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# Valuing Time and Reliability: Assessing the Evidence From Road Pricing Demonstrations

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## Abstract

This paper reports results from evaluations of two recent road pricing demonstrations in Southern California. These demonstration projects provide particularly useful opportunities for measuring commuters' values of time and reliability. Unlike most revealed preference studies of value of time, the choice to pay to use the toll facilities in these demonstrations is relatively independent from other travel choices such as whether to use public transit. Unlike most stated preference studies, the scenarios presented in these surveys are real ones that travelers have faced or know about from media coverage. By combining revealed and stated preference data, the studies have obtained enough independent variation in variables to disentangle effects of cost, time, and reliability, while still grounding the results in real behavior. Both sets of studies find that the value of time saved on the morning commute is quite high when based on revealed behavior (between $20 and $40 per hour), and more than 50% lower when based on hypothetical behavior. When satisfactorily identified, reliability is also valued quite highly. There is substantial heterogeneity in these values across the population, but it is difficult to isolate its exact origins.

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# Valuing Time and Reliability: Assessing the Evidence from Road Pricing Demonstrations

David Brownstone and Kenneth A. Small

Since 1994, a series of demonstration projects in the United States has provided some real-life experience with congestion pricing. One form, represented by two projects in southern California and one in the Houston area, combines pricing with priority for high-occupancy vehicles in the form of "High Occupancy/Toll" (HOT) lanes. In this scheme, a set of express lanes on an otherwise free and congested road offers high-quality service to people who are willing to pay a time-varying toll and/or who ride in carpools.

These projects provide an opportunity to study some behavioral parameters that are central to the evaluation of transportation projects. The most important is the "value of time" (VOT), i.e. the marginal rate of substitution of travel time for money in a travelers' indirect utility function. Another is the "value of reliability" (VOR), which measures willingness to pay for reductions in the day-to-day variability of travel times facing a particular type of trip. In addition, the extent of heterogeneity in VOT and VOR across the population of travelers has been shown to sometimes significantly affect project evaluation (Kenneth A. Small and Jia Yan [2001]).

This paper reviews and compares results on VOT, VOR, and their heterogeneity from five different data sets taken from the two HOT-lane projects in southern California. These projects provide particularly useful data for a number of reasons. First, the choice to pay to use the toll facilities is relatively independent from other travel choices because very little transit service exists on these corridors. Second, one of the projects contains sources of independent variation of travel time, reliability, and cost that makes it possible to sort out their separate effects on travel choices. Third, local travelers' familiarity with these projects, through direct experience or media coverage, makes it possible to collect "stated preference" (SP) data on hypothetical choices in a setting where travelers are likely to understand the context.

The ability to collect meaningful SP data presents an opportunity to examine reasons for the rather large differences seen in recent literature between estimated values of time from revealed preference (RP) studies and those from SP studies. It also opens the possibility of combining RP and SP data so as to simultaneously take advantage of the realism of the former and the controllability of the latter.

# I. Project Descriptions

The State Route 91 (SR91) facility in Orange County, California, is a privately-funded set of express lanes in the center of ten miles of the very congested Riverside Freeway, linking job centers in Orange and Los Angeles counties to outlying residential areas. It uses electronic toll collection and has a complex but preset time-varying pricing structure, presumably designed to maximize revenue for the private toll operator. Prices vary hour by hour and follow different schedules on different days of the week, including weekends. There are separate schedules for inbound and outbound directions, but all our data are inbound. See Edward Sullivan et al. (2000) for more information. Between 1996 and 2000, one of the authors of this paper (Small) and various colleagues have collected five separate data sets on this corridor, three of which are included in the comparisons of this paper.

The Interstate 15 (I-15) facility is a publicly-funded project that allows solo drivers to pay to use reversible carpool lanes over an eight-mile congested segment of the I-15 freeway linking San Diego employment centers with inland northern suburbs. The I-15 project also uses electronic toll collection, with carpools exempted. In this case, the price is varied in real time to prevent the express lanes from becoming congested, a procedure sometimes called "dynamic pricing." The other author of this paper (Brownstone) and his colleagues have surveyed five waves of a panel of travelers on this corridor; the third and fifth waves, collected in Fall 1998 and Fall 1999, are used in the results described here. See Golob and Golob (2001) and Golob et. al. (1998) for more information.

