Estimating the value of travel time saving and statistical life in road travels in Brazil (English Short version)

Tatiana Ferrari[*,a], Luisa Dusi[a], Fabiano Pompemayer[a]

[a]*IPEA - Institute of Applied Economic Research. Setor Bancario Sul, Quadra 1, Edificio BNDES, Brasilia, DF, Brazil*

Abstract

In this paper, we discuss the methodological procedures and the computation of the value of travel time saving and value of statistical life in road travels in Brazil. A stated preference experiment was carried out, in which we bring some innovations in order to control for hypothetical bias. The survey was conducted online through the snowball technique, requesting respondents to choose between two hypothetical routes with different levels of three attributes: toll cost, time and number of deaths. The mixed logit model was used to estimate the willingness to pay for the travel time saving and for the death risk reduction. The results show significant difference in the values given the certainty level in the individual´s answer. The model is also estimated controlled for travel and individual characteristics. Despite the important results found, the first ones in our knowledge for the Brazilian context, the data collection was biased which made it impossible to extrapolate the results to the population.

1. Introduction

Brazil has a road network of about 1.8 million kilometers, being the main means of transportation in the country. However, data from the Highway Survey conducted by the National Transport Confederation (CNT, 2016) show that the general state of Brazilian roads is deficient: only 12.3% of the roads are paved, 86.6% are single carriageways and 42.2% have no shoulder. According to the evaluation carried out by CNT, deficiencies in roads cause high fuel consumption, greater wear and tear on the vehicle fleet, greater occurrence of accidents and environmental damage. In addition, roads with limited capacity and boreholes considerably increase travel time.

Pompermayer (2017) shows that the average annual expenditures of the National Department of Transportation Infrastructure (DNIT), only with recovery

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[*]Corresponding Author

Email addresses: `tatianak.ferrari@gmail.com` (Tatiana Ferrari), `luiza.dusi@ipea.gov.br` (Luisa Dusi), `fabiano.pompermayer@ipea.gov.br` (Fabiano Pompemayer)

and maintenance of the Brazilian road network, are more than R$ 8 billion and still insufficient to maintain an acceptable quality standard.

The scarce resources cause public policy makers to prioritize different investments in road infrastructure. Improvements in the condition of roads can result in important gains in reducing travel time, reducing vehicle costs and maintenance, and reducing the number of fatal accidents. Thus, intervention projects can be justified through cost-benefit analyses. For this, it is necessary to obtain the monetary values of such benefits.

According to the microeconomic theory of revealed preference, the value of goods and services can be derived by observing the choices made by individuals. However, time and the reduction of the risk of death do not have market value, because they are not tangible and subjective benefits.

In view of this, the study aims to obtain estimates related to the parameters of time savings value and the value of statistical life for the Brazilian case, in order to subsidize cost-benefit analyses of investment projects in highways, as well as in other projects or policies involving these parameters. The methodology used consisted of survey application to obtain the declared preference (PD) of individuals and the use of the Mixed Multinomial Logit model, of discrete choice, to estimate the willingness to pay (WTP) for these attributes.

The rest of this paper is organized as follows. Section 2 describes briefly the topics in the survey; Section 3 the methodology adopted for preference analysis; and Section 4 presents the estimation results.

2. Survey Design

2.1. Survey Structure

The survey consists of seven sections, namely:

(1) Introduction and first set of social-economic data;
(2) Travel habits from last 12 months;
(3) Last or most frequent trip made by car or motorcycle in Brazilian highways;
(4) Stated choice experiment;
(5) Debrief;
(6) Complementary questions;
(7) Second set of social-economic data.

One question in particular is worth pointing out: we asked the respondents about their involvement in accidents, or of their relatives. To test if the recollection of a possible/actual accident would influence their choice behavior when answering the experiment we randomized the position of this question: either immediately before or after the experiment.

