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Estimating the Value of Risk Reduction for Pedestrians in the Road Environment: An Exploratory Analysis

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Abstract

In recent years there has been a re-focus on the valuation of a statistical life from the ex post or human capital method to an ex ante willingness to pay (WTP) approach. This is in part a recognition that we need to focus on establishing the amount, ex ante, that individuals are willing to pay to reduce the risk of exposure to circumstances that might lead to death or degree of injury in the road environment. This study sets out a framework in which to identify the degree of preference heterogeneity in WTP of pedestrians to avoid being killed or injured. A stated choice experiment approach is developed. The empirical setting is a choice of walking route for a particular trip that a sample of pedestrians periodically undertakes in Australia. Mixed logit models are estimated to obtain the marginal (dis)utilities associated with each influence on the choice amongst the attribute packages offered in the stated choice scenarios. These conditional estimates are used to obtain the WTP distributions for fatality and classes of injury avoidance, which are then aggregated to obtain estimates for pedestrians of the value of risk reduction (VRR).

Keywords: Value of statistical life, value of risk reduction, fatalities, serious injury, pedestrians, choice experiment, willingness to pay, survey, Australia

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1 Introduction

An important conceptual advance in the state of practice of road safety valuation was achieved in the 1980s by valuing road safety according to subjective preferences rather than by using the heavily criticised *human capital* (*HC*) approach (see Jones-Lee and Loomes 2003 for a review). The *HC* approach rests on accounting principles: the benefit of avoiding a premature death is given by the present value of the income flow the economy could lose in that case (Ashenfelter 2006). More appropriately, the *value of risk reductions* (*VRR*) – initially known as the *value of a statistical life* (VSL) where the focus has historically been predominantly on fatalities[1] – is based on subjective preferences, and defined as the amount of money that individuals are willing to pay for reducing the risk of their premature death or of injury, while performing a certain risky activity. The focus on the VRR in contrast to the *HC* value has empirically yielded higher benefits for risk avoidance, and hence the social net benefit of safety policy measures has increased in countries such as the UK, USA, Sweden and New Zealand, where the ex ante WTP approach has been progressively implemented to elicit individuals' preferences, prompting many road safety interventions, otherwise not socially profitable, in the developed world. In the Australian context, this HC approach remains in place, with substantially lower estimates of VRR than other western economies.

The *VRR (or the specialised VSL and in the UK in recent years referred to as VPF – value of preventing a fatality)* for road contexts was estimated originally using contingent valuation (CV), standard gamble or the chained method (Viscusi et al. 1991; Jones Lee et al. 1993; Beattie et al. 1998; Carthy et al. 1998, de Blaeij et al. 2003). These methods are still in widespread use. In these original studies people were confronted with situations expressing risk as very small probabilities, and needing a trade-off between risk and money to arrive at a monetary value[2]. An alternative approach has evolved in more recent time in part response to a concern that the context in the previous sentence may not be as realistic a representation of the actual choices of pedestrian movement where individuals have to consider a larger bundle of attributes describing each alternative (i.e., walk time, road infrastructure, and safety associated with each route alternative).

Ortúzar and Rizzi (2000, 2001) and Rizzi and Ortúzar (2003) were the first proponents of a different approach based on the Stated Choice (SC) technique; this was later followed by de Blaeij et al. (2002) in the context of a Dutch study that tested the new approach. In a SC survey, individuals are asked to choose among different alternatives, the attribute levels of which vary according to a statistical design aimed at maximising the precision of the parameter estimates. As such, SC allows the analyst to mimic actual choices with a high degree of realism, and for this reason most experts believe that it is an appropriate elicitation method for the valuation of intangibles (McFadden 1998; Louviere et al. 2000). The approach has also been applied by de Blaeij et al. (2002), Iragüen and Ortúzar (2004) and Hojman et al. (2005) and is the starting position for the current study.

This paper develops an ex ante willingness to pay (WTP) model as input into the calculation of the value of a statistical life in the context of a fatality and three classes

[1] Given the continued common use of the phrase VSL, we will also use it herein to be equivalent to VRR, which is what many studies have always assumed.

[2] Some of these studies posed a risk – risk trade-off. However, in order to arrive at a monetary value a risk – money trade off is necessary, sooner or later.

of injury (defined below) for pedestrians in the road environment. The method has also been implemented in the context of car drivers and passengers (see Hensher et al. 2009). Surveys were undertaken in late 2007 in New South Wales to obtain WTP distributions, which are then combined with secondary data on the recent history of fatalities and injuries as well as exposure (measured in kilometres), to obtain estimates of VRR. Given the relatively small sample size, the data is used to illustrate the approach to valuation, and although the findings are in line with international evidence (see Section 8), we suggest that a larger sample might be appropriate before drawing policy implications.

2 The Value of Fatal and Injury Risk Reductions

Assume a route is used by N pedestrians. If person n walks more than once in a reference period, say m_n times, this gives rise to m_n pseudo-members with a total population of $N=\sum_{n=1}^{N} m_n$, observations, i.e., the individuals of a population. This population exactly amounts to the flow on a route in a given period (say a year). A pedestrian trip on a route provides a level of dissatisfaction given by a deterministic indirect utility function $V= V(r, t)$, where r stands for risk of a fatal accident or class of injury, and t for the walking time; there could be more attributes, of course. The injury classes studied are:

- *Severe permanent injury* (or serious) (*SI*), defined as an injury that requires hospitalisation for a long period and results in some permanent disability;
- *Injuries requiring hospitalisation* (*HI*) defined as an injury that requires hospitalisation but there is a full recovery; and
- *Minor injury* (*MI*) defined as an injury that requires some medical treatment but no hospitalisation.