On both projects, the toll is announced on a message sign prior to the point where the driver has to choose which lane to enter.

The two projects differ in some ways that affect efforts to measure behavioral parameters. On SR91, the fixed toll schedule and the profit motive of the operator (who has a free hand in setting tolls, subject only to an overall rate of return cap) result in considerable variation in the ratio of time savings to toll across different hours of the week. Furthermore, the daily pattern of reliability is still different because the effects of incidents tend to be long-lasting and so unreliability peaks at a later time of day than does mean or median travel time. Another advantage of this corridor to the analyst is that carpools of three or more people can travel in the express lanes for half price, thereby providing additional variation in the price paid. On I-15, by contrast, the

toll is varied in real time in six-minute intervals, and is targeted explicitly to maintain a constant speed in the express lanes. This makes the toll more closely correlated with the travel-time savings and improved reliability realized in the express lanes. Also, carpools can use the I-15 express lanes for free, so they do not face an interesting lane choice.

Dynamic pricing on I-15 introduces a new feature that is a nuisance for the analyst but also an opportunity to study a very interesting phenomenon. Travelers can use the observed toll to learn something about how bad congestion is in the unpriced lanes. For example, if on a particular day the observed toll is unusually high for that time of day, this fact informs the driver that congestion in the unpriced lanes ahead is unusually severe. As on SR91, we assume that drivers are familiar with the day-to-day distribution of travel times for any given time of day. Thus the I-15 toll plays two different roles, pricing and signaling, which must be separately accounted for. This is done by using the actual toll that day as the cost value, and including as an additional variable the difference between actual toll and median toll; our reported values of VOT are calculated only with respect to the toll coefficient itself, not this additional variable; VOT refers therefore to willingness to pay for a leftward shift in the entire distribution of travel times.

On SR91, by contrast, informal observations by our test drivers suggest that drivers do not have much information about congestion beyond the distribution across days. This is because congestion ahead cannot be predicted very well by conditions upstream of the toll lanes. Furthermore, an earlier study on SR91 by Emily Parkany (1999) found that drivers make little use of information sources about congestion other than the radio, which provides only crude information about travel times to be expected on a specific stretch of highway. Thus we believe the travel-time distribution, not its realization on the day in question, is the most important travel variable affecting traveler choice on SR91.

## II. Empirical Issues

In this section we consider and attempt to answer a number of empirical questions that arise from studies of value of time (VOT) and value of reliability (VOR). Table 1 provides selected results.

### *A. How Big Is the Value of Time?*

While there has always been variation among empirical estimates, a decade ago there seemed enough consistency for Small (1992) to suggest that:

> [A] reasonable average value of time for journey to work is 50 percent of the gross wage rate.... [I]t varies among different industrialized cities from perhaps 20 to 100 percent of the gross wage rate, and among population subgroups by even more. (p. 44)

Recently, however, John Calfee and Clifford Winston (1998) have argued, based on results from a nationwide SP survey, that the average value of time is much lower for long-distance automobile commuters. They suggest this is due to self-selection of low-VOT individuals into residential locations requiring long automobile commutes.

Results from the SR91 and I-15 corridors consistently obtain median values of time based on RP data of $20 to $45 per hour, at least five times as large as the results of Calfee et al. (2001). These values are typically on the order of 60 percent of the wage rates in the sample (e.g. Terence C. Lam and Kenneth A. Small [2001]), consistent with Small's earlier summary. It may be that high prices in the Los Angeles area have skewed the residential sorting process described by Calfee and Winston so that even long-distance commuters there have higher values of time than in other regions. But there are also other explanations for the differences, as discussed later.