3. Methodology

Estimates for the value of travel time savings and of risk of death reduction on roads travels was obtained by applying the discrete choice model. This approach considers that each individual n has a set of alternatives, each having a series of associated characteristics (x_{nj}). The individual will choose the alternative that maximizes their utility, account for observable and unobserved factors, so that $U_{ni} > U_{nj}$ for $\forall j \neq i$.:

$$U_{nj} = V_{ni} + \epsilon_{ni} = \beta_n' X_{nj} + \epsilon_{nj}$$

where x_{nj} is a vector of observed variables that gives the utility of individual n for the alternative i, β_n is the correspondent vector of coefficients of variables x_{nj} representing the individual's tastes, and ϵ_{ni} is an unobserved random term that represents the effects of omitted variable.

The route choice process of our stated preference experiment allow us to derive the subjective valuations of the attributes, which are called Willingness to Pay (WTP) and expresses the marginal substitution rate between the considered attribute and the cost, given a constant utility.

Among the different class of models, we find the the mixed logit model more appropriate for modeling our choice data, since it allows the coefficients of the model to have variations between the individuals. According to Train (2002), the mixed logit probabilities are the integral of standard logit probabilities over a density of parameters. If the utility is linear in β, can be expressed as:

$$P_{ni} = \int \frac{exp(x_{ni}'\beta)}{\sum_{j=1}^{J} exp(x_{nj}'\beta)} f(\beta|\theta)d\beta \tag{1}$$

where, $x_{ni}'\beta$ are the portion of utility observed, which depends on parameters β and $f(\beta|\theta)$ is a density function of β. In this terms, the mixed logit model is a mixture of a logit function evaluated in different β's, with a mixed distribution in $f(\beta|\theta)$.

In the stated preference experiment each respondent has a sequence of route choice (nine times in our particular case). To count all of then it is necessary to take the product of the Equation 1:

$$S_n = \int \prod_{t=1}^{T} \prod_{j=1}^{J} \left[\frac{exp(x_{ni}'\beta)}{\sum_{j=1}^{J} exp(x_{nj}'\beta)} \right]^{y_{njt}} f(\beta|\theta)d\beta$$

with, $y_{njt} = 1$ if the alternative j was choosen in t, and 0 otherwise.

As stated by Hensher and Greene (2003) the choice probability in mixed logit models "cannot be calculated exactly because the integral does not have a closed form. The integral is approximated through simulation". The simulated probability (SP) that an individual chooses alternative i could be obtained through the maximization of the likelihood function. In general, this simulation is given by a Halton's sequence.

$$SP = \sum_{n=1}^{N} ln\Big(\frac{1}{R}\sum_{r=1}^{R}\prod_{t=1}^{T}\prod_{j=1}^{J}\left[\frac{exp(x'_{nit}\beta_n^{[r]})}{\sum_{j=1}^{J}exp(x'_{njt}\beta_n^{[r]})}\right]^{y_{njt}}\Big) \qquad (2)$$

With $\beta_n^{[r]}$ representing the number of drawings (r = number of Halton's draws) for individual n given the assumed distribution by β.

Thus, three specifications arise with the use of the mixed logit model: 1) select the variables that should be considered as random; 2) the choice of the statistical distribution for the random coefficients; and 3) determine the number of Halton draws for the simulation.

The random variables included in the model are the ones of the stated preference experiment: cost, time and risk of death. The other variables that may be included, as the characteristics of the respondent and of the travel, are treat as no random.

The normal distribution is the standard distribution in statistical software and generally applied in mixed logit models. However, Hess et al. (2005) shows that, since the normal distribution is unbounded, every real number has a probability of being estimated in the simulation process´´. In the case of parameters that have a strictly negative distribution, but has a mean close to zero with a long tail into the negative space of numbers´´, as in the case of time and risk of death reduction, "the symmetrical nature of the normal distribution can, in approximation, lead to a significant share of positive values, even though such values are not actually revealed by the data´´.