Jones Lee (1994), focussing only on fatality, formally defined the *VRR* as the value of avoiding one expected death, which corresponds to the population (or sample) average of the marginal rate of substitution between income and risk of death for person n (MRS_n) plus a covariance term that accounts for possible correlation between WTP and reduced risk (δr_n)[3]:

$$MRS_n = \frac{\partial V_n / \partial r}{\partial V_n / \partial c\,|_{V=\bar{V}}}, \tag{1}$$

$$VRR = \frac{1}{N}\sum_{n=1}^{N} MRS_n + N\,\mathrm{cov}\left(MRS_n, |\delta r_n|\right). \tag{2}$$

[3] $\mathrm{cov}\left(MRS_n, \delta r_n\right) = \sum_n MRS_n \delta r_n - \frac{1}{N}\sum_n MRS_n \frac{1}{N}\sum_n \delta r_n$

In empirical work, it is typically assumed that there is no correlation between WTP and δr in the population. Then, Equation (2) simplifies to Equation (3), below, and to estimate the *VRR* it is sufficient to have a good estimate of the *MRS*. This assumption would be correct, for example, if δr were the same for every individual.

$$VRR = \frac{1}{N}\sum_{n=1}^{N} MRS_n \, . \qquad (3)$$

The *MRS* can be interpreted as an implicit value for the own life, and averaging it over all individuals walking in a particular road environment yields the *VRR*. The *MRS* depends on personal risk perceptions according to the functional form of V_n. The same analysis can be carried out in terms of fatal accidents, *f*, (or injuries), instead of risks, *r*. However, in this case the *VRR* is derived differently (but yields the same value):

$$VRR = \frac{1}{e}\sum_{n=1}^{N} \frac{\partial V_n / \partial f}{\partial V_n / \partial c}\Bigg|_{V=\bar{V}} = \frac{1}{e}\sum_{n=1}^{N} SVCR_n \, , \qquad (4)$$

where *e* represents the number of fatalities or injuries (by class) per accident and *SVCR* is the subjective value of fatal accident injury (by class) reductions. Equation (4) embodies the definition of community WTP for road safety as the sum of individual marginal rates of substitution between income and number of fatalities and injuries (by class). If we think in terms of a hypothetical road situation whose owners were able to extract the full consumer's (compensatory) surplus, the *SVCR* would be the maximum property tax rate increase due to a safety improvement for individual *n*, such that he is as well-off as before the improvement. If the *VRR* is higher than the cost of reducing one fatality or one injury (by class), the safety project should be desirable from the community standpoint; in what follows we will assume that *e* is equal to one.

We will now show one advantage of dealing with the variable number of fatal or injury accidents, rather than risk, in empirical work. From Equations (2) and (4), it follows that[4]

$$VRR = \sum_{n=1}^{N} SVCR_n = \frac{1}{N}\sum_{n=1}^{N} MRS_n + N\,\mathrm{cov}\left(MRS_n, \left|\delta r_n\right|\right). \qquad (5)$$

In other words, estimating the *SVCR* and aggregating across individuals will yield the correct *VRR* irrespective of the value of $\mathrm{cov}(\bullet,\bullet)$, and this follows from the very definition of our public good; one statistical death (or injury class reduction) reduction[5] (per unit of time) in a particular road environment. This suggests that to elicit the *VRR*, rather than asking people to place a value on risk reductions, they

[4] In the computations, fatalities are already divided by total kilometres, so the number of fatalities per fatal accident is implicitly considered. Then we do not have to divide again by e.

[5] A statistical death reduction means saving one life, on average, per unit of time (obviously whose life is saved is unknown).

should be asked to value a reduction in fatal or injury class accidents; this task is far easier from the respondents' standpoint as we will see below[6].

2.1 Making the model operational

The model can be made operational within a (binary) choice framework (and generalised to multiple choice settings) where the indirect deterministic utility of each available alternative *j* is

$$V_j = \alpha F_j + \eta SI_j + \theta HI_j + \varphi MI_j + \beta c_j + \gamma t_j, \quad (i = 1, 2) \qquad (6)$$

where *F* is the number of *fatalities*, *SI* is the number of *severe permanent* (or serious) *injuries*, *HI* is number of *injuries requiring hospitalisation*, *MI* is the number of *minor injuries* not requiring hospitalisation, *t* is walk time and c is the Council rate or housing rent increase to cover road environment safety improvements. The *SVCR* is equal to α/β for fatalities for every individual, η/β for serious injuries (Hojman et al. 2005), θ/β for hospitalised injuries, and φ/β for minor injuries for every individual.

The choice of a financial attribute is controversial but necessary, since there is no actual market in which payments can be made to reflect the value in monetary units of reducing the risk of *a pedestrian* being killed or injured in the road environment. Bonsall et al. (1992) discuss this issue is some detail in the context of preserving public transport, and support abstract charges combined with bus fares as the monetary metric. In the UK context they warn about the risk of strategic bias associated with local property taxes (where there is an expectation of change); however they tend to support a payment mechanism that has a universal application that is a flat rate per resident (what they call a 'Community Charge'). The Council Rate herein is used as a way of identifying the payment mechanism for house owners, with house rents for those who rent. Both are deemed to be "realistic, appropriate and universal" in the words of Bonsall et al. (1992, p80). For Council rates, they are universal for home owners, easily understood and recognised as subject to change and often containing amounts that are hypothecated or earmarked to a specific support services (e.g., waste collection, road maintenance). We argue that a very specific service is the investment in road safety measures such as road crossings and traffic lights. For renters, it is also possible to understand that a component of rent can be a contribution to supporting local amenity. Extensive piloting of the survey instrument was also undertaken where not only were data collected, but trained interviews also probed respondents about the survey instrument and their understanding of each aspect of it. This was followed by a larger initial study where respondents were able to communicate in an open ended question about the SC task. Not a single mention was made of not understanding the