### *B. How Important Is Reliability?*

Not all the studies have been able to disentangle reliability from other factors well enough to measure its effects. Measuring reliability requires substantial numbers of observations of speeds by day and by time of day. Most such measurements rely upon magnetic loop detectors embed-

ded in the roadway, which measure the density of vehicles and the time between vehicles. Converting this information to speed requires assumptions about the distribution of vehicle lengths. In addition, loop detectors are notoriously subject to failures that result in mistaken readings, which must be recognized and deleted, as well as missing readings. Thus there are numerous uncertainties in the mathematical algorithms used to derive speed information from loop detector data, as well as maddening gaps in the data coverage. In most of the studies described here, loop detector data are used only as supplements to data obtained painstakingly from students driving on the relevant sections of roadway with stopwatches. Brownstone, Golob, and Kazimi (2001) document the large systematic errors in the loop detector data for the I-15 study, and they describe a multiple imputations methodology that accounts for these errors.

Theory suggests that the most common measure of unreliability, the standard deviation of travel times across days, will only imperfectly capture traveler preferences. The reason is that most theories of why people don't like unreliable travel are based on costs of unexpected arrival times at work (John Bates et al. [2001]). These costs are probably greater for being late than early. But using the standard deviation implies that small and large travel times have symmetric effects. For this reason, the SR91 and I-15 studies rely on measures of the upper tail of the distribution of travel times, such as the difference between the $90^{th}$ and $50^{th}$ percentile travel times. Such a measure should be closely related to the chance of being substantially later than expected.[1]

Furthermore, reliability is closely intertwined with the signaling function of the real-time price on the I-15 express lanes, because travelers care more about the information content of the signal if travel time is unreliable. For this reason, the I-15 study contains as a variable the interaction between toll and travel-time unreliability. This control seems to be necessary for obtaining sensible results, but unfortunately it causes the coefficient of reliability to be measured only imprecisely.

Because of these difficulties, only the SR91 studies appear to have satisfactorily identified the coefficients of unreliability in RP data. The results are fairly sensitive to specification. They suggest that reliability is valued at something like 95 to 140 percent of median travel time,

[1] Small, Winston, and Jia Yan (2002) (hereafter SWY) use instead the 80th-50th percentile difference because the data are too sparse to accurately pick out the 90th percentile.

depending on the measure.[2] Multiplying these values by the actual travel-time and reliability differences found during the peak period on SR91 in 1999, Small. Winston, and Yan (2002) (SWY) find that the travel time accounts for about two-thirds, and reliability one-third, of the service quality differential between the free and express lanes.

One of the studies finds a much higher VOR for women than men – roughly twice as high.[3] This provides one explanation for the consistent finding across nearly all studies on these two corridors that, other things equal, women are more likely to choose the toll road. One possible explanation for this result is that women have more child-care responsibilities, which reduce their scheduling flexibility.

### *C. Do Stated Preference Estimates Underestimate Value of Time?*

Two of the studies, one on each facility, have collected data on revealed preferences (RP) and stated preferences (SP) from the same or overlapping subsets of respondents. They have then attempted to compare values of time from these two sources in a controlled manner. In both cases, the median SP estimates are about half the median RP estimates. These values are shown in Table 1 as "SWY: joint RP/SP" and as Ghosh Wav 5 Fastrak users". (Fastrak is the brand name of the electronic transponder system used for toll collection.) The differences shown between the SP and RP VOT estimates are statistically significant (the standard error estimates of the VOT estimates are not shown in Table 1).

In the case of Small, Winston, and Yan (2002) (SWY), the values shown are from a joint model in which the RP and SP observations were allowed to have separate coefficients on cost, travel time, and unreliability, as well as separate alternative-specific constants. There are 522 distinct individuals with RP information and 81 distinct individuals with SP information (for a total of 633 SP observations, since each respondent was given up to eight SP scenarios). These two subsamples have 55 distinct individuals in common. As we see from Table 1, the resulting median VOT for the SP results is just under half that for RP, while the amount of heterogeneity (as a fraction of the median value) is more than twice as large in the SP sample.

