

**The Demand Curve Under Road Pricing and
the Problem of Political Feasibility**

Charles Lave

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THE DEMAND CURVE UNDER ROAD PRICING AND THE PROBLEM OF POLITICAL FEASIBILITY

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Abstract—Road pricing is widely advocated as a solution to congestion problems. The underlying theory is well developed, and we even have the technology to implement it without toll booths. Only political barriers remain. Decision makers are reluctant to retrofit tolls on existing highways because they do not know what circumstances might make such an action acceptable to the public. This paper develops a graphical model that displays the interaction between road capacity, user demand, travel speed and toll charges. The model is then used to analyze the sources of public resistance to road pricing. Might the potential response to road pricing be predicted using data from the new toll roads now being built around the United States? Our model shows it cannot. Political success depends on the demand characteristics at the right-hand side of the demand curve, while toll road data only trace out the left-hand side of the curve. Our model also shows situations where the new toll roads are likely to generate public anger. The Appendix discusses an experimental design that uses unobtrusive measures to assess the effect of a transportation project.

1 INTRODUCTION

This paper develops a new way to depict the demand for travel on a priced road, and then uses this tool to analyze two important questions. First, what factors determine whether road pricing will be politically acceptable? Second, what might we learn about road pricing from the toll road experiments planned around the United States?

Is road pricing a feasible method for reducing traffic congestion? Economists argue that road pricing would be an effective way to deal with congestion (Small, 1993), and there is strong empirical evidence that raising the cost to use some given road segment will actually reduce demand for its use (two good collections of articles are Button, 1986, and Small, 1993). But implementation hinges on a political question: Will it be politically feasible to impose road pricing on existing highways?

It has been proposed to answer the feasibility question by studying public acceptance of the new toll roads that will soon be opened around the U S (Poole, 1993). These roads seem like a felicitous natural experiment: We can see how drivers respond when they are asked to pay for the privilege of using a highway. Unfortunately, this is not the experiment we need. The analysis developed here shows that new toll roads and retrofitting prices on existing roads are likely to be perceived by drivers as two fundamentally different situations. Hence, the data derived from a new roadway cannot tell us about the driver responses that would occur if we imposed user charges on an existing roadway. Furthermore, the analysis highlights conditions where the new toll roads, themselves, are likely to generate considerable political problems.

2 THE DEMAND CURVE IF ROAD PRICING IS IMPOSED

We want to picture the driver's demand for a highway once a user fee is imposed on it. Demand is a function of price and speed—drivers will pay more for a high-speed journey than a congested one. But speed is related to the number of users. Thus, the demand curve for a priced highway must show the interaction between three factors: the fee (cents per mile), the number of drivers who want to use the highway and the speed. How can we depict such a curve?

Hau (1993) provides a complex representation. The solution developed here is simpler: I define each speed as a separate commodity (e.g. the driver chooses between buying

a 25-mph trip and a 40-mph trip) Thus, one demand curve shows drivers' demand for travel at 25 mph, another curve shows drivers' demand for travel at 40 mph, etc. Figure 1 shows the family of demand curves The top curve shows demand for 55-mph travel in some given geographic area As the user fee drops, more drivers want to buy this 55-mph commodity. The curve slopes downward for two reasons. (a) The value of time differs across individuals; and (b) given the diversity of origins and destinations, some drivers have better alternatives than others. At the right-hand end of the demand curve are drivers with low value of time, or good alternative routes or flexibility to postpone the trip to another hour. At the left-hand end of the demand curve are drivers with high value of time, or poor alternative routes or inflexible schedules The successive curves move upward because at any given price, more drivers are interested in using a high-speed road than a low-speed road

Consider the equilibrium on a no-fee highway The horizontal axis of the graph corresponds to a price of zero. At zero price, Q_1 number of drivers would want to use this highway if its average speed were 25 mph, but more drivers, Q_4 , would want to use it if the average speed were 55 mph Now suppose that the physical capacity of this highway is Q_1 cars per hour; the equilibrium speed will be 25 mph Suppose we had started with fewer than Q_1 users The absence of congestion permits a speed higher than 25 mph, but that higher speed attracts more drivers As more drivers enter the road, average speed falls until it reaches 25 mph at Q_1 If the capacity of the highway had been Q_4 , then equilibrium would have occurred at an average speed of 55 mph