Hence, the following alternative distributions are tested: lognormal, triangular and normal distribution truncated at zero. The better model fit is obtained by the model using the Normal distribution truncated at zero. In this case,

$$\beta_{k,ir} = \begin{cases} \beta_k + \omega_k W_{k.ir}, & \text{if } \beta_{k_i r} > 0 \\ 0, & \text{otherwise.} \end{cases} W_{k_i r} \; N(0,1) \qquad (3)$$

The third specification refers to the number of Halton draws to be considered. The model were tested using different numbers of draws, comparing the efficiency and time of processing. It was observed that after 500 Halton draws the model stabilized, with no significant gains in efficiency with the increase in number of simulations and therefore, this number was established for the model.

4. Results

4.1. General model

We first approach a general model, considering only the game attributes: cost, time and death.

Table **??** presents the estimation of the respondent's preferences according to the mixed logit model, considering the specifications of section 3. The coefficients were significant at 1% and present the expected sign. It's important to emphasize that the variable's signs were switched due to the truncated distribution adopted

previously. Therefore, the positive result for cost, time and death mean an negative impact, that is, when traveling the individuals prefer the route with lowest cost, travel time and death risk.

```
##
## General Mixed Logit Result
## =====================================================
##                                   choice
## -----------------------------------------------------
## Intercept                -0.870*** (0.063)
## Cost                      0.157*** (0.003)
## Life                      0.359*** (0.009)
## Time                      0.072*** (0.002)
## sd.cost                   0.065*** (0.002)
## sd.life                   0.324*** (0.012)
## sd.time                   0.021*** (0.002)
## N                             25,730
## R2                             0.313
## Log Likelihood              -12,114.600
## LR Test                 11,032.590*** (df = 7)
## =====================================================
## Notes:         ***Significant at the 1 percent level.
##                 **Significant at the 5 percent level.
##                  *Significant at the 10 percent level.
```

	WTP_200km	Values
tempo	Time (BRL per hour)	27.62
morte	Life(BRL per 1 death)	2.29

Considering the baseline distance of 200km, the model estimated a willingness to pay of R$27,60 for a travel time saving of one hour and R$2,29 for risk reduction of one death.
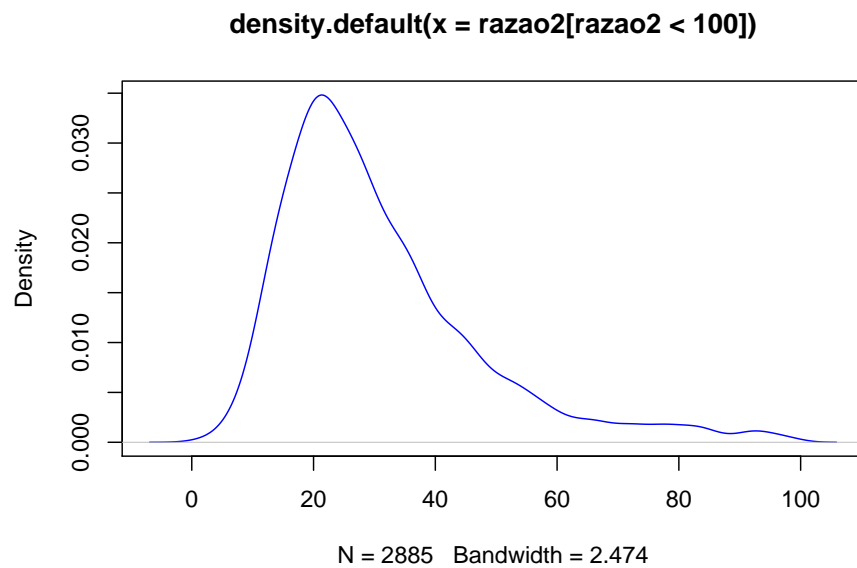
The WTP values are random variables with an unknown distribution. With the means and the standard deviation values of the variables, we used a simulation process to estimate the values' distribution for individuals, considering the interval of 0 to 100 Brazilian Reais.

Figure?? presents the distribution for WTP as a Kernel Density. It is concentrated at the beginning of the distribution, where values for WTP are lower. For death risk reduction, 95% of the distribution is concentrated up to BRL 10, while the WTP for travel time saving seems to be more distributed and with a lengthened tail. However, that occurs only due to the value conversion to value per hour. Therefore, we have a strong concentration of individuals who are willing to pay between BRL 10 and BRL 40 for the reduction of one hour in their travel time.