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[2] For example, Lam and Small (2001) find VOR/VOT=1.39 with unreliability measured as the $90^{th}$-$50^{th}$ percentile difference (Table 3, Model 1c). SWY measure *median* VOR and VOT in the population, finding they have a ratio of 0.97 (Table 3, RP estimates).

[3] Lam and Small (2001), Tables 8-11.

In the case of Ghosh (2001), two separate models are estimated on the RP and SP observations, which were obtained mostly from the same individuals in the same telephone interview. These are all individuals who had already obtained a transponder that enable them to use the express lane if they so choose. The sample sizes are 266 for RP and 306 for SP. These models account for a more complete choice set than others, including as possible choices five combinations of route (i.e. express versus regular lanes), car occupancy, and transponder acquisition. Again, the median VOT from the SP responses is less than half that from RP. In this case the heterogeneity is relatively greater for RP than SP. Ghosh's results were also replicated using a joint mixed logit model that is very close to SWY's model. This mixed logit model (not shown in the table) implies RP VOT three times the size of SP VOT from a sample of 456 I-15 commuters.

These results give substantial weight to the hypothesis that earlier differences among RP and SP studies are caused by systematic differences in RP and SP methodologies. While we cannot say with any certainty which is more trustworthy, it is clear that RP results correspond to what planners need to know in order to evaluate transportation projects. This is because the analyses that form the basis for project evaluation are in terms of actual travel times, similar to what is measured in RP variables. If people react differently to hypothetical scenarios than to real ones with the same conditions, it is the latter that normative studies must replicate in order to provide guidance about the benefits or costs of changes in the transportation environment.

We hypothesize that the difference is at least partly caused by a systematic misperception travel times. In studies of both SR91 and I-15, people have been asked to report the travel-time savings they think they could realize by using the express lanes. Their responses are typically slightly more than twice the actual travel-time savings. A possible reason for this could be that they focus on total delays on a portion of their trip that is actually longer than the section where there is an express-lane option; they may mistakenly think that this larger delay would all be eliminated by using the express lanes. Another possible reason is an impatience with heavy traffic that leads them to exaggerate how much time the delays are actually causing them. (The latter might be related to the finding of a few studies that congested travel time is valued at about twice as much per minute as uncongested travel time.) Whatever the reason, if people experiencing a 10-minute time delay record it mentally as 20 minutes, then they probably react to a hypothetical question involving a 20-minute delay in the same way that they react to a real

situation involving a 10-minute delay. This would cause their measured value of time in the hypothetical situation to be exactly half the value observed in real situations.

To investigate this further, Ghosh (2001, Section 5.2) tried using perceived time savings to explain route, mode, and transponder choice. In the best specification, perception error (defined as perceived minus actual time savings) is simply added as an explanatory variable to the model of line 12 in Table 1. He finds that commuters with larger positive perception errors are more likely to use the toll facility. However, the RP values of time were not changed by including this variable, suggesting that RP results may not be affected by perceptual problems. Whether or not SP results are so affected, as our hypothesis implies, remains to be studied.

### *D. Are Estimated VOT and VOR Sensitive to Error Structure?*

Hensher (2001) compares values of time estimated from several alternative statistical models, using SP responses from a sample of people asked to consider intercity high-speed rail service for non-work trips in Australia. He finds that the estimated median values of time are substantially larger when the model allows for more general correlation structures in the error terms and for more unobserved variability across the sample. He interprets this finding to mean that at least for this data set, the more sophisticated models correctly measure values of time and the simplified models underestimate them.

In three cases, otherwise identical models have been estimated with varying degrees of complexity in the error structure. Based on these, we are unable to replicate Hensher's finding. For one example, earlier results from the SP portion of the SR91 data, not reported in SWY, compared a binary logit model with no random parameters to one with a random constant and another with a random constant and two additional random parameters. The results are shown in Table 2. (These include some variables solely for comparison with other models not described here.) Accounting for random parameters produces great improvements in goodness of fit, and the estimated standard deviations of the parameters are strongly statistically significant. Yet these results do not show substantial differences in either median VOT or median VOR.

