine indirectly the population of *new* I-PASS owners by looking at the differences in I-PASS account concentrations between these two dates. These owners are the inframarginal group of drivers who did not switch initially in the old pricing regime, because the time advantages of I-PASS ownership did not outweigh the costs; however, this group switched to the I-PASS after the new pricing regime became evident.

Table 1 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 code level between August 2004 and February 2005. 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 and likelihood of tollway use. Median worker income had a stronger correlation with the choice to own I-PASS prior to the price change ($\rho = 0.70$ for the share of I-PASS accounts in August 2004 in column 1, row 4) than with the choice to own it following the price change ($\rho = 0.58$ for the change in I-PASS accounts in column 3, row 4). I-PASS penetration by August 2004 is strongly correlated with the fraction of workers in a zip code that potentially could take the tollway to work, if they were to drive ($\rho = 0.70$, column 1, row 7). It is informative that this relationship is somewhat weaker for the *change* in I-PASS ownership over the period from August 2004 to February 2005 ($\rho = 0.63$, column 3, row 7). This finding suggests that after the new pricing regime went into effect, I-PASS ownership became somewhat less tied to strictly work-related travel.

The negative correlations between distance (and similarly for travel time and toll costs) with both the August 2004 I-PASS ownership rate and the change in this rate may be surprising at first glance. It should be noted, however, that the commuting distance has a relatively strong negative correlation with the median income ($\rho = -0.38$, column 4, row 10) and the fraction of all workers who could use the tollway to get to work ($\rho = -0.59$, column 7, row 10). On most commutes, the distance variable includes not only the tollway segment but also the distance in getting to the tollway and in getting from the tollway to work. It therefore appears likely that longer commutes for potential tollway users are generally associated with zip codes that are actually quite far from the tollway. In such zip codes, fewer commuters use the tollway, which translates into a smaller demand for I-PASS. Next, a significant negative correlation between the median income and distance variables suggests that lower-income drivers are the ones making the longer distance commutes (a point underscored earlier in figure 6).

Comparing the correlations of both periods' average share of I-PASS only lanes along the likely tollway commuting routes suggests that there was relatively little supply effect in play by early 2005. Before the toll price change, I-PASS lane ratios and the number of I-PASS accounts were negatively correlated ($\rho = -0.20$, column 1, row 12). This can be explained by the fact that I-PASS lanes were first added to mainline plazas, which had lower *relative* use of I-PASS due to the higher diversity of users at these plazas.[24] The I-PASS lane ratios for July 2004 and January 2005 are virtually uncorrelated with each other, as most of the plazas that received I-PASS lanes by July 2004 did not gain any by January 2005, while most of the plazas that had no I-PASS lanes in July 2004 received at least one by January 2005.[25]

TABLE 1

Summary statistics and pairwise correlations

	Share of I-PASS accounts in Aug. 2004	Share of I-PASS accounts in Feb. 2005	Change in I-PASS accounts	Median worker income	Share of of college graduates	Share of recent immigrants	Share of potential tollway commuters	Share of likely tollway commuters	Among potential tollway commuters: Average I-PASS tolls	Average distance to work	Average solo drive time	Average share of I-PASS only lanes in Jul. 2004	Average share of I-PASS only lanes in Jan. 2005
				(dollars)					(dollars)	(miles)	(minutes)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1)													
(2)	0.98												
(3)	0.84	0.93											
(4)	0.70	0.68	0.58										
(5)	0.61	0.58	0.46	0.76									
(6)	0.12	0.14	0.17	0.00	0.13								
(7)	0.70	0.70	0.63	0.45	0.26	0.17							
(8)	0.67	0.67	0.61	0.41	0.21	0.17	0.99						
(9)	−0.35	−0.37	−0.36	−0.33	−0.31	−0.37	−0.36	−0.36					
(10)	−0.51	−0.54	−0.52	−0.38	−0.35	−0.40	−0.59	−0.59	0.75				
(11)	−0.46	−0.48	−0.47	−0.31	−0.27	−0.34	−0.57	−0.58	0.63	0.89			
(12)	−0.20	−0.21	−0.20	−0.19	−0.08	−0.08	−0.29	−0.29	0.50	0.26	0.24		
(13)	0.27	0.25	0.19	0.21	0.16	0.08	0.14	0.16	−0.04	−0.12	−0.06	−0.02	
Mean	0.12	0.20	0.08	70,577	0.20	0.05	0.19	0.16	0.80	49.13	53.10	0.17	0.24
Median	0.07	0.14	0.06	68,849	0.15	0.02	0.17	0.15	0.72	41.74	46.88	0.17	0.23

Notes: The shares of I-PASS accounts in August 2004 and February 2005 are taken with respect to the total adult population (aged 16 years and older) in a given zip code. The shares of college graduates (aged 25 years and older) and recent immigrants are taken with respect to the total adult population in a given zip code. The U.S. Census defines recent immigrants as those who immigrated to the U.S. from 1990 through 2000. Potential tollway commuters are defined as those who could drive to work and whose residence and work locations suggest tollway commutes. The share of potential tollway commuters is taken with respect to the total number of workers in a given zip code, regardless of their current commute mode. Likely tollway commuters are defined as those who do drive to work and whose residence and work locations suggest tollway commutes. The share of likely tollway commuters is taken with respect to the total number of workers in a given zip code who drive to work. Workers' commute routes and modes of transportation are based on the data from the Census Transportation Planning Package 2000.