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```r
fig1 <- plot(density( razao1[razao1 < 100] ), col = "red")
```

density.default(x = razao1[razao1 < 100])

N = 2994   Bandwidth = 0.3903
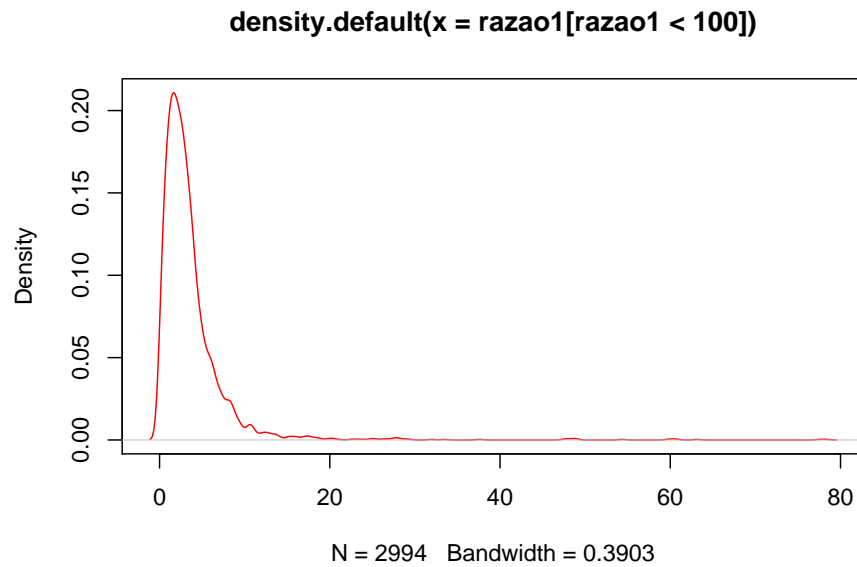
```r
# Recreate Figure 2
fig2 <- plot(density( razao2[razao2 < 100] ), col = "blue")
```

density.default(x = razao2[razao2 < 100])

N = 2885   Bandwidth = 2.474