The current version of the SWY model (lines 4-5) was also re-estimated for this paper with simpler error structures (lines 6 and 7). A comparison of the RP values of time (lines 4, 6, and 7) show no apparent trend in median VOT.

Ghosh (2001, Section 3.1) compares conditional logit, nested logit, heteroskedastic extreme value, and mixed logit models for a 5-alternative choice model including the choice of whether to carpool and whether to purchase a transponder required to use the I-15 lanes. The heteroskedastic extreme value model showed the best improvement in overall fit, but the implied values of time show no clear pattern and are not statistically different from each other (Ghosh, Table 6). The most general model, mixed logit, yielded the lowest values of time, which contradicts Hensher's findings.

### *E. Heterogeneity and Variable Specification*

The observed heterogeneity in VOT or VOR depends, of course, on what variables are interacted with travel time or unreliability in the specification. In the SR91 and I-15 studies, most models contain interaction terms between travel time and two or three powers of distance, in each case leading to an inverted U-shaped relationship between value of time and distance over the applicable values of distance. In some models, travel time is also interacted with income. In some, unreliability is interacted with toll (I-15 only) and/or with various traits of individuals such as work-hour flexibility, gender, and income.

In many cases, the model fits as well or better if instead these traits are interacted with alternative dummies – e.g., they are allowed simply to shift the alternative-specific constant for choosing the express lanes. The two forms often produce similar estimates of most coefficients, including those determining median VOT and VOR. However, they produce drastically different predictions of the observed heterogeneity of VOT and VOR. If unobserved heterogeneity is also allowed by the specification, through random parameters, then it will also be different. Complicating the interpretation of results is the fact that unobserved heterogeneity typically affects the normalization of the error term and therefore may cause most coefficients to be scaled upward or downward.

Currently, this inability to distinguish clearly between different specifications of interaction terms is an important limiting factor for understanding the forms of heterogeneity in travel behavior. We suspect that the greatest future advances in this understanding will come not from more sophisticated specifications of error terms or random parameters, but rather from better measures of the individual traits that systematically affect the value travelers place on time and reliability.

Observed heterogeneity also complicates the estimation of summary statistics like median VOT. Two of the studies in Table 1, SWY and Steimetz and Brownstone (2002), include various interaction terms among toll, time savings, income, and commute distance. Their specifications imply that estimated VOT is a highly nonlinear function of observed data and parameter estimates. Most of the results for median VOT reported in Table 1 are evaluated at the point estimates of the unknown parameters. A better estimate is the expected value of median VOT, where the expectation is taken over the sampling distribution of the parameter estimates. (This expected value is also asymptotically equal to the optimal Bayesian posterior estimate of median VOT.) This calculation, where performed, is marked * in Table 1. In the two cases where it is calculated both ways, using point estimates of parameters appears to overstate the median VOT.

### *F. Conclusions*

Perhaps the most satisfying conclusion from studies of the I-15 and SR 91 toll facilities is that they yield very similar estimates of the value of time. When the I-15 sample is weighted to match the income and commute distance distribution in the SR 91 sample, all studies find a roughly $20 VOT for people with characteristics of SR91 commuters. This level of agreement is surprising since the corridors differ in their pricing schemes, and the studies used different survey questionnaires and different survey modes (telephone for the I 15 and mostly mail for the SR 91). This close agreement gives us confidence that our empirical findings are not just artifacts of a particular survey and model.

We find that commuters' VOT on these corridors is roughly consistent with Small's (1992) earlier findings, and at least twice as large as more recent SP results. We are able to replicate a 100 percent difference between SP and RP VOT estimates within our samples, so at least some of the difference is inherent in the methodologies, at least as currently practiced in these studies. Since SP methods are increasingly used for project evaluation, our results suggest that this use of SP VOT estimates will undervalue projects to reduce congested travel time. Explaining the large differences between SP and RP estimates is clearly an important topic for future research.