Sources: Authors' calculations based on data from the Illinois State Toll Highway Authority and U.S. Census Bureau, 2000 U.S. Census.

TABLE 2

Income group summaries

Panel A. Summary statistics and I-PASS acquisition costs

Income group	Number of zip codes	Total adult population	Median income of a working household	Mean share of college graduates	Mean share of recent immigrants	Mean distance to I-PASS sales outlet
		(million)	*(dollars)*			*(miles)*
Low	152	2.49	53,989	0.12	0.11	7.11
Middle	271	3.41	70,838	0.19	0.08	6.36
High	138	2.45	88,100	0.39	0.06	2.41

Panel B. Driving choices

Income group	Number of workers	Share driving to work	Share likely driving to work on a freeway	Share likely driving to work on a tollway	Mean commute of likely tollway driver	Mean distance to tollway
	(million)				*(miles)*	*(miles)*
Low	1.30	0.74	0.64	0.11	43.90	13.41
Middle	2.11	0.85	0.68	0.16	40.26	10.97
High	1.70	0.82	0.59	0.23	32.34	6.58

Notes: In both panels, all reported means across zip codes in a given income group are population-weighted. The low-income group consists of zip codes with a median household income below $60,000. The middle-income group consists of zip codes with a median household income between $60,000 and $80,000. The high-income group consists of zip codes with a median household income above $80,000. The U.S. Census defines recent immigrants as those who immigrated to the U.S. from 1990 through 2000.

Sources: Authors' calculations based on data from the Illinois State Toll Highway Authority and U.S. Census Bureau, 2000 U.S. Census.

Summary statistics by income groups

Given the primary importance of income, we next present summary statistics of the key variables in the I-PASS ownership decision by income group. Specifically, we compare characteristics of zip codes in which the median income of working households was below $60,000, between $60,000 and $80,000, and above $80,000; in table 2, we label these income groups as low, middle, and high, respectively. As shown in panel A of table 2, these three income groups account for 152, 271, and 138 zip codes with populations of 2.5 million, 3.4 million, and 2.5 million residents aged 16 years and older, respectively. As hypothesized, residents of wealthier zip codes likely have lower costs of acquiring I-PASS information and purchasing the transponder: Wealthier zip codes have substantially higher education levels, have a lower share of recent immigrants, and are located much closer, on average, to I-PASS retail outlets (2.4 miles versus 7.1 miles).

Panel B of table 2 presents the driving choices made by members of different income groups. Although the residents of high-income zip codes have only a somewhat greater propensity to drive to work, the breakdown between likely tollway and freeway travel is quite different. Among residents of high-income zip codes, nearly one in four would likely find it advantageous to commute to work via the tollway (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 percent of lower-income zip code residents. Similarly, the appeal of the Illinois Tollway for nonwork travel, as gauged by the distance to the nearest tollway exit, is likely greater for high-income zip codes. This difference reflects the strategic choice of many high-income households to live in neighborhoods close to the tollway, which serves as a convenient gateway for their workday commutes and leisure activities.

In table 3, we take a closer look at the most active tollway users—those who currently drive to work and whose residence and work locations suggest tollway commutes. Table 3 summarizes the overall commuting distance, as well as the monetary toll payments, for such drivers, again by the three income groups we established in table 2. To derive distance estimates (as shown in panel A of table 3), we sum the actual length of the tollway segment and the two straight-line offtollway segments connecting the two zip codes.[26] Remarkably, our mapping of the tollway and U.S. Census information suggests that the median tollway commuter in the high-income group travels around 60 miles per day. The median tollway commute among residents of the low-income zip codes is nearly 20 percent longer (approximately 72 miles per day). These differences get magnified substantially in the

TABLE 3

Trip distance and toll payments of likely tollway commuters, by income group

Panel A. One-way total distance to work, including tollway and nontollway segments

Income group	10th percentile	25th percentile	Median	75th percentile	90th percentile	Interquartile range
	(- - - - - -	- - - - - -	- - miles - -	- - - - - -	- - - - - -	- -)
Low	26.2	29.9	36.0	44.5	78.9	14.6
Middle	21.9	26.1	34.1	49.9	64.9	23.8
High	21.1	24.0	29.2	33.6	40.2	9.6

Panel B. Annual toll payments before the toll increase, assuming 240 workdays and one round trip each workday

Income group	10th percentile	25th percentile	Median	75th percentile	90th percentile	Interquartile range
	(- - - - - -	- - - - - -	- - dollars - -	- - - - - -	- - - - - -	- -)
Low	244	248	286	374	518	126
Middle	225	255	314	373	457	118
High	215	236	267	323	385	87

Notes: Likely tollway commuters are defined as those who do drive to work and whose residence and work locations suggest tollway commutes. The low-income group consists of zip codes with a median household income below $60,000. The middle-income group consists of zip codes with a median household income between $60,000 and $80,000. The high-income group consists of zip codes with a median household income above $80,000.
Sources: Authors' calculations based on data from the Illinois State Toll Highway Authority and U.S. Census Bureau, 2000 U.S. Census.