```
# grid.arrange(fig1, fig2, ncol = 2)
```

One of the factors that can influence the individual's perception of the value they're willing to pay is if they are - or are not - road users. As stated by Sen (1993), information access can considerably change individual's choice behaviour. Our survey informs respondents about travel conditions as travel time and number of deaths by road accidents, while also reminding them of their personal travel experience, as to give context and therefore improve their perception when answering the game. Nevertheless, we allowed all participants to respond to the game, frequent travelers or not, who have travelled on roads in the last 12 months, as well as the ones who didn't.

As observed in Table **??**, there was a clear difference in perception of users and non-users of roads. The ones who hadn't traveled in the past 12 months had a WTP for reducing death risk significantly higher than the ones who did travel, being willing to pay R$0,90 more.

For travel time savings, it is interesting to notice that non-user individuals had similar preferences, with the variable's standard deviation being not significant, that is, the importance of time was homogeneous between individuals of the stratum. The willingness to pay, as with the previous parameter, was superior to the one of users.

This behaviour might be explained by difference in the amount of knowledge and access to information that users and non-users have. Non-users might have used their urban area commute experience as a reference. Also, they don't have knowledge about other incurred travel costs, road conditions and other aspects that might alter their perception to the point of being willing to pay higher prices for reduction of travel time and of death risk.

Finally, in this general analysis, we estimated the WTP of respondents according to the degree of certainty with which they answered the game. The calibration through the certainty approach allows us to remove some behavioural deviance inherent to the stated preference method. Since we are applying a monetary value to an intangible good, that is, which doesn't have a market value, the respondent might not be acquainted with the object of choice and therefore have some difficulties when evaluating their preferences for these goods.

The purpose of this approach is to exclude answers in which there was a considerable amount of uncertainty declared. However, the literature shows that there is no consensus regarding the acceptable degree of certainty, as the review carried out by Beck et al. (2016) verified: several studies use 8 and others use 7 as a threshold, amongst other values.

Graphic 1 shows the pattern of answer certainty (CA) for each question of the experiment. Most answers had a high level of certainty. Grades from 7 to 10 summed over 80% of answers in most questions. The ones with a higher level of uncertainty, that is, more than 15% of grades under 7 (items: 3, 4, 13, 18, 19, 22, 23 and 27) are the ones with highest value for toll (R$40).

We separated the answers into three groups based on the declared degree of certainty: Certain - CA from 7 to 10; Some certainty - CA from 4 to 6; Uncertain

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Variables	No traveller		Traveller		GM with frequency	
	Coef.	t-value	Coef.	t-value	Coef.	t-value
Average						
Intercepto	1.020	4.168	0.856	13.157	0.858	-11.104