Consider next road pricing. Assume we start with a congested highway Q_1 physical capacity and a 25-mph equilibrium Suppose we want to decrease congestion enough to increase the speed to 40 mph. We look in the highway capacity manual and discover that a reduction of traffic to Q_2 cars per hour will produce a 40-mph speed. So how do we get $(Q_1 - Q_2)$ cars to leave the highway? Drivers are now operating on the 25-mph demand curve; a price of P_1 intersects that demand curve at B and lowers the quantity demanded to Q_2 cars—only Q_2 cars are willing to pay P_1 to travel 25 mph Once $(Q_1 - Q_2)$ cars leave the road, the average speed will increase to 40 mph But at a price of P_1 and a speed of 40 mph, demand increases to point C , which, of course, creates enough congestion to lower speed below 40 mph. In fact then, it is the intersection of the 40-mph throughput constraint with the 40-mph demand curve that we need: A price of P_2 reduces demand to Q_2 . D is the equilibrium, not B

Likewise, to find the price where traffic flows at 55 mph, we find from the highway capacity manual that we must reduce demand to Q_3 cars Then look at the intersection of

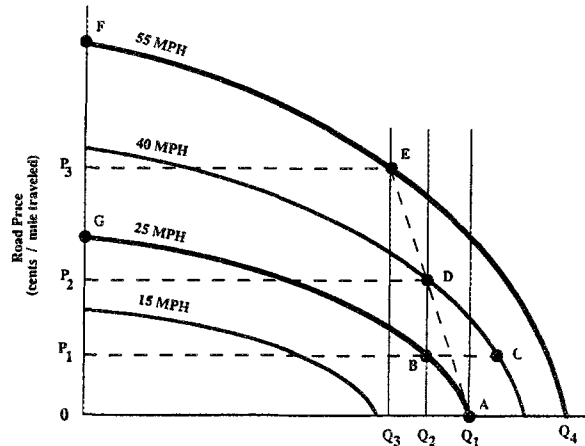


Fig. 1 Number of people who wish to travel at the given speed Diversion of drivers away from the road after a user-fee is imposed on it

Q_3 with the 55-mph demand curve, point E , to see that a price of P_3 will produce the necessary reduction in vehicles.

Finally, we might construct a composite demand curve that incorporated the three-way relationship between price, usage and speed. It would be the points $ADEF$ (assuming a 55-mph speed limit keeps users on the EF portion of the curve)

2.1 Welfare analysis of a road under road pricing

Consider the consumer welfare implications of road pricing for this particular set of demand curves. With no fee, the speed was 25 mph, and the aggregate consumer surplus was the area bounded by points AGO . A fee of P_3 results in an average speed of 55 mph, with consumer surplus of AFP_3 . That is, with this set of demand curves, aggregate consumer surplus might actually fall: Clearly the new area, AFP_3 , is smaller than the old area, AGO , so the change in consumers surplus depends on how the government uses the new toll revenue, Q_3EP_3O . If the revenue is spent on projects that are valued by the drivers, consumer surplus rises; if the revenue is spent on projects that the drivers do not value, consumer surplus falls.

Figure 2 shows another possible set of demand curves. Some drivers value driving at 55 mph very highly; they have few alternatives, little flexibility or high value of time. Some drivers value driving at 55 mph a medium amount, and some only a little. For this set of demand curves, road pricing increases aggregate consumer surplus, regardless of what is done with the fees. Area CFP_2 is greater than area Q_1DO .

Figure 3 repeats the demand curves from Fig. 1. Almost everyone highly values going 55 mph. Depending on how the government spends the new revenue, aggregate consumer surplus can fall. Now let's see how this kind of analysis can be used to explore the political feasibility of road pricing.