[6] The two approaches are mutually consistent only when respondents have the correct aggregate flow in mind (i.e., they would value an extra fatal or serious injury accident per year differently if they were to make the only pedestrian trip that year, than when millions of such trips would be made). In this sense although a formulation in terms of number of accidents may sound more natural and easy-to-understand than a formulation in terms of probabilities to most respondents, the cognitive burden may not become any lighter.

role that council rates or rental income played in the games. We are unaware of any protest vote associated with Council rates, despite complaints about State-wide imposts such as stamp duties on house sales and increasing vehicle registration charges. Local Council expenditure appears to be non-controversial, especially since residents can see much more clearly where the money is spent. Both the rent and the rates apply to the 'household' unit and are not apportioned to an individual (as a pedestrian) per se, given evidence from pre-pilot focus groups that indicated that individuals see the financial impost on the household as the appropriate financial dimension in which they can assess the additional charge pursuant to investment in specific safety initiatives[7].

Let U_{nsj} denote the utility of alternative *j* in choice set *s* perceived by respondent *n*. U_{nsj} may be partitioned into two components, an observed (by the analyst) component of utility, V_{nsj}, and an unobserved (and un-modeled) component, ε_{nsj}, such that

$$U_{nsj} = V_{nsj} + \varepsilon_{nsj}. \tag{7}$$

The observed component of utility is typically assumed to be a linear relationship of observed attribute levels of each alternative, *x*, and their corresponding weights (parameters), β (as per Equation 6). It is possible for some or all of the parameter weights to vary with density $f(\beta \mid \Omega)$ over the sampled population. By allowing the parameter weights to vary between and not within respondents (i.e., as random parameters), the model accounts for the pseudo panel nature of SC type data (Ortúzar and Willumsen 2001; Train 2009). Under such an assumption, the observed components of utility may be represented as Equation (8).

$$V_{nsj} = \sum_{k=1}^{K} \beta_{nk} x_{nsjk}. \tag{8}$$

Assuming that (some of) the parameters are randomly distributed over the population with assumed density $f(\beta \mid \theta)$., the choice probabilities of the model therefore depend on the random parameters. In estimating the model, rather than calculate a single probability for each alternative, the choice probabilities for each random draw are taken from the assumed probability distribution(s). In this way, multiple choice probabilities are obtained for each alternative, as opposed to a single set of probabilities as obtained from the typical multinomial logit (MNL) model. It is the expectation of these probabilities over the random draws which are calculated and used in the model estimation process. The expected choice probabilities for the model are given in Equation (9).

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[7] What is missing from our study is knowledge of the frequency of walking in the road environment over the monthly period of the rent or rates. This may have an influence on the perception of value for money in safety initiatives; however we have had to assume by implication that the WTP is invariant to the frequency of walking in the

$$E\left[P_{nsj}\right] = \int_{\beta} \frac{\exp\left(V_{nsj}\right)}{\sum_{i \in J_{ns}} \exp\left(V_{nsi}\right)} f\left(\beta \mid \theta\right) d\beta. \tag{9}$$

Equation (9) represents the choice probability at the level of the alternatives. In the version of the *model* accounting for the panel format of SC data, the choice probability given in Equation (9), whilst calculated, is not of direct interest. Rather, what is of interest are the probabilities of observing the sequence of choices made by each respondent, not the probabilities that specific alternatives will be observed to be chosen. To this end, we define the probability P_n^* that a certain respondent *n* has made a certain sequence of choices $\{j \mid y_{nsj} = 1\}_{s \in S_n}$ with respect to the set of choice situations, S_n, by

$$P_n^* = \int_{\beta} \prod_{s \in S_n} \prod_{j \in J_{ns}} \left(P_{nsj}\right)^{y_{nsj}} f\left(\beta \mid \theta\right) d\beta, \tag{10}$$

which is what is used in model estimation (see e.g., Hensher and Greene 2003; Hensher et al. 2005; Sillano and Ortúzar 2005; Train 2009).

2.2Aggregating individual WTP to the population

The community demand for a public good is given by the summation of the WTP for the good by each individual (WTP_n). The public good is the avoidance of a fatality (or class of injury) known as the *value of risk reduction* (*VRR*) in the road vehicle environment. It can be shown (Jones Lee 1994; Rizzi and Ortúzar 2003) that the value of avoiding one event equals the population average of *MRS* (see Section 2 above).

Herein we focus on pedestrians, excluding other contexts such as motorcyclists, car drivers and passengers, etc. Importantly, the aggregate VRR (i.e., Equation (5)) represents the valuation for one of the full set of impacted stakeholder classes; and hence is not the maximum VRR for society as a whole for fatalities and injury classes. However; the segment studied is arguably a substantial contribution to the community VRR. The sources of community aggregate WTP are many and varied. These include users' WTP (including altruism if it exists) and non-users' WTP[8]. The WTP of non-users is unlikely to be the same as users' WTP (which includes the self-interest value). One cannot scale to the whole population from a sub-population. To capture the WTP of non-pedestrians, one should consider a survey on non-users to infer their WTP. Thus multiplying drivers' WTP by the total population instead of by the pedestrians' population will over-estimate the WTP for this segment.