**Table 1. Comparison of Selected Model Results**

| | | Estimation | | Coefficients used for computing VOT, VOR | VOT ($/hour) | | | median VOR[a] | |
|---|---|---|---|---|---|---|---|---|---|
| | | Type of data | Error compo-nents included | | median | heterogeneity (inter-quartile range) | | Male | Female |
| | **SR91** | | | | | observed | unob-served | | |
| 1 | Lam-Small: route only[b] | RP | none | RP | 24 | 8 | NA | $12/hr | $30/hr |
| 2 | Lam-Small: route,mode,transponder[c] | RP | none | RP | 23 | NR | NA | $15/hr | $32/hr |
| 3 | SWY[d] | RP | none | RP | 25 | 13 | NR | NA | |
| 4 | SWY[e,f] | RP/SP | full[g] | RP | 20* | 4* | 11* | $28/hr[h] | |
| 5 | SWY[e,I] | RP/SP | full[g] | SP | 9* | 2* | 13* | $4/incident | |
| 6 | SWY[j] | RP/SP | partial[k] | RP | 21* | NR | NA | NA | |
| 7 | SWY[j] | RP/SP | none | RP | 20* | NR | NA | NA | |
| | | | | | | | | | |
| | **I-15** | | | | | | | | |
| 8 | Brownstone et al. (wave 3)[m] | RP | none | RP | 30 | 20 | NA | NA | |
| 9 | Steimetz-Brownstone (wave 5)[n] | RP | none | RP | 45, 30* | 52 | NA | NR | |
| 10 | Steimetz-Brownstone (wave 5) weighted to match SR91 sample[p] | RP | none | RP | 22 | 26 | NA | NR | |
| 11 | Ghosh: route, mode, transponder[q] | RP | 4 coeff's | RP | 24, 21* | 19, 22* | 30[r] | NA | |
| 12 | Ghosh: route, mode, transponder[q] | RP | none | RP | 27 | 23 | NA | NA | |
| 13 | Ghosh: route, cond'l on transponder[s] | RP | none | RP | 40 | 31 | NA | NA | |
| 14 | Ghosh: route, cond'l on transponder[s] | SP | none | SP | 16 | 3 | NA | NA | |
| 15 | Ghosh: route, cond'l on no transpond-er[s] | SP | none | SP | 13 | 3 | NA | NA | |
| | | | | | | | | | |
| | **Other** | | | | | | | | |
| 16 | Calfee-Winston-Stempski[t] | SP | 4 coeff's | SP | 4 | NR | 1 | NA | |

Notes to Table 1:

NA: not applicable (variable not included in model).

NR: not reported (variable included but resulting distribution not calculated).

* Calculated by drawing from asymptotic distribution of parameter estimates as well as from other sources.

[a] Unreliability is measured as 90$^{th}$ minus 50$^{th}$ percentile of travel-time distribution except where otherwise noted.

[b] Lam and Small (2001), Table 6, Model 1f..

[c] Lam and Small (2001), Table 11, Model 4d.

[d] Calculations for this paper, from coefficients of Small, Winston, and Yan (2002), Table 2, "RP Only" model.

[e] Model was estimated on combined RP and SP data, with separate coefficients for RP, SP observations. Observed heterogeneity is not reported in SWY, but was calculated for this paper.

[f] SWY, Table 3, "RP Estimates."

[g] Error components include constants, repeated SP observations with correlation between SP and RP observations for the same individual, and random coefficients of cost, travel time, and unreliability.

[h] Unreliability was measured as the 80$^{th}$ minus 50$^{th}$ percentile of travel-time distribution.

[i] SWY, Table 3, "SP Estimates."

[j] Additional models estimated for this paper: same specification and data as in lines 4-5 except with fewer error components.

[k] Includes an error component for repeated SP observations to allow them to be correlated, and allows for correlation between the SP and RP observations for the same individual.

[m] Brownstone et al. (forthcoming), VOT calculations described in text.

[n] Steimetz and Brownstone (2002), Table 4. Uncertain travel times are multiply imputed based on prediction models using loop detectors and other variables.