3 POLITICAL FEASIBILITY

Will the public accept a user fee that is imposed on an existing highway? This is the key issue in the whole road-pricing debate. (For two recent treatments, see Gomez-Ibanez, 1992, and Giuliano, 1993.) It seems reasonable to postulate that acceptance depends on a major condition: The amount of inconvenience to those drivers who are pushed off by the new fees must be quite low compared to the gain for the drivers who remain. Some road-pricing advocates take this outcome for granted. They argue something like this. Suppose we now have a very congested highway carrying roughly 2000 cars per lane-hour;

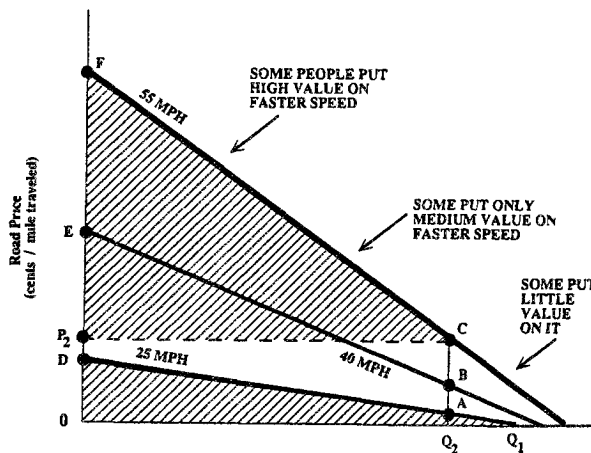


Fig 2 Number of people who wish to travel at the given speed. Change in consumer surplus after a user-fee is imposed

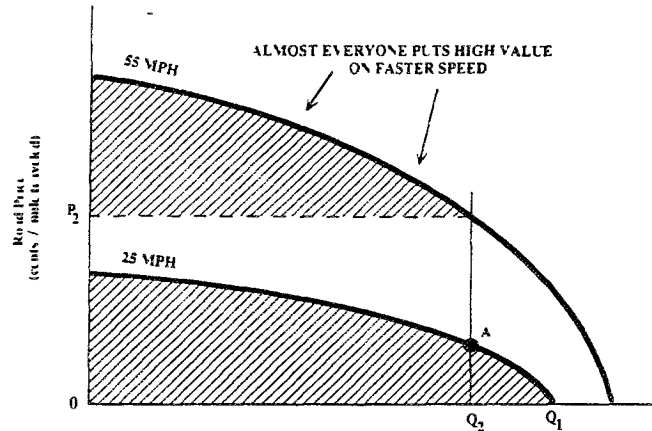


Fig 3 Number of people who wish to travel at the given speed Change in consumer surplus after a user-fee is imposed

we choose a fee sufficient to push 100 users off the highway; traffic then flows smoothly; 1900 persons gain and only 100 lose; thus the public should be happy

But it is not sufficient that the number of losers is small. Political acceptance also depends on the change in utility. If road pricing is to be politically acceptable, we need to satisfy three conditions:

1. The loss in utility to those pushed off is small—perhaps they have good alternatives, and so are quite willing to move
2. The gain in utility of the users is large—perhaps they get a substantial time savings while paying only a small road fee
3. The proportion of losers to gainers must be low

The proportion of losers, and the size of their loss, depends on the shape of the demand curve. Assume it looks like Fig. 2. In the absence of fees, the highway is in equilibrium at Q_1 with a \$0 fee. A fee of P_2 , say 5 cents per mile, suffices to reduce usage and move the equilibrium to Q_2 . The drivers who leave lose little utility (area Q_1AQ_2) because they have low value of time or excellent alternatives—perhaps the local road network is good, or the freeway leg of their trip was short, or perhaps they suffer only a small inconvenience from postponing the trip to a later hour. Almost all those drivers who remain gain a great deal of utility (as explained in the next section). Under these circumstances, few will protest and many will support the toll. Political acceptability is likely.

But suppose the demand curves look like Fig. 3. We need a high fee, say 15 cents per mile, to remove enough drivers. Those who are pushed off lose a substantial amount of consumer surplus, area Q_2AQ_1 . The large loss makes them likely to protest strongly, show up at hearings, write letters, etc. Now consider the drivers who remain. They have lost a substantial amount of utility: The user fees seem to wipe out most of the benefit associated with the higher travel speed. (For the moment, assume these motorists do not place much value on those things for which the user fees are to be spent. The basis for their subjective reaction is discussed later.)