TABLE 4

I-PASS ownership ratios, by income group

Income group	Relative to adult population		Relative to workers who drive to work		Relative to likely tollway commuters	
	Aug. 2004	Feb. 2005	Aug. 2004	Feb. 2005	Aug. 2004	Feb. 2005
	(- - - - - -	- - - - - -	- - - - percentage	points - - - -	- - - - - -	- -)
Low	2.7	5.2	6.8	13.4	48.2	95.0
Middle	10.6	18.3	20.3	34.8	104.2	179.1
High	26.5	39.9	46.7	70.2	166.0	249.5

Notes: The adult population includes everyone aged 16 years and older (legal driving age in Illinois). The population of workers who drive to work is determined on the basis of the Census Transportation Planning Package 2000, "Journey-to-Work." Likely tollway commuters are defined as those who do drive to work and whose residence and work locations suggest tollway commutes. The low-income group consists of zip codes with a median household income below $60,000. The middle-income group consists of zip codes with a median household income between $60,000 and $80,000. The high-income group consists of zip codes with a median household income above $80,000.
Sources: Authors' calculations based on data from the Illinois State Toll Highway Authority and U.S. Census Bureau, 2000 U.S. Census.

tails of the distribution. About 10 percent of tollway drivers in low-income zip codes travel in excess of 150 miles per day just to get to work and back, while a comparable figure for high-income zip codes is "only" around 80 miles! However, the disparities in total toll payments across income groups are not nearly as dramatic (see panel B of table 3). Indeed, the median drivers in all three income groups pay approximately the same amount in tolls. This result serves as yet another indicator that low-income tollway users spend a smaller fraction of their overall commute on the tollway, as they live in neighborhoods farther away from the toll road network.

Table 4 allows us to compare I-PASS ownership before and after the change in the price for cash tolls across income groups for three different population slices: the adult population (that is, those of legal driving age, which is 16 in Illinois), the number of workers who drive to work, and the number of such drivers who would be likely to use the toll roads.[27] The results for these three different denominators essentially parallel each other, and thus, we focus on the likely toll road commuters for convenience. Even prior to the increase in cash tolls (in August 2004), the number of I-PASS transponders approximately equaled the number of likely tollway commuters for the middle-income group, and exceeded it substantially for the high-income group. In contrast, I-PASS penetration among residents in low-income zip codes stood at about 50 percent of the likely daily tollway commuters.

The dramatic relative price change on January 1, 2005, and the concurrent advertising campaign were sufficient to boost percentages across all income groups, while roughly preserving dramatic differences in relative levels of ownership. After the toll price change, I-PASS penetration among likely tollway drivers reached 95 percent for the low-income group. Among residents of the more affluent neighborhoods, I-PASS ownership vastly exceeded the number of the daily tollway commuters, suggesting the appeal of the electronic payment option even for the occasional tollway drivers in those areas.

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

Regression analysis of I-PASS ownership

There are two key questions that cannot be resolved with the simple bivariate contrasts presented in the previous section. First, did variables associated with the daily tollway commute—distance, cost, and congestion—affect the payment choice either before or after the pricing change? And second, did different aspects of the pricing change—higher cash toll payments and exposure to advertising—have a differential effect on the payment choice of different income groups? These questions can only be entertained in a multivariate regression framework, to which we turn next.

The econometric model and variable selection

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

$$6)\quad \ln[(i/p)_z / (1 - i/p)_z] = \beta X_z + \varepsilon_z ,$$

which is estimated by weighted least squares to account for heteroscedasticity 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 code z, and $\Lambda(\beta X_z)$ is based on first-stage (ordinary least squares, or 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, \$15,000–\$35,000, \$35,000–\$75,000, \$75,000–\$150,000, and above \$150,000, with households whose income is less than \$15,000 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 a zip code's population that are college graduates, as well as 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. To gauge the likelihood of using the tollway for *any* purpose, we include the distance to the nearest tollway exit from the zip code of residence. 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 equation 5 (p. 28).

The final subset of explanatory variables consists of the arguments of the I-PASS demand function for likely tollway users that commute to work daily, as outlined previously in the subsection where we discussed some accounting identities. These variables are available only for workers, and hence would be applicable to the I-PASS demand function of commuters only.[28] Specifically, these variables include weighted averages of the commuting time for likely tollway drivers, these drivers' estimated toll costs, and 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.