[8] The non-users' WTP includes an altruistic component to the extent that they only care about the safety of other people, not their overall wellbeing; it could also include other factors too, such as personal grief if the victim was known to them, inconvenience if the accident causes disruption, loss if the accident consumes public resources, distaste or squeamishness about the idea of accidents, heightened sense of danger in "the world out there" (we thank an anonymous referee for having noted this).

For pedestrians, the *WTP* is the pedestrian's marginal rate of substitution between income and number of annual pedestrian fatalities in the road environment; and *VRR* is the summation of *WTP (separately for fatalities and classes of injury on a specific route)* over all pedestrians that walk in a specific road environment in a given year. Summing *WTP* values over all pedestrians (annual flow) on each route, we obtain four values - the value of fatality risk reductions (*VSL*), the value of serious (permanent) injury risk reductions (*VSI*), the value of hospitalised (non-permanent) injury risk reductions (*VHI*), and the value of minor injury risk reductions (*VMI*). The survey does not consider the pedestrian's WTP for not harming other motorised or non-motorised users, at least explicitly, since the fatalities and injuries refer to individuals walking in the road environment.

With a focus on specific pedestrian trips, we have to convert the individual WTP to a *pedestrian population exposure risk measure*. This link is critical to the validity of the community WTP and cannot be disassociated from the specific level of risk associated with each pedestrian trip. The *exposure* of interest is reflected in the number of pedestrian trips and associated walking kilometres undertaken by each pedestrian in the population. The trip kilometres associated with walking has to be expanded up to the relevant population, based on the number of times an individual in a sub-population is exposed to risk. Identifying the actual amount of pedestrian trip activity is crucial in aggregating up the average WTP per trip. The formulae for inputting the calculations for each risk class are

$\textit{Community } VRR_{l,vf}\ (= VSL_{l,vf}) = \textit{Community } VSL_l\ ;\ l = \textit{region location } 1,2,\ldots,L,$

$\textit{Community } VRR_{l,vsi}\ (= VSL_{l,vsi}) = \textit{Community } VSI_l\ ;\ l = \textit{region location } 1,2,\ldots,L,$

$\textit{Community } VRR_{l,vhi}\ (= VSL_{l,vhi}) = \textit{Community } VSI_l\ ;\ l = \textit{region location } 1,2,\ldots,L,$

$\textit{Community } VRR_{l,vmi}\ (= VSL_{l,vmi}) = \textit{Community } VSI_l\ ;\ l = \textit{region location } 1,2,\ldots,L.$

where *si* = serious, *hi* = hospitalised and *mi* minor injury.

The components of the calculation of the Community VRR can be defined as WTP/*chance*, where *chance* is defined by the relationship between the *risk* as measured by the number of fatalities or injuries in a class (*I*= *si, hi*, or *mi*) per annum, and *exposure* defined by the annual number of walk kilometres (AAVKM) (Equations 11 and 12).

$$\text{Community VSL} = \frac{WTP\ per\ trip_l}{Trip\ Kms} \times \frac{AAVKM_l \times 365}{\#\ fatalities_l}, \quad \text{and} \qquad (11)$$

$$\text{Community VI} = \frac{WTP\ per\ trip_l}{Trip\ Kms} \times \frac{AAVKM_l \times 365}{\#JI_l}, \qquad (12)$$

The WTP is an average or median WTP per person per trip; the average number of fatalities or injuries in a class and the average annual daily vehicle kilometres is an average over the last five years. Five years is selected because accidents are very random in nature, so it is good to have averages over such a period of years.

To illustrate how this formula will work, let us assume a representative pedestrian WTP (averaged over all pedestrians in the sample in the l^{th} region) of \$0.10 per walk kilometre. Let us assume from our population data in the l^{th} region that the chance of death per annum associated with pedestrian activity is three fatalities ÷ 6,000,000 pedestrian walk kilometres per annum. The VSL is the WTP of the representative pedestrian trip (assumed to be two kms) divided by the chance of death. This is \$0.20 ÷ [3/6,000,000] = \$400,000. This is the sum that society would be willing to pay to reduce the risk by one statistical pedestrian death.

To be able to translate the WTP estimates (converted from per pedestrian trip to per km) from the sampled population used in model estimation, we need data on (i) the number of fatalities and injuries by class in typical road environments in each region, and (ii) the aggregate annual pedestrian kilometres for these roads. One major challenge is in how to work with a road network where the risks vary quite substantially across the network, within each region. That is, where the ratio of accidents to flow or exposure per route differs. There are two main options: (i) to work with each route's safety record, or (ii) to group routes according to some characteristic, and work with their aggregated road safety record (for example, route A: 1 death per year; flow, 2,000,000; route B: 2 deaths per year; flow 3,500,000; aggregated: 3 deaths per 5,500,000 flow). In the latter situation, if routes are of different lengths it may be necessary to standardise in terms of deaths (and injuries in a class) per million pedestrian vehicle-kilometres.

We suggest that a way forward for pedestrians is to sample representative routes and obtain data on annual pedestrian kilometres (based on number of trips and average distance if trip kilometres are not readily available), and accident record (road environment pedestrian fatalities and injuries by class). As long as we have information on the amount of pedestrian activity on each of these roads, compared to the entire eligible regional network, we can use this data on exposure (annual pedestrian kilometres) and risk (aggregated fatalities and respective injury classes) to obtain the chance indicator for Equations (11) and (12).