3.1 Who wins, who whines?

Let's look more closely at the ratio of winners to losers after user fees are imposed on a road. In Fig. 4, all drivers who wish to use the road have been ranked, with the driver willing to pay the most, Jim, on the extreme left; Dan and Ed do not value 55 mph as much. We impose a user fee, P_2 , to force some drivers off the road. How many losers will there be? Let's enumerate them: Any driver who is priced off the road is worse off. But even some of the drivers who continue using the road will be worse off unless the

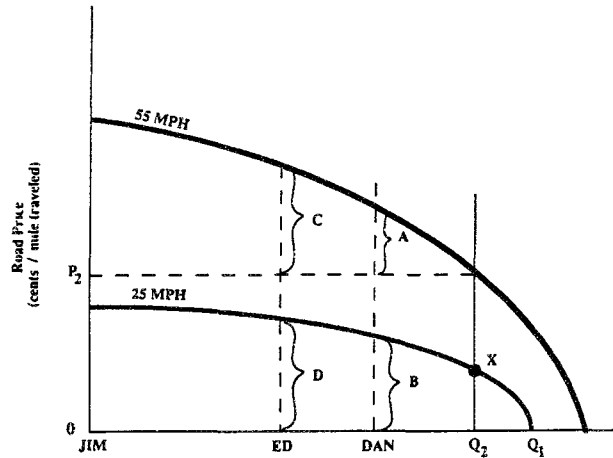


Fig 4 Number of people who wish to travel at the given speed Congestion-pricing who wins, who whines?

government uses the fee revenues for things the drivers value. Dan is worse off – he still uses the road but his perceived consumer surplus has been reduced ($A < B$) For Ed, C and D are equal, so Ed's perceived consumer surplus is unchanged. Thus all drivers to the right of Ed may perceive that they are worse off after the fee is imposed, and their political actions will depend on these perceptions.

Suppose the government says it will use the fee revenues to reduce general taxes. How will this promise be perceived? Consider a driver who is forced off the freeway. Twice a day he passes that freeway and is reminded that he cannot afford it anymore. But only once a year, at income tax time, does he benefit from the lower tax. Furthermore, the tax reduction will be small and hence hard to perceive (\$250 per year from a \$1 dollar daily fee). The driver may even be skeptical that there was any tax reduction at all since he knows that such promises are often just political talk.

That is, the cost to those who are priced off the road is direct, immediate and rubbed in twice a day. The benefits are at best indirect, distant and diffuse – considering them to be mere political rhetoric, drivers may disregard them entirely. (The perception problem is discussed in Button, 1984.) There used to be Q_1 users, so all the drivers between Ed and Q_1 are likely to perceive themselves as worse off than they were before. Even if this were only 25% of the former users, that is a lot of potential protestors, probably enough to stop road pricing on this particular road. In this case, there is political trouble because of the high proportion of losers. It is also possible to encounter strong political opposition with only a few losers if the loss of utility per driver is high. Consider those drivers who are priced off (those between Q_1 and Q_2): Since their loss of consumer surplus, Q_1Q_2X , is large, they are likely to be very determined opponents of road pricing.

In conclusion, the right-hand end of the demand curve is critical to determining the ratio of winners to losers and the intensity of their feelings, and hence the political acceptability of road pricing. In the next section I show that the data generated by the toll road experiments will only tell us about the shape at the left-hand side of the demand curve. That is, they will not tell us what we need to know.

4 THE DEMAND CURVE FOR A PARALLEL TOLL ROAD

A number of places around the U.S. are building toll roads to supplement an existing congested highway system. Is it possible to use these toll roads as a natural experiment to test the efficacy and political acceptability of road pricing? This section shows that such data will not provide the information we need: No driver will be priced off the existing road, so we will learn nothing about the willingness to leave (the shape of the right-hand end of the demand curve). Instead the toll roads will lure away those existing users who