TABLE 5

I-PASS ownership prior to the toll rate increase for cash, August 2004

Weighted least squares logistic regression on zip-code-level grouped data

Dependent variable: **Share of zip codes with I-PASS relative to adult population**	**All observations**	**Greater Chicago area only**
Share of households with income in $15,000–$35,000 range	2.53 (2.1)	3.63 (2.0)
Share of households with income in $35,000–$75,000 range	5.18 (8.6)	6.17 (6.6)
Share of households with income in $75,000–$150,000 range	5.44 (8.1)	6.35 (6.3)
Share of households with income above $150,000	3.91 (5.8)	4.76 (4.6)
Share of population with a bachelor's degree or more	1.41 (6.4)	1.47 (4.9)
Share of recent immigrants	−0.83 (−2.6)	−0.85 (−2.0)
Share with I-PASS in neighboring zip codes in August 2004	1.95 (10.8)	1.82 (7.4)
Distance to the nearest tollway exit	−0.07 (−6.9)	−0.05 (−2.4)
Distance to the nearest Jewel-Osco store (miles)	−0.02 (−5.9)	−0.02 (−0.9)
Share of likely tollway commuters	0.35 (0.5)	0.19 (0.4)
Average travel time × Share of likely tollway commuters	0.04 (3.2)	0.04 (2.3)
Average toll costs × Share of likely tollway commuters	0.46 (0.7)	0.38 (−0.4)
Average share of I-PASS only lanes in July 2004 × Share of likely tollway commuters	2.97 (1.7)	3.47 (1.5)
Constant	−6.89	−7.78
Number of observations	547	271
Adjusted R-squared	0.86	0.84
Root mean square error	0.42	0.40

Notes: The *t* statistics are in parentheses, and the standard errors are not corrected for spatial correlation. The adult population includes everyone aged 16 years and older. Likely tollway commuters are defined as those who do drive to work and whose residence and work locations suggest tollway commutes. The second column of results drops all zip codes outside of Cook County, where the City of Chicago is located, and the six counties surrounding it. The U.S. Census defines recent immigrants as those who immigrated to the U.S. from 1990 through 2000.
Sources: Authors' calculations based on data from the Illinois State Toll Highway Authority and U.S. Census Bureau, 2000 U.S. Census.

As suggested by equation 5, each of these regressors is multiplied by the share of likely toll commuters, $(n/p)_z$, to account for the fact that they capture only a part of total I-PASS demand.

This model is used to analyze the tollway payment choice under the old, non-price-differentiated regime, as well as the choice to acquire the I-PASS under the new pricing regime. The null hypotheses—outlined in the section presenting our simple model of payment choice—form our benchmark for evaluating estimated regression coefficients.

The case of identical marginal prices for cash and I-PASS in 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 years and older in that zip code. We refer to this variable as "I-PASS ownership rate." Table 5 presents the results from estimating equation 6 on the joint Illinois Tollway–U.S. Census data set.[29]

The first column of results 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 $35,000 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 after controlling for direct effects of income. The share of population made up by recent immigrants has a negative effect on ownership shares; presumably, their costs would tend to be higher because of greater language and institutional knowledge barriers to obtaining I-PASS. Although this effect is statistically significant, it is not economically large as shown later. Still, other variables meant to gauge participation costs come in very strongly. In particular, all else being equal, I-PASS penetration rates are higher for those living closer to I-PASS retail outlets (Jewel-Osco 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.[30]

For the subset of "tollway travel" variables, we find higher I-PASS ownership for zip codes with higher shares of likely tollway drivers, as well as for zip codes where such likely tollway drivers face longer commutes to work. Those with commuting routes more heavily saturated with I-PASS only gates are only marginally more likely to own I-PASS transponders (p value of 0.09). These results line up well with the hypotheses outlined previously. 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 the 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 adjusted R-squared value of 0.86. 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 1 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 nonlinear 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 predict these effects at mean values of X by using

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

The strongest marginal effect derives from zip code concentration in the $75,000–$150,000 range. A zip code that consists of 29 percent of such households (75th percentile value) is estimated to have an I-PASS ownership rate that is 5.1 percentage points higher than a zip code in which only 14 percent of households fall in this income range (25th percentile value). At first glance, an increase of 5.1 percentage points may seem insignificant, but one needs to keep in mind that the unconditional mean of I-PASS ownership as a *fraction of population* aged 16 years and older amounted to only 12.9 percent in August 2004.[31] Relative to this benchmark, the estimated effects of moving from one end of the interquartile range to the other are as follows: share of college graduates (+1.3 percent), share of recent immigrants (–0.3 percent), distance to nearest Jewel-Osco store (–2.5 percent), distance to the tollway (–3.0 percent), commute time (+1.4 percent), share of I-PASS only lanes (+0.7 percent), and share of I-PASS penetration rates in neighboring zip codes (+3.0 percent). Thus, the key variables appear to be both economically and statistically significant.