3 Designing the Stated Choice Experiment

The method implemented in the present study to obtain estimates of WTP and hence VRR involves the use of SC experiments in which we systematically vary combinations of levels of each attribute to reveal new opportunities relative to the existing circumstance of time-cost on offer (see Louviere et al. 2000; and Hensher et al. 2005). Through the SC experiment we are able to observe a sample of pedestrians making choices between the current walk trip attribute level bundle (i.e., a package of service levels), and other attribute level bundles. This approach is a powerful method capable of separating out the independent contributions of each time and cost component, and quality differences, between links and routes. Previous research by the authors (e.g., Rizzi and Ortúzar 2003) has given us confidence in the use of SC methods to capture trade-offs between traditional travel attributes such as time and cost and carefully crafted attributes representing safety in the road environment.

For this study, a SC experiment is used to capture the preferences of pedestrians for road safety, travel times and Council rate/housing rent increases that deliver infrastructure designed to improve safety in the road environment. Underlying SC experiments are what are known as experimental designs. An experimental design is used to systematically determine the attribute levels shown as part of the SC experiment.

To identify candidate attributes for the choice experiment, this study was preceded by a literature review, and then a pilot survey of 11 pedestrians interviewed by four trained interviewers. Data from the pilot questionnaires were collected and analysed, with additional comments from respondents collected after the survey was concluded, to confirm the appropriateness of the attributes and their levels. This was then followed by a main survey, as part of a government funded study. The models that were estimated enabled us to establish the appropriateness of each attribute and the attribute ranges, and the possibility of missing attributes. The earlier study focused on fatalities and severe injuries; however, it raised concerns about the ability of respondents to distinguish between severe injuries and other injuries that were not investigated. This led to a decision to undertaken a new survey that could distinguish between the three classes of injury specified in the current paper.

3.1 Experimental design

The pedestrian user questionnaire employed an unlabelled SC experiment where the alternatives relate to two hypothetical routes. Respondents were shown 10 choice situations each, and asked to select the pedestrian route which they would most likely use if faced with these alternatives in real life. For each choice situation, respondents were also allowed to select neither route in a subsequent question.

The primary question for those generating experimental designs for SC studies is simply that of 'how best to allocate the attribute levels to the design matrix'. Traditionally, researchers have relied on the principle of orthogonality (i.e., allocate the attribute levels to the design matrix in such a way that the correlation between any two columns is zero) to populate the choice situations shown to respondents (see Louviere et al. 2000 for a review of orthogonal designs). The past decade, however, has seen fundamental changes in the methods employed to construct experimental designs underlying SC experiments (see e.g., Huber and Zwerina 1996; Toner et al. 1999; Watson et al. 2000; Sándor and Wedel 2001, 2002, 2005; Kanninen 2002; Kessels et al. 2006; Ferrini and Scarpa 2007; Vermeulen et al. 2008; Bliemer and Rose 2009; Yu et al. 2009)[9].

Primarily, these research efforts have concentrated on the concept of improving the *statistical efficiency* of experimental designs generated for SC studies. In doing so, researchers have defined statistical efficiency in terms of increased precision of the parameter estimates for a fixed sample size. In taking such a definition, statistical efficiency within the literature has therefore been linked to the standard errors likely to be obtained from the experiment, with designs that can be expected to i) yield lower standard errors for a given sample size, or ii) the same standard errors given a smaller sample size, being deemed more statistically efficient. In order to calculate the statistical efficiency of a design, Huber and Zwerina (1996), Sándor and Wedel (2001) and Kanninen (2002), amongst others, have shown that the common use of logit models to analyze discrete choice data requires *a priori* information about the parameter estimates, as well as the final econometric model form to be estimated.

Information on the expected parameter estimates is required in order to calculate the expected utilities for each of the alternatives present within the design. Once known, the expected utilities may in turn be used to calculate the likely choice

[9] The most common statistical designs are available in the software package NGene (see www.choice-metrics.com).

probabilities. Hence, given knowledge of the attribute levels (the design), expected parameter estimate values and choice probabilities, it becomes a straightforward exercise to calculate the asymptotic variance-covariance (AVC) matrix for the design, from which the expected standard errors can be obtained. By manipulating the attribute levels of the alternatives, for known (assumed) parameter values, the analyst is able to minimize the elements within the AVC matrix, which in the case of the diagonals means lower standard errors and hence greater reliability in the estimates at a fixed sample size, or even at a reduced sample size. The linking of the experimental design generation process to attempts to reduce the asymptotic standard errors of the parameter estimates has resulted in a class of designs known as '*efficient designs*' where a design that, when used in practice, is expected to produce smaller asymptotic standard errors for a given sample size is thought of as being more '*efficient*'.

The most widely used measure is called the *D-error*, which takes the determinant of the AVC matrix Ω_1, assuming only a single respondent. Other measures exist, such as the *A*-error, which takes the trace (sum of the diagonal elements) of the AVC matrix, however, in contrast to the *D*-error, the *A*-error is sensitive to scaling of the parameters and attributes, hence here only the *D*-error will be discussed. The *D*-errors are a function of the experimental design *X* and the prior values (or prior probability distributions) β, and can be mathematically formulated as:

$$D_z\text{-error} = \det\left(\Omega_1(X,0)\right)^{1/K}, \quad (13)$$

$$D_p\text{-error} = \det\left(\Omega_1(X,\beta)\right)^{1/K}, \quad (14)$$

$$D_b\text{-error} = \int_\beta \det\left(\Omega_1(X,\beta)\right)^{1/K} \phi(\beta \mid \theta) d\beta. \quad (15)$$

where *K* is the number of parameters to be estimated. Within the literature, designs which are optimised without any information on the priors (i.e., assuming β=0) are referred to as D_z–efficient designs (Equation (13), whereas designs optimised for specific fixed (non-zero) prior parameters are referred to as D_p–efficient designs (Equation (14)). In (Bayesian) D_b– efficient designs (Equation (15)), the priors β are assumed to be random variables with a joint probability density function $\phi(\cdot)$ with given parameters θ.