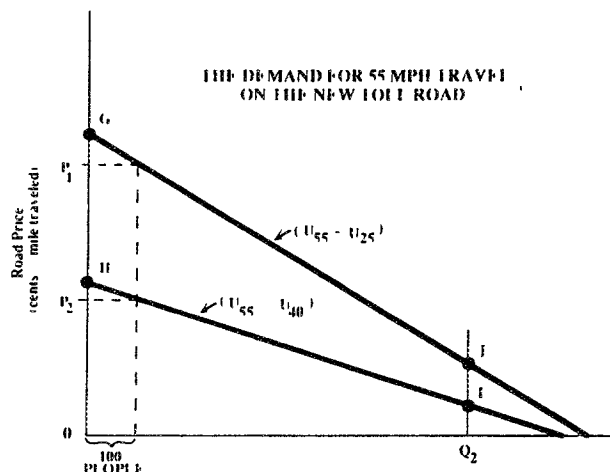


Fig. 5 Number of people who wish to travel at the given speed. Diversion of drivers between free-road and toll-road

highly value speed (the ones on the left-hand end). Political feasibility depends on the shape of the right-hand portion of the demand curve, the toll road data only trace out the shape of the left-hand end of the curve.

Consider a typical toll road experiment. A new highway (or a new lane) will be built parallel to the existing free road. The driver's decision becomes, "Shall I continue to use the existing free road, or shall I switch to the new road and pay extra to go faster?" Imagine a driver located at point Q_2 in Fig. 2. The value associated with going 55 mph is C . How much will he pay for the privilege of using the 55-mph road? The answer is not P_2 because his improvement in utility is not C , it is only $C - A$: He already receives A amount of utility from the 25-mph free road.¹ Additionally, consider the individual at the extreme left-hand side of the demand curve. If he switches to the toll road, his utility increases by $F - D$, so that is the maximum price he would pay.

Figure 5 shows curves that describe the demand for 55-mph travel on the new toll road. These curves determine the switching decision: stay put or move to the toll road? The top curve $U_{55} - U_{25}$ shows the utility associated with moving between the existing 25-mph road and the new 55-mph toll road. $U_{55} - U_{25}$ is the result of subtracting the 25-mph demand curve in Fig. 2 from the 55-mph demand curve. That is, point G in Fig. 5 is equal to the quantity $F - D$ in Fig. 2; and point J is equal to the quantity $C - A$. (We have also drawn in the demand curve that describes the decision for switching between a 40-mph highway and 55-mph highway. Point H in Fig. 4 is equal to the quantity $F - E$ in Fig. 2; point I is equal to $C - B$.)

Suppose we set the fee on the new toll road at P_1 in Fig. 5. Initially, 100 drivers will be diverted from the free road to the toll road. But if 100 drivers leave the free road, its congestion drops and its average speed rises to 40 mph. Toll road users will notice that they are only getting a 15-mph speed advantage over the old road instead of the 30-mph speed advantage they paid for. Curve $U_{55} - U_{40}$ shows what they are willing to pay for a 15-mph increase. In fact, the toll that will divert 100 users is P_2 : At that price, 100 users will leave the free road to travel at 55 mph on the toll road; the remaining users of the free road will increase their speed to 40 mph.

Two things are notable about this result: First, the users who switch to the new road are from the left-hand end of the demand curve (assuming the curves converge monotonically), hence the toll road experiment will trace out the shape of the left-hand end of the curve — which is not the data we need.

¹In the toll road case, he compares the move to the free alternative (stay put on the 25-mph road) and acts in terms of the difference. In the road-pricing case, the 25-mph road is not an alternative because a user fee was placed on it. He pays the new fee or gets off.

Second, toll road customers are not paying for absolute speed, they are paying for *relative* speed. Even though the toll road has the capacity to handle more cars, it must not do so lest the free road speed up too much. Tolls must be set so high that only a few of the current old road users are interested in switching. The toll road will operate well below its capacity. Thus, almost all drivers will still be mired in traffic on the free road, staring at an essentially empty toll road whose price is set at prohibitive levels. They are stuck while the solution to their problem, the parallel road, remains empty and priced out of reach. This outcome seems certain to produce public anger. (Suppose we build a one-lane toll road to relieve congestion on a parallel four-lane free road. As an approximation, removing 100 cars per hour from a 25-mph congested lane will increase its speed to 40 mph, so the four no-fee lanes can contribute a total of only 400 cars to the toll road. This is much less than the capacity of the toll road. But if the authorities lower the toll, to allow more users to afford the toll road, they will decongest the unpriced lanes and the toll road will no longer have a speed advantage to sell.)