We also 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 Cook County, where the City of Chicago is located, and the six counties surrounding it. 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 commutes, suggesting they place a somewhat lower value on electronic toll payment. The second column of results in table 5 suggests that the only difference from eliminating these distant zip codes is the disappearance of proximity to Jewel-Osco stores as an explanatory factor. Jewel-Osco 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 the distance to a Jewel-Osco store in the base case formulation may capture not only the higher cost of I-PASS acquisition for those living farther away from such a store, but also lower I-PASS demand among drivers living outside the greater Chicago area who have other commuting alternatives.

The pricing experiment: Doubling of cash tolls and using an advertising campaign

We look at the *change* in I-PASS ownership between August 2004 and February 2005 to analyze the effects of the pricing increase. 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 figure 6 (p. 32). To restate, the new pricing regime had two distinguishing characteristics: a dramatic change in relative prices for cash and electronic payments and a widespread advertising campaign that presumably lowered participation costs for I-PASS acquisition.[32] We are interested in whether these two effects had different (or any) effects for payment choice in each of the income groups. Given the very high rates of I-PASS participation among residents of wealthy zip codes (see table 4, p. 36) prior to the change and the parallel shift in ownership thereafter, we hypothesize that the incremental demand in 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 price change, to be affected by the toll hike for cash.

The regression results, presented in table 6, 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 high-income zip codes, the income distribution is not found to have any effect on the decision to acquire the I-PASS after the price change. For households in low-income zip codes, the coefficient for the fraction in the top income category stands out, largely because there are very few such households (1.5 percent) residing in these zip codes. 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.

The other variables associated with participation costs are neighboring zip code 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 middle-income zip codes, suggesting a possibility of stronger informal spillover effects there. Interestingly, living farther away from a Jewel-Osco grocery store is estimated to have a negative effect on I-PASS purchases after the toll hike for cash only in middle-income 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 6 reveals a strong positive effect of toll costs on *incremental* I-PASS ownership for low-income zip codes and virtually no effect for the two higher-income categories. In fact, for middle-income and high-income zip codes, the likelihood of acquiring I-PASS after the pricing change was negatively related to commuting time, suggesting that heavy commuters had likely purchased transponders well before the new regime went into effect.

In sum, we find some evidence that, on average, low-income zip codes responded to the cost doubling aspect of the toll pricing change, while medium-income and high-income neighborhoods were affected by the convenience of I-PASS acquisition through heavily advertised retail outlets. This breakdown is consistent with the picture presented in the summary tables, where the number of I-PASS accounts relative to the number of likely regular tollway users (that is, 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 who responded to the advertising campaign. I-PASS ownership in low-income zip codes also rose to include nearly all regular tollway commuters, who were apparently held back by high participation costs (whether real or perceived) and who were faced with the prospect of nominal toll outlays being doubled if they continued to shun the electronic payment option.

TABLE 6

Change in I-PASS ownership following the toll rate increase for cash

Weighted least squares logistic regression on zip-code-level grouped data

Dependent variable: Change in share of zip codes with I-PASS relative to adult population	Low-income	Middle-income	High-income
Share of households with income in $15,000–$35,000 range	−0.733 (−0.3)	2.197 (1.4)	−4.403 (−0.53)
Share of households with income in $35,000–$75,000 range	2.599 (2.6)	4.611 (4.3)	−0.158 (1.75)
Share of households with income in $75,000–$150,000 range	5.625 (5.6)	3.896 (4.0)	0.504 (0.52)
Share of households with income above $150,000	18.102 (18.1)	5.791 (2.5)	−0.170 (0.63)
Share of population with a bachelor's degree or more	−0.214 (−0.3)	0.116 (0.3)	−0.744 (0.21)
Share of recent immigrants	0.359 (0.7)	−0.035 (−0.1)	−0.495 (0.42)
Share with I-PASS in neighboring zip codes in August 2004	1.447 (5.7)	1.440 (5.7)	0.553 (2.69)
Distance to the nearest tollway exit	−0.058 (−4.2)	−0.059 (−5.9)	−0.063 (5.7)
Distance to the nearest Jewel-Osco store (miles)	0.008 (1.7)	−0.010 (−2.6)	−0.029 (−3.16)
Share of likely tollway commuters	−5.095 (−0.9)	5.600 (4.4)	4.871 (2.23)
Average travel time × Share of likely tollway commuters	0.002 (0.0)	−0.101 (−3.8)	−0.082 (−0.68)
Average toll costs × Share of likely tollway commuters	4.614 (2.1)	0.931 (0.9)	−0.262 (1.74)
Average share of I-PASS only lanes in January 2005 × Share of likely tollway commuters	20.031 (2.3)	−0.584 (−0.2)	−2.063 (0.77)
Constant	−5.637	−6.462	−1.361
Number of observations	137	263	151
Adjusted R-squared	0.78	0.78	0.51
Root mean square error	0.41	0.38	0.32