For the present study, given a lack of knowledge about the precise parameter estimates, we generated a Bayesian *D*-efficient design with 60 choice tasks each. Sixty choice tasks represented the smallest number of scenarios achievable after accounting for attribute level balance and degrees of freedom, the latter based on the levels of each and every attribute in the choice set (see Table 1). The designs were generated assuming that all attributes would be treated as linear in the marginal utilities. All parameter priors were drawn using Uniform distributions with population moments as shown in Table 1. The best design located had a D_b-error of 0.008409 over 1,000 Halton draws.

Within each design, the 60 choice scenarios were subsequently grouped into six blocks of 10 choice tasks recognising that an individual cannot be expected to asses all 60 choice scenarios. The process by which this was done involved calculating the correlation of each design attribute with the blocking variable, and fixing the design, varying the blocking column in such a way as to minimise the maximum correlation found. In this way, minimum confoundment with the blocks exists when estimating models based on data pooled across the blocks. The Computer Assisted Personal Interview (CAPI) was then programmed to allocate a random start block to the initial respondent, and then to rotate each of the blocks over subsequent respondents. This was done to maintain as equal as possible exposure of the blocks to respondents within the data set. As such, each respondent saw a total of 10 SC screens during the survey process.

3.2 The final choice experiment

The SC experiments presented respondents with two alternative routes which differed in terms of the attributes or characteristics of the walking routes. The attributes and levels for each of the attributes are described in Table 1. Figure 1 shows an example SC screen. The experiment did not pivot around a recent walk trip, but relied solely on the predetermined levels which are shown in Table 1.

Table 1: Summary of Attributes and Associated Levels for Pedestrian Walking Experiments

Attribute	Levels
Number of lanes to cross (each way)	1, 2, 3
Speed limit	60, 80 ,90, 100, 110
Crossing type	None, Zebra (pedestrian) Crossing, Traffic Lights, Pedestrian Overpass
Walking time for the entire trip	10, 15, 20, 25, 30, 35, 40
Council Rate/ Housing Rent increase per month	$0, $25, $50, $75, $100
Number of deaths per year	0, 1, 2, 3, 4, 5
Number of severe permanent injuries per year	0,1,2,3,4,5,6,7,8,9
Number of injuries requiring hospitalisation per year	0,1,2,3,4,5,6,7,8,9,…,19
Number of minor injuries per year	0,1,2,3,4,5,6,7,8,9,…,29

Number of lanes to cross (each way) of a major road that must be crossed as part of the entire walking journey.
The ***speed limit*** of the major road that must be crossed as part of the walking journey.
The type of ***crossing*** that may be accessed to traverse the major road that must be crossed as part of the walking journey.
A per month Council ***rates/housing rent increase***. This attribute was necessary so that a WTP could be calculated for the study.
Number of pedestrian deaths per year along the major road that must be crossed. The attribute was described to respondents as the number of pedestrians who have been killed using this road in the past 12 months.
Number of pedestrian severe permanent injuries per year along the route which represent the number of people who have been severely injured in pedestrian accidents using this road in the past 12 months, requiring hospitalisation for a long period of time and resulting in permanent disability.
Number of (non-severe and permanent) pedestrian hospitalisation injuries per year along the route which represent the number of people who have been severely injured in pedestrian accidents using this road in the past 12 months, requiring hospitalisation after which a full recover is made.
Number of pedestrian minor injuries per year along the route which represent the number of people who have been severely injured in pedestrian accidents using this road in the past 12 months, requiring some medical treatment but no hospitalisation.