5 WHAT WE CAN LEARN FROM A TOLL ROAD EXPERIMENT

Even though they cannot evaluate the political feasibility of road pricing, toll road experiments are still well worth pursuing. They can test public response to time-of-day pricing. They can test, and debug, the automatic vehicle identification and billing system. And they are a useful step in educating the public to the notion that road use is not necessarily free.

5.1 *Using a fixed toll to evaluate variable pricing*

Economists envision different prices throughout the day—high at peak periods and low when congestion is less severe. How will the public react to the price variability? Will drivers be willing to make the necessary decision each time they begin a new journey: “Given the difference in dollar costs and congestion levels between the free network and the tolled network, which should I use?”

At first glance, data from many of the proposed toll road experiments do not seem useful for evaluating this question since many of the proposed toll roads will have a fixed price throughout the day. However, these data can be used to evaluate motorists’ reactions to time-of-day pricing. To see this, perform a simple thought experiment.

Imagine a congested freeway that runs north and south, and an uncongested toll road that parallels it. And imagine a driver at the south end of these roads, considering whether to use the toll road or the freeway. She makes her choice by balancing the toll against the time difference between the alternatives. She will happily pay the toll to save, say, 20 minutes; but she chooses the freeway when the time saving falls to only five minutes. It is the cost per minute of saved time that determines her decision, not the absolute size of the toll. As the relative congestion between the two roads varies over the day, the cost per saved minute will vary as well, even though the toll is fixed. Under time-of-day pricing, the cost per saved minute varies as a function of both relative congestion and the variable toll. In the toll road experiments, only one of these will vary, but for analytic purposes the situation is identical.

5.2 *Testing the billing and automatic vehicle identification systems*

The startup period for new technologies is likely to produce problems (e.g. the early experience with the fare card system on the Washington Metro, the automatic train control system on the Bay Area Rapid Transit system, the door actuation system on the Boeing Light Rail Vehicle in Boston and so on). It seems likely that the startup period for the new automatic vehicle identification (AVI) system, and the automated billing system that are to be used by the toll roads, will produce problems too. So the chance for a realistic test is a valuable opportunity, since both these technologies are vital to a road-pricing scheme. We do not want to incur the danger that the concept of road pricing will be condemned because of public frustration with the failures of the peripheral technologies in a “guilt by association” process.

5.3. *The pricing precedent*

Finally, a toll road experiment can acclimate the public to the notion that road use can be priced. This is especially valuable on the West Coast, where drivers have no historic experience with toll roads.

6 MIGHT WE MODEL THE RIGHT-HAND END?

Can we model the shape of the right-hand portion of the demand curve using other known data? What would we need to know? If a fee were imposed on an existing road, driver reactions would depend on two things: how much they value a minute of saved time, and the number of minutes lost if they get off the newly priced road. The interaction of these two parameters determines the response elasticity.

The first parameter, value of time, is a stable, predictable behavioral parameter that has been well studied in the literature (Hensher, 1989). We know it is a function of personal characteristics: The main determinants are income and trip purpose. But the second parameter, time lost, will seem almost random in any given situation because it depends on so many other factors. It varies with all the characteristics of the area, the trip and the time of day. To estimate the amount of time lost, we need to know the person's origin and destination, the average speed of the alternative routes between these points, the average speed and cost of the alternative modes and even the alternative ways that this trip purpose might be achieved such as chaining it to another trip or postponing it until later.

Thus, to model the right-hand end of the demand curve we require (a) a complete traffic flow model (traffic volumes and speeds for the whole road network) and (b) a complete description of the trips and the drivers (the origin and destination of each trip, any desired trip chaining, the desired arrival times and the value of time of the driver on each trip). This is a formidable amount of data, and it will require formidable computations to convert it into a demand curve.

It might be possible to collect all these data and do all these analyses, but it is not likely that anyone will attempt such a daunting task. Thus we cannot produce the information we need to determine political feasibility. The new data generated from the toll roads are not relevant, and the old data are too expensive to collect and process.

7 CONCLUSION

What does it mean to say we will test the concept of road pricing? We don't need an experiment to tell us that raising the cost of some link will divert drivers away from it, though public officials may need convincing. Rather, we need to explore the political response to pricing. How upset will drivers be when fees are imposed? What is the elasticity that relates public anger to the amount of disruption cost? This paper argues that the political response will depend on the relative numbers of losers and gainers and the amount of utility lost by those motorists who are priced off.