Notes: The *t* statistics are in parentheses, and standard errors are not corrected for spatial correlation. The new I-PASS owners are defined as February 2005 owners less the August 2004 owners. The adult population includes everyone aged 16 years and older. Likely tollway commuters are defined as those who do drive to work and whose residence and work locations suggest tollway commutes. The low-income group consists of zip codes with a median household income below $60,000. The middle-income group consists of zip codes with a median household income between $60,000 and $80,000. The high-income group consists of zip codes with a median household income above $80,000. The U.S. Census defines recent immigrants as those who immigrated to the U.S. from 1990 through 2000.

Sources: Authors' calculations based on data from the Illinois State Toll Highway Authority and U.S. Census Bureau, 2000 U.S. Census.

Conclusion

In an attempt to accelerate the adoption of its electronic payment system, the Illinois State Toll Highway Authority adopted a new toll pricing structure at the beginning of 2005 that strongly penalized cash payments. While in nominal terms the tolls were doubled for cash, as a percent of overall explicit and implicit outlays for autos, this toll hike was relatively small. Nonetheless, the pricing change induced a very broad spectrum of drivers to switch to electronic payment. Without more detailed information on those who use the toll roads 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 a further substantial increase in relative costs.

However, we find that following the price change, the number of I-PASS accounts among residents of low-income zip codes nearly reached the number of likely tollway commuters (presumably the group with the most intense demand). For residents in more affluent locales, I-PASS ownership levels greatly exceeded the number required to satisfy tollway commuting demand. The high levels of I-PASS ownership after the price change reflect occasional, non-work-related tollway use, which is likely more important in more affluent neighborhoods in part because they are often located relatively near the tollway. A variety of evidence suggests that income was an important determinant of I-PASS ownership. Our regression evidence further suggests that cost was a consideration for the low-income group, but not for the more affluent groups that were influenced by the ease of getting I-PASS.

The verdict on whether the price increase and the attendant jump in I-PASS ownership will result in congestion relief has to wait until the conclusion of the open road tolling construction program. However, the results of this natural experiment do suggest that a combination of mass marketing and toll price changes can redirect enough drivers from cash to electronic payment to allow congestion relief to move from the drawing board to the roadway.

NOTES

[1]A number of recent papers have studied other aspects of designing and implementing congestion relief policies. For instance, Small, Winston, and Yan (2005) obtain estimates of commuters' value of time using data on choices of the commuters who participate in the variable-pricing experiment in Orange County, CA. Small, Winston, and Yan (2006) focus on the design of optimal pricing policies, taking into account their political sustainability.

[2]In this article, both the system of roads and the Illinois State Toll Highway Authority itself are referred to as the Illinois Tollway.

[3]Open road tolling, also called "no-stop" tolling, refers to a toll road system on which payments are collected electronically from vehicles traveling at highway speeds.

[4]Although I-PASS is currently used as a congestion pricing mechanism for trucks, it is not currently used for this purpose for passenger cars.

[5]Texas Transportation Institute (2005).

[6]The Illinois Tollway is located in the northern part of the state with spokes going north to Wisconsin, west to Iowa, and south to northwestern Indiana from Chicago.

[7]This argument only works up to a point, since making roads less congested may invite enough new motorists to make traffic worse than it had been before. The behavioral response to a change in a decision-making environment is similar in spirit to the study by Peltzman (1975) on whether mandatory seat belt use generates an overall reduction in road fatalities.

[8]Governor Rod Blagojevich unveiled the plan on August 25, 2004, and the board of directors for the Illinois Tollway approved it on September 30, 2004.

[9]Open road tolling (no-stop toll payment collection) had been implemented at most toll plazas by the end of 2006.

[10]A detailed account of the assumptions used for this imputation is available on request.

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

[12]Whereas the costs of acquiring and maintaining an electronic transponder are similar for commuters and leisure drivers, greater tollway utilization by the former group necessarily generates higher monetary and time savings.

[13]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 motorists have the option of choosing another gate when it is seemingly going to be faster.

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

[15]One could assume that all remaining cash payers are transient drivers who view their tollway trips as one-time events. At the peak of the morning rush hour after the price hike, the fraction of cash payers (15.6 percent) seems too large for that to be a fully satisfactory explanation.

[16]Another disadvantage of I-PASS is the potential loss of privacy, which distinguishes it from cash; see appendix 3. Some motorists place a 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 quantify them empirically.

[17]The algorithm for gauging the likelihood of the tollway commute is described in detail in appendix 2.

[18]We also consider the case of separate demand functions for everyday and occasional commuters ($n^{d,t}$ and $n^{nd,t}$).