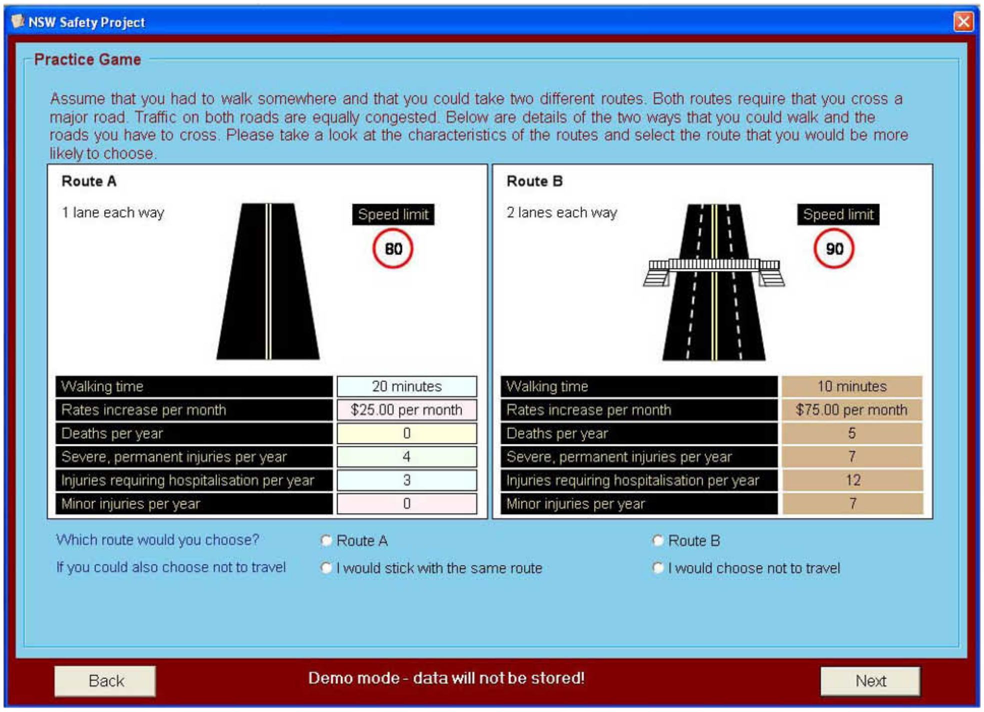

Figure 1: Example of a Final Stated Choice Screen

To be eligible for the final sample, respondents were required to have walked along and crossed a main road[10] as a pedestrian in the last week. This eligibility was pre-determined from a phone screener. In explaining the SC task to respondents during the actual interview, interviewers were trained to make it clear that the walking time was for the entire trip, and that the respondent did not have to deviate from their path in order to walk to an over pass or other surface level crossing if they did not wish to do so. The assumption that both roads had the same level of congestion was used in order to avoid having to include the level of congestion on the road as an attribute of each alternative. This does not imply 'safe' since the road can still have traffic moving at speeds below the free flow level that are dangerous. The use of wording such as 'major road' and the equal level of congestion across both roads was extensively tested in initial focus groups, a pilot survey and an initial study and were found to be well understood by pedestrians in terms of its physical setting and clarity of meaning[11].

[10] The meaning of a 'main road' is very clear in Australia. These are mainly arterial and non-freeway routes where maximum legal speed limit is 60 kph for the majority of such roads with some permitting up to 80kph.

[11] We considered whether simply saying that a respondent has a choice between two routes with say six and three fatal accidents respectively would be sufficient. To some respondents, six and three might seem low numbers depending on their perception of overall traffic, while to others both could be high numbers. It is the perceptions of respondents that matter, and these would in part be conditioned on their experience with specific main roads (as defined in footnote 10). Furthermore, the pilot and feedback from the initial study indicated that the perception of an unsafe environment is aligned with the speed limit, the number of lanes and the pedestrian crossing infrastructure, that are included in the choice scenarios, and not the amount of traffic per se. This point is linked to the eternal discussion about what really matters,

4 The CAPI Questionnaire Layout

The data collected in the study were obtained from face-to-face interviews. All data were entered by trained interviewers directly into the CAPI system which was implemented on laptops[12]. The survey consisted of five major sections:

(i) The introduction to the survey task and background on the study;
(ii) Question related to house ownership and rent paid per month or Council rates paid per year;
(iii) A SC experiment in which the respondent compares the levels of walking times, infrastructure available to assist in crossing roads (e.g., zebra crossings, traffic lights, overpasses), costs in terms of increases in housing rents/Council rates[13], and the number of pedestrian deaths and the three classes of injuries suffered on the part of the road respondents were told they had to cross. Each respondent was shown two alternative routes and asked to select the one they would most likely take, after which they were given the opportunity to select neither route. The process of choosing amongst the alternatives is repeated a total of ten times (each choice situation involves varying the levels of the attributes described above).
(iv) Questions on their experiences, or experiences of close friends/relatives with regards to road accidents; and
(v) Some socio-economic questions collected to establish the representativeness of the sample.

5 Descriptive Profile of Data

The final effective sample size was 99 pedestrian trips. A total of 743 contacts were made of which 79.05 percent were refusals and 7.65 percent belonged to already completed quota segments. As such, the 312 respondents who made up the final sample represented 13.3 percent of all contacts made by the survey firm. The 99 trips were sampled from a quota frame of 60 urban and 30 non-urban residents who had undertaken a pedestrian trip in the last week *in their local area*, and hence any safety improvements in the pedestrian environment would relate to the jurisdiction where each respondent lived as a renter or owner. Within each geographical setting we quota sampled males and females 50:50 and divided them equally by three age classes (18-

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i.e., is it the objective risk measure or the subjective one? We believe it is the latter; for example when we buy a safety gadget, most probably we do not know exactly how much the risk reduction is.

[12] The survey instrument is designed in such a way that all information must be provided. Until each question is answered, the survey will not proceed on and a warning message appears.

[13] Participants were told by interviewers, using a fixed text, that there would be a fixed community surcharge that would be added onto the rent if one rented accommodation, or added to local council property rates for home owners, *for all residents regardless of the amount of pedestrian activity*, and it is used to provide infrastructure to improve safety in the road environment for pedestrians. This infrastructure was the suite of crossing options for existing roads. No new roads were to be built. Indeed in the survey areas we witness a lot of local safety treatments along the lines of the survey options, and hence the contexts are very real. It was also made clear that the choices made by the respondent would affect the investment decisions of the local government authority.

Table 2: Summary of Sample

Age	Gender	Sydney	Bathurst	Total
19 or under	Male	2	1	3
	Female	3	2	5
	Total	5	3	8
20-24	Male	3	3	6
	Female	0	2	2
	Total	3	5	8
25-34	Male	4	1	5
	Female	3	2	5
	Total	7	3	10
35-44	Male	3	1	4
	Female	2	0	2
	Total	5	1	6
45-54	Male	6	0	6
	Female	3	3	6
	Total	9	3	12
55-64	Male	2	1	3
	Female	3	2	5
	Total	5	3	8
65 or over	Male	8	1	9
	Female	6	4	10
	Total	14	5	19

30, 31-60, and 61 and over). The overall aggregate composition by gender and age lined up approximately with the Australian Bureau of Statistics Census 2006 Sydney and Bathurst profiles of population. We were unable, however, to source any data on the population profile of pedestrians. Summary effective sample profiles are given in Table 2.