Custo	0.127	13.063	0.159	-50.968	0.157	52.695
Tempo	0.061	9.073	0.073	37.697	0.072	38.867
Morte	0.397	13.003	0.354	38.167	0.359	40.258
Frequncia					0,003*	0.272
SD						
Custo	0.061	6.903	0.065	26.738	0.065	27.367
Tempo	0.015	1.916	0.021	11.512	0.021	12.690
Morte	0.261	6,7112*	0.330	26.082	0.324	27.020
Estatsticas						
Log-likelihood	-785.81		-11325		-12115	
McFadden R^2	0.28689		0.31479		0.31288	
Resultados - base 200km						
WTP Time	28.71		27.53		27.60	
WTP Risk	3.12		2.23		2.29	

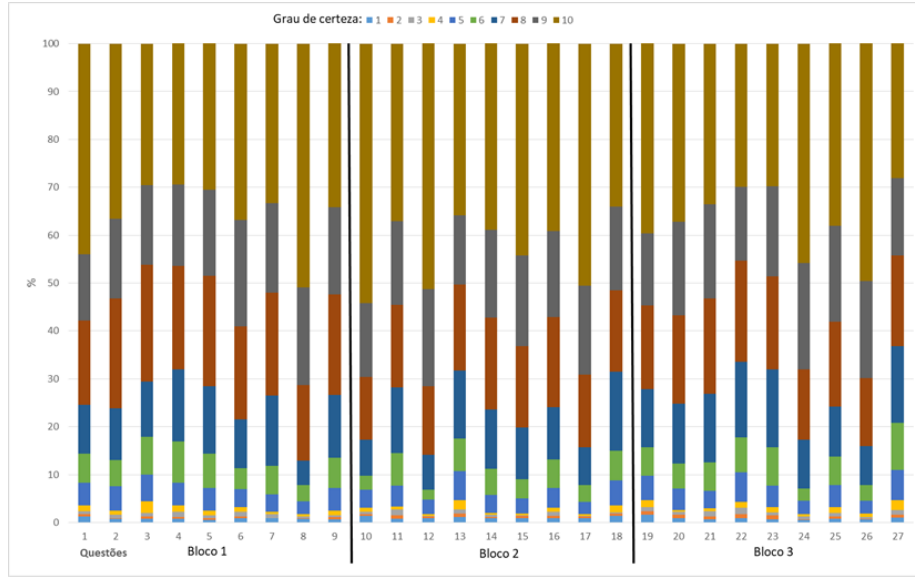Figure 1: Mixed Logit to travellers and no travellers.

Figure 2: Certainty approach report.

- CA up to 3.

The results of the mixed logit model estimation for each CA group is presented on Table. Graphics and shows the Kernel Density for risk of death reduction and travel time savings respectively.

We can observe that there is a significant variation in answer patterns when considering the respondents certainty of choice. The results, in addition, show that when the answer was made with uncertainty, the estimations for the parameters of death, time and their respective standard deviations weren't significant at 10%. Notice that choices made with certainty provided a higher value to death risk reduction and, as the trade-off with cost became closer to the threshold (higher prices), the level of certainty decreased.

This trade-off can easily be observed in the Kernel Density graphs (Table and. The curve of uncertain answers is concentrated in lower values of WTP while the certain answers is better distributed. In contrast, the curve of uncertain choice also presents a distribution with a tail with greater length. This pattern shows that the uncertainty was generated in cases when the individual did not accept to pay a higher price for improvement, but was not confident to renounce the benefits, or that he agreed to pay the higher price for improvements but disapproved the value proposed.

4.2. EXPANDED MODEL

The expanded model was estimated to observe the systematic heterogeneity of preferences, which can occur due to different socioeconomic characteristics or
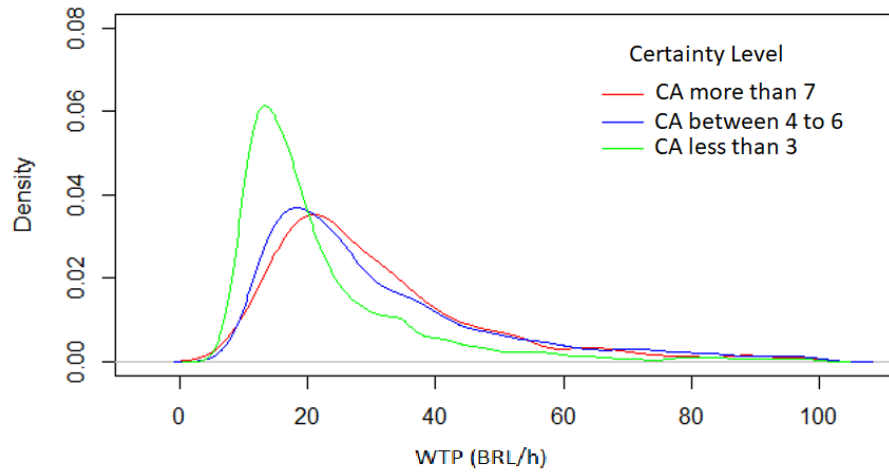
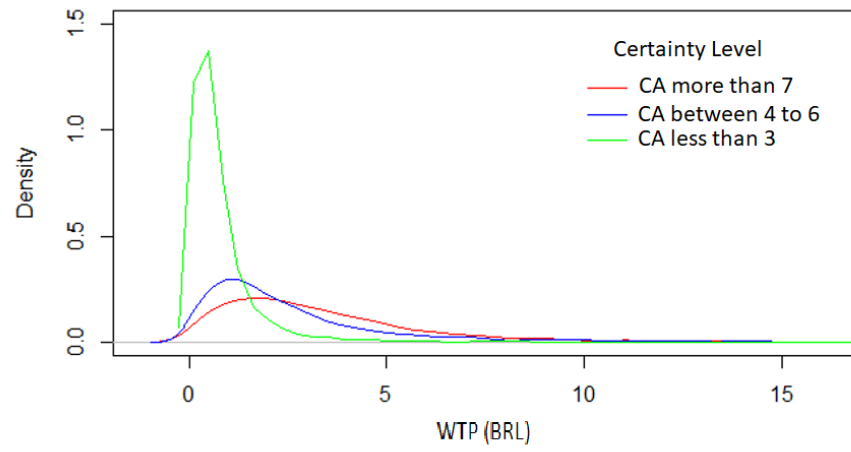Figure 3: WTP distribution of travel time saving by CA.

Figure 4: WTP distribution of risk of death reduction by CA.

Variables	Certain		Some certainty		Uncertain	
	Coef.	S.E	Coef.	S.E	Coef.	S.E
Average						
Intercept	-0,971	0.072	0.554	0.161	0.108*	0.341
Cost	0.178	0.004	0.077	0.006	0.063	0.012
Time	0.080	0.002	0.037	0.004	0.019	0.008
Life	0.425	0.011	0.139	0.020	-0.005*	0.164
SD						
Cost	0.074	0.003	0.059	0.010	0.035	0.0195
Time	0.022	0.002	0.002	0.043	0.00006*	0.2729
Life	0.378	0.015	0.127*	0.046	0.364*	0.2224
Statistics						
Log-likelihood	-9800.6		-1837.3		-333.18	
McFadden R^2	0.35517		0.097356		0.080764	
Results - 200km						
WTP Time	27.18		28.78		18.47	
WTP Life	2.39		1.79		0.08	

* indicates not significance

Figure 5: .

to different travel behaviour from each respondent. Thus, we added the following characteristics to the general model:

1. Household Income
2. Number of children
3. Trip Purpose
4. Traffic accident question`s position in questionnaire
5. Occurrence of traffic accident in last 5 years
6. Gender
7. Age group
8. If committed any traffic infractions
9. If the respondent imagined himself as being alone or with company.