[p] From same model as previous row, but VOT distribution recomputed for this paper after reweighting individuals in I-15 sample to have same joint distribution of income and distance as the SR91 sample.

[q] Ghosh (2001), Table 6, p. 78, weighted models, parts 1 and 3. Logit error structure with 5 alternatives: (1) Free lanes, solo driver, no transponder; (2) Free lanes, solo, with transponder; (3) Express lanes, solo, with transponder; (4) Express lanes, carpool, no transponder; (5) Express lanes, carpool, with transponder. Estimated on data from wave 5 of the I-15 panel study.

[r] Approximated as 1.35 times the reported standard deviation of drawn values of time. The factor 1.35 is the difference between the 75$^{th}$ and 25$^{th}$ percentiles of the standard normal distribution.

[s] Ghosh (2001), Table 16, p. 113. Estimated on data from wave 5 of the I-15 panel study.

[t] Calfee, Winston, and Stempski (2001), Table 5, Scenario 1. We have approximated the inter-quartile range IQR of the value of time from the reported estimates of the means $\mu$ and standard deviations $\sigma$ of price $p$ and time $t$ according to the following formula, which would apply if $\mu_p$ and $\mu_t$ were each normally ad independently distributed:

$$\frac{\mathrm{IQR}(\mu_t/\mu_p)}{(\mu_t/\mu_p)} = 1.35\cdot\left[(\sigma_t/\mu_t)^2+(\sigma_t/\mu_t)^2\right]^{1/2}.$$

In this formula, the factor 1.35 is the difference between the 75$^{th}$ and 25$^{th}$ percentiles of the standard normal distribution. Calfee et al. report the 90$^{th}$ and 10$^{th}$ percentiles, whose difference is $2.00.

**Table 2. Comparison of SP Models With and Without Random Parameters (SR91)**

| Independent Variable | Parameters Randomized: | | |
|---|---|---|---|
| | None | Constant | Constant, time, reliab. |
| | | | |
| Constant: | | | |
| mean | -1.502 (0.858) | -2.452 (2.213) | -4.870 (3.497) |
| std. dev. | | 3.368 (0.603) | 4.364 (1.395) |
| | | | |
| Cost ($) | -0.497 (0.118) | -1.060 (0.194) | -1.380 (0.344) |
| Travel time (min.): | | | |
| mean | -0.104 (0.018) | -0.218 (0.037) | -0.277 (0.066) |
| std. dev. | | | 0.200 (0.085) |
| Unreliability[a]: | | | |
| mean | -2.496 (0.618) | -5.402 (1.188) | -6.690 (1.762) |
| std. dev. | | | 7.148 (2.122) |
| | | | |
| Car occupancy | 0.438 (0.158) | 0.955 (0.347) | 1.455 (0.798) |
| Work-site size[b] | -0.390 (0.135) | -0.670 (0.234) | -1.180 (0.766) |
| Distance[c] | -0.345 (0.338) | -1.015 (0.898) | -0.536 (1.163) |
| Distance squared | 0.047 (0.035) | 0.119 (0.089) | 0.080 (0.101) |
| Work-hour flexibility[d] | 0.707 (0.385) | 1.485 (0.959) | 2.129 (1.724) |
| Education[e] | 0.310 (0.421) | 0.626 (1.064) | 1.023 (2.068) |
| | | | |
| log-likelihood | -326.26 | -235.75 | -227.20 |
| # of observations | 601 | 601 | 601 |
| Implied mean VOT ($/hr) | 12.55 | 12.35 | 12.08 |
| Implied mean VOR ($/incident) | 5.02 | 5.09 | 4.85 |

Notes:
Dependent variable: choice of toll road.
Standard errors in parentheses.
All travel variables describe a one-way trip.
[a] Fraction of trips with unexpected delays of 10 minutes or more (SP question)
[b] Number of workers at work site, in 1000s
[c] One-way commute distance, in units of 10 miles
[d] Dummy variable equal 1 if work arrival time or work departure time are flexible
[e] Dummy variable equal 1 if have bachelor degree or higher

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