[19]The "zip code data" are actually reported by the U.S. Census-defined geographic areas called zip code tabulation areas (ZCTAs), which cover essentially the same geography with some minor differences. For a description of ZCTAs see www.census.gov/geo/ZCTA/zcta.html. For simplicity, we refer to ZCTAs as zip codes throughout this article.

[20]Stata programs used in constructing this data set are available upon request.

[21]We used the travel time for those who 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 who carpool, for example, could include several stops and would not be representative of the actual commute.

[22]In some cases the Illinois Tollway was not able to filter out commercial I-PASS accounts if the registrant gave a business address but applied under his/her own name. Therefore, there are a handful of zip codes that have too many I-PASS accounts per person to be plausible for personal use (a ratio of above one transponder per person). These zip codes are indicated as white areas in the maps and are ignored in the analysis.

[23] The three income groups (below $60,000, between $60,000 and $80,000, and above $80,000) are made up of 152, 271, and 138 zip codes, respectively. The cutoff points represent the 25th and 75th percentiles of working household income in the zip codes in our sample. Since figure 6 is centered on a smaller seven-county area, the income grouping appears biased toward the higher-income groups.

[24]Mainline plazas are not entry or exit points but rather through points where tolls are collected. Plazas at onramps and offramps are more likely to serve users from the distinct areas where they are located, whereas mainline plazas would likely serve users from any area geographically preceding it (in other words, mainline plazas would serve a more diverse population). It is also likely that mainline plazas see a higher rate of incidental travelers who drive longer distances than plazas at onramps and offramps.

[25]Around 70 percent of those plazas that did not have I-PASS lanes in July 2004 did receive at least one by January 2005. Only 25 percent 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 I-PASS lanes.

[26]Here, as elsewhere in this article, distance is measured between the centroids of two zip codes.

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

[28]For commuters judged likely not to use toll roads, 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, and other segments of the population without a daily commute to work.

[29]Most of the explanatory variables are time-invariant; that is, they are taken from the 2000 U.S. 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 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 in neighboring zip codes. Note that the first of these variables combines time-invariant origin–destination data from the U.S. Census with time-specific data from the Illinois Tollway that reflect current lane configuration.

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

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

[32]The advertising campaign made it easy to acquire information about the features of I-PASS accounts and to learn about the Illinois Tollway's plans for changes in lane configurations that favored electronic payments. The campaign also made obvious the large *relative* difference in cash toll prices, with the words "twice as much" and "double the cost" featured prominently in media coverage of the impending change.

APPENDIX 1. CONVERTING THE PAYMENT MODE MODEL TO AN ECONOMETRIC MODEL: AN ILLUSTRATIVE EXAMPLE

To map the simple framework of equation 4 (p. 26) to data, one needs to assume a specific functional form for preferences. As an example, we analyze the constant elasticity of substitution (CES) preference specification.[1] 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 an individual's demographics, such as education level and/or access to low-cost subscription technologies, for example, the Internet.

Then for the I-PASS transponder choice T of individual i, equation 3 (p. 26) becomes

A1) $$G_{i,T} = V_i + w_i \times H_i - O - F(E_i, w_i) - N_i \times m_T,$$

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

And for the other two lane choices, the exact change lane or attendant lane, equation 3 becomes

A2) $$G_{i,e} = V_i + w_i \times H_i - N_i \times m_T.$$

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 (for example, 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 equation 2 (p. 26) as

A3) $$L_{i,T} = (24 \times 60) - H(w_i) - N_i \times t_T \times L.$$

Let the CES utility be given by the following:

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

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 distributed.[2] Using equation 4, the probability of signing up for an I-PASS, which costs more but saves on travel time, is equivalent to:

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

Using the expressions for L, G , and $c(t)$ from equations A3 and A1 and approximating $c'(t)$ by Δc, we obtain:

A4)
$$\text{prob}(\textit{I-PASS chosen over other alternatives}) =$$
$$\text{prob}\begin{pmatrix} -\ln(h) + \ln\left(O + F(E_i, w_i) + N(m_T - m_e)\right) \\ +(1+\rho)\ln\begin{pmatrix} [(24 \times 60) - H(w_i) - N_i \times t_T] \\ /[V_i + Hw_i - O - F(E_i, w_i) \\ -N_i \times m_T] \end{pmatrix} \leq \ln\varepsilon \end{pmatrix}.$$

Our discussion here has focused on the choice between the I-PASS and a *single* alternative (say, the exact change toll). Consequently, the binary specification in equation A4 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.