From the items listed above, numbers 2, 3 and 5 did not present statistical significance at the level of 90%, that is, they do not influence the respondents' preferences when making a choice between routes A and B, as shown in Table. All other characteristics were significant at 99%, except for the position of the accident question, which was significant at 95%.

Table shows the WTP values calculated for each characteristic with significance equal to or higher than 95%. Female respondents declared to be willing to pay considerably more for safety than male subjects, in contrast to the WTP for time savings, which was more valued by the male respondents, except with a smaller disparity.

For safety as for time savings, the age group and income group are proportional to he willingness to pay, as expected. That is, the older and the better financial conditions, the higher the willingness to pay. It is also higher when the respondent imagined himself traveling accompanied. In this case, the subject probably considered dividing the toll cost between driver and passengers or considered that the benefits are multiplied by the number of occupants in the car.

The respondents who received a fine for any kind of traffic infraction in the last 12 months were classified as having risky behaviour, also known as Risk Lovers. As expected, they are willing to pay higher prices to reduce travel time and to reduce risk than respondents who didn't present such behaviour.

References

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Hess, S., Bierlaire, M., Polak, J.W., 2005. Estimation of value of travel-time savings using mixed logit models. Transportation Research Part A: Policy and Practice 39, 221–236.

Pompermayer, F.M., 2017. Simulação de parceria público-privada para as rodovias federais: Impactos sobre orçamento fiscal, usuários e contribuintes. Instituto de Pesquisa Econômica Aplicada (Ipea).

Variables	Coef.	Std. Error	t-value
Average			
Intercept	-1.021	0.214	-4.775***
Cost	0.161	0.003	49.076***
Time	0.073	0.002	36.273***
Life	0.360	0.010	37.348***
Income	-0.053	0.017	-3.022***
Children	0.026	0.023	-0.741
Purpose	-0.017	0.023	-0.741
Accident	0.085	0.043	1,964**
Family accident	-0.021	0.046	-0.466
Gender	0.245	0.048	5,111***
Age	-0.124	0.022	-5.390***
Risk	0.267	0.045	5.952***
Way of travel	-0.166	0.045	-3.665***
SD			
Cost	0.063	0.003	24.546***
Time	0.021	0.002	11.188***
Life	0.321	0.012	25.044***
Statistics			
Log-Likelihood		-10357	
McFadden R^2		0,32188	

Note: *** indicates significance at 1%; ** indicates significance at 5%;

and * indicates significance at 10%; without asterisks means no significant

Figure 6: Mixed Logit Model Result controled by socioeconomic characteristics and travel behavior.

Variables	WTP death risk (R$/1 life)	WTP time saving (R$/per hour)
Gender		
Men	2.12	27.84
Women	2.60	26.13
Age		
until 24	1.90	26.35
25 to 34	2.01	27.87
35 to 44	2.40	27.23
45 to 54	2.66	29.07
55 to 64	2.50	22.69
up to 65	3.42	31.57
Income		
until R$1,874	1.99	14.32
R$1,874 to R$2,811	1.98	22.74
R$2,811 to R$4,685	1.76	23.77
R$4,685 to R$9,370	2.25	25.80
R$9,370 to R$18,740	2.26	27.66
more then R$18,740	2.77	35.12
Accident Question		
Before the game	2.28	27.81
After the game	2.26	26.72
Way of travel		
Alone	2.01	26.28
with company	2.47	27.98
Risk behavior		
Fine received	2.36	29.46
No Fine received	2.21	25.75

Figure 7: WTP by socioeconomic characteristics.

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