To depict these utilities, I develop a new way to analyze the demand curves for a highway with a user fee. I show that the losses and gains—the political impacts—are strongly dependent on how high the price must be set to push enough drivers off, and this depends on the shape at the right-hand end of the demand curve. But the toll road experiments involve an increment to capacity, new roads or new lanes. So the experiments are exploring the shape at the wrong end of the demand curve.

The toll road experiments will be useful in other ways. They explore drivers' responses to variable pricing, they provide a chance to debug the billing and AVI systems that will be vital to the success of a road pricing scheme and they acclimate the public to the possibility that roads might be priced.

Finally, the model shows that the toll roads, themselves, are likely to produce considerable public anger when they begin to operate. The great majority of motorists on the parallel free road will still be mired in traffic, while the apparent solution to their problem, an "unfairly expensive" toll road, sits essentially empty beside them.

Acknowledgements—In the early stages of this work, I benefited from discussing the issues with Jane Hall, in the later stages Amihai Glazer, Pete Fielding and Kenneth Small provided important help

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APPENDIX USING NONOBTRUSIVE MEASURES TO EVALUATE A NATURAL EXPERIMENT WITH CONGESTION CHARGES

Jane Hall and Charles Lave

We describe a measurement procedure that might be used to evaluate a road-pricing experiment. The procedure requires only minimal cooperation from a small group of commuters who will carry electronic sensors in their vehicles. Once signed up, there is no further intervention in their lives: no travel diaries or extensive questionnaires. This unobtrusive measurement procedure should be attractive for other kinds of policy evaluation and demonstration projects as well. Our procedure is described for the case of a new road proposed to be built in Southern California, but could also (and more productively) be used to evaluate how tolls affect behavior when they are added to an existing road.

Approval has been given to build a toll road in parallel with a highly congested freeway in Orange County, California. It will be financed by a combination of developer fees and government assistance. Designated the San Joaquin Hills Corridor (SJHC), the toll road will be 15 miles long and connects to the Interstate 5 and 405 freeways (I-5 and I-405) at its southern and northern ends. Utilizing the opening of the SJHC toll road as a natural experiment, we will focus on choices of drivers who live south of the toll road intersection. Which drivers will use the toll road, at what times of day, and for what purposes?

In overall terms, we will follow the behavior of a sample of drivers over time, starting from before the new toll road is opened. The primary observational tool will be automatic vehicle identification (AVI) technology. Each car in the sample will have an AVI plate, and there will be AVI detectors on the new toll road, the existing freeways, and the major parallel roads.

To simplify the study, we will use drivers who now travel what will become the full length of the SJHC toll road. We will identify potential candidates by a license plate study of vehicles at the north end of the SJHC/I-405 intersection, matching these against vehicle registration information to identify those whose homes are south of the SJHC/I-5 intersection. A random sample of these households will be selected and asked to participate in the study. As an incentive to participate, we will offer free tuneups to their vehicles (which will also allow us to do emissions monitoring of the vehicles). Participants will be asked to attach an AVI plate on their vehicles, and they will fill out a brief questionnaire listing basic demographic data and information about their current travel patterns.

We will have AVI detectors along the I-5 and I-405 freeways, the SJHC, the major parallel roads and in the neighborhoods of the participants. Starting about six months before the opening of the toll road, we will begin collecting baseline data on current travel patterns using the AVI detectors. (Although the AVI detectors do not identify which household member is using the vehicle, the initial questionnaire will discover the principal driver of each vehicle, and previous studies have shown that the principal user of a vehicle tends to be constant.)

Once the SJHC toll road is opened, we can monitor changes in travel patterns accurately and unobtrusively. We don't need daily travel diaries or further questionnaires. Our AVI detectors will record the daily decisions made by each driver. We expect the proportion of drivers using the toll road to vary as a function of the cost per saved minute and the household characteristics. (In the initial household interview we will ask whether commuters commonly run errands off the I-5 and/or the I-405. The frequency of such trip chaining will affect the observed percentage of daily diversions onto the toll road.)

With a monitoring period of a year, we can measure diversion effects. With a monitoring period of two to four years, we may be able to measure any home relocation effects as well.