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

[2]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 2. CONSTRUCTING ZIP CODE MEASURES FOR DAILY COMMUTES AND TOLLWAY VERSUS FREEWAY CHOICE

The U.S. Census provides detailed information on home-to-work commutes at the level of census *tract*, a geographical unit that is generally 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 census tracts 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 these 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 the geographic distribution of workers over a given census tract, we made the simplifying assumption that they were evenly distributed. 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 come in pairs relating to a commute pattern, this allocation must be performed for both the origin and destination census tracts. Once all of the workers of these census tract commute pairs were assigned proportionally to zip code commute pairs, the worker data could be summed up by unique zip code pairs. We then calculated a weighted average of travel time and income, using as weights the proportion of workers in a specific census tract pair to total workers residing in a given zip code. 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 Illinois 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 it 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, we used Maptitude to assist in this determination. First, we used this mapping software to create a file that contained the longitude and latitude of the center points of all zip codes in our sample. From this file, we were able to determine the straight-line distance (as the crow flies) between all of our zip code pairs and what direction the destination is from the origin.

Next, Maptitude includes a point layer that details the longitude and latitude of all exits on all highways as well as toll plaza points on tollways.[1] We merged these data with information from the Illinois Tollway's website detailing which of these points allow a vehicle to get on or off the tollway and in what direction. The file on zip code geography was matched to the exit file. We then selected the two closest onramps to each origin zip code and the two closest offramps to each destination zip code that allowed the commuter to go in the direction of her 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.[2] We then picked the shortest commute pattern for each zip code 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 drive on more convenient freeways at their disposal. To resolve this, we need a model of tollway versus freeway choice. Clearly, commuters living farther away 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 nontollway 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—that is, on such routes, motorists might encounter a greater number of irritations along the way in the course of numerous daily commutes.

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 code centroids, say, $\overrightarrow{AB}_{cf}$, was at least X percent of the distance from the center of zip code A to zip code B using the tollway, $\overrightarrow{AB}_{tw}$, then the motorist would use the tollway. That is, if $\overrightarrow{AB}_{cf} > X \times \overrightarrow{AB}_{tw}$, then the motorist would use the tollway; otherwise the motorist would not. The value we settled on for X is described in the following paragraphs.

We used MapQuest to determine whether this common online direction tool would indicate using the tollway between each of our zip code pairs. A comparison of MapQuest predictions with the simple geometric measure revealed a fair number of inconsistencies. In most cases, for zip code pairs that were designated for tollway travel by the "crow flies" model, but not by MapQuest, the total distance traveled was relatively large. Similarly, the opposite was true when travel distances were relatively small.

We then needed a way to determine which of the two approaches was a better predictor of tollway use. We chose to do this by comparing the average number of vehicles that entered and exited the tollway on each onramp and offramp during the rush-hour period with the number of workers we expected to do so based on each of the two models. Both methods worked fairly well, but the "crow flies" model had a better fit for longer distances and the MapQuest method for shorter ones. Because MapQuest calculates paths based on perfect driving conditions, this discrepancy may be explained by the fact that during rush-hour commutes, the longer one travels, the more opportunities there are for adjusting one's route in response to road conditions.[3]

Finally, we decided to combine the two methods, allowing MapQuest to indicate tollway use for shorter distances and the "crow flies" method for longer distances. The cutoff that we found to maximize the latter method's precision was 0.49. In other words, it was assumed that in a populated area, such as the greater Chicagoland area, there would be another route between the two points that would take less than the tollway travel time if the tollway route is more than about twice the direct distance. Overall, the distance threshold that maximized the accuracy of the combined model was 18 miles. In sum, if the distance between two zip code center points was less than or equal to 18 miles, we let MapQuest determine if the tollway was the preferred route; if the distance between the zip codes was greater than 18 miles, our "crow flies" model would indicate toll road use if the path along the toll road was less than twice as long as the actual distance between the zip code pair. This hybrid model had a correlation of around 0.8 with the rush-hour vehicle data.

[1]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.

[2]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 assume that the commuter does not take the tollway to get to work.

[3]There is also a geographic reason why the "crow flies" approach works in the outer counties. In the absence of natural barriers on the flat Illinois prairie, outer counties have a grid-like pattern of town, county, and state roads, which almost always provides simple alternatives to toll or interstate roads and which natives from the region intuit. In urban areas, these alternatives are more difficult to divine without local knowledge that takes into account the existence of more barriers to the free flow of traffic.

APPENDIX 3. SURVEY INFORMATION ON REASONS WHY ILLINOIS 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 Illinois Tollway users at five locations: one plaza each on the North-South Tollway (I-355) and the North Tri-State Tollway (I-94/I-294) and three locations around I-55, which lies near the Illinois Tollway. The survey collected information about the origin and destination of a particular trip, the purpose of the trip, the trip's frequency, vehicle occupancy, and vehicle type. Respondents were asked whether they owned an I-PASS. Those who did not own an I-PASS were asked two final survey questions: Why have you not purchased I-PASS and 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.[1]

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 of 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*. Those respondents who 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 who traveled less frequently than weekly, they most often answered that they had not purchased an I-PASS because they rarely used the toll roads. In over 20 percent of returned surveys, 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.[2]

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 they 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 was likely to happen across all groups of Illinois Tollway motorists.

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

[2]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, which is not actually the case.

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