Forty eight out of the 99 respondents own their current place of residence with the remaining 51 renting. Table 3 reports the number of respondents who have been exposed to road accidents either by personal experience or via someone they personally know. Eleven percent of pedestrians know someone who has died in a road related accident.

Table 3: Pedestrian Age Group Sample Breakdown by Gender

	Died	**Permanently and Severely injured**	**Hospitalised non-permanent Injury**	**Minor Injury**
Personally	-	3	6	16
Know someone	11	6	17	18

6 Model Analysis

A Mixed logit model was estimated[14]. Unlike the Multinomial logit (MNL) model, the mixed logit model is capable of estimating both non-random and random parameters, as described in Section 2.1. Non-random parameters assume homogeneity in preferences, in terms of the marginal utilities associated with an attribute across the entire sample. Random parameter distributions in the mixed logit model relax the assumption of homogeneity in preferences, allowing for heterogeneity of the marginal utilities of the model attributes. Random parameters require that the analyst assume that the heterogeneity in preferences follow a known distribution over the population. The model was estimated using 1,000 Halton draws per random parameter (each defined by a constrained triangular distribution[15]) with the panel form (i.e., 10 choice scenarios per person) taken into account in estimation. We initially allowed the random parameters to have an unconstrained triangular (and normal) distribution, but for the majority of the attributes the mean and/or standard deviation parameter estimates were not statistically significant. This suggests that the extent of taste heterogeneity is not sufficient to be captured by a fully unconstrained distribution, and hence we selected a constrained triangular distribution, which accommodates preference heterogeneity within a constrained utility space. We defined the mean of this distribution as a free parameter, β, and fixed its two endpoints at zero and 2β, so there is no free variance (scaling) parameter. The parameter can be positive or negative, and in our case it is negative, which is behaviourally valid. Note that distributions are analytical and not strictly behavioural, so it makes sense to impose meaningful behavioural conditions.

In addition to the choice experiment attributes, we investigated interactions between each of the attributes and socioeconomic characteristics, namely respondent age, gender and personal income. We found three significant interactions (listed below) that are systematic sources of taste variation in the sample that enrich the way in which each respondent is assigned to the parameter distributions associated with fatalities and injuries.

The utility expressions are:

$$U(Route\ A) = SC1 + \beta_{nocr}\times no\ crossing + \beta_{zcr}\times zebra\ crossing + \beta_{tlcr}\times traffic\ lights + \beta_{avspd}\times speed\ limit + \beta_{ff}\times walk\ time + \beta_{C}\times rate\ inc + \beta_{death}\times deaths + \beta_{inj}\times injury + \beta_{injho}\times injuryho + \beta_{injmi}\times injurymi + \beta_{death}\times deaths\times age + \beta_{injho}\times injuryho\times age + \beta_{injho}\times injuryho * male$$

$$U(Route\ B) = SC2 + \beta_{nocr}\times no\ crossing + \beta_{zcr}\times zebra\ crossing + \beta_{tlcr}\times traffic\ lights + \beta_{avspd}\times speed\ limit + \beta_{ff}\times walk\ time + \beta_{C}\times rate\ inc + \beta_{death}\times deaths + \beta_{inj}\times injury + \beta_{injho}\times injuryho + \beta_{injmi}\times injurymi + \beta_{death}\times deaths * age + \beta_{injho}\times injuryho\times age + \beta_{injho}\times injuryho * male$$

[14] We also estimated a model that included scale heterogeneity; however the empirical evidence on WTP was almost the same as that reported herein and hence we chose the mixed logit model where the focus is on preference heterogeneity. See Greene and Hensher (2010) and Hess and Rose (2011) for details of scale heterogeneity models.

[15] Let c be the centre and s the spread. The density starts at c-s, rises linearly to c, and then drops linearly to c+s. It is zero below c-s and above c+s. The mean and mode are c. The standard deviation is the spread divided by $\sqrt{6}$; hence the spread is the standard deviation times $\sqrt{6}$. The height of the tent at c is 1/s (such that each side of the tent has area s×(1/s)×(1/2)=1/2, and both sides have area 1/2+1/2=1, as required for a density). The slope is $1/s^2$.

U(no travel) = 0

where SC*i* (*i*=1,2) = alternative-specific constants for each of the alternatives, deaths = number of fatalities per annum, injury = number of permanent severe injuries, injuryho = number of major injuries hospitalized, and injurvmi = number of minor injuries, age is person's age in years and male is a dummy variable equal to 1 if male.

The final discrete choice model estimated on the pedestrian segment of data is reported in Table 4. The final sample used for estimation consisted of all 99 sampled respondents or 990 observations. The final mixed logit model produced a good model fit with a rho-square of 0.309.

Prior to estimating the model, the type of road crossing attribute was dummy coded with the overpass attribute level representing the base attribute level in the coding scheme. Also, for the final model, the number of permanent severe, and major hospitalised non-permanent injuries were pooled, as earlier modelling suggested that the marginal utilities for these two attributes were not statistically different, and hence the two parameters could not be treated as different.

Table 4: Final Pedestrian Model

rp = random parameter, *fp* = fixed parameter

Attributes		**Parameter**	**(*t*-ratio)**
Random Parameters			
Constrained Triangular Distribution			
Deaths	*rp*	-0.446	(-5.11)
Major Injuries (permanent severe and hospitalised non-permanent injury)	*rp*	-0.046	(-3.09)
Minor Injuries	*rp*	-0.054	(-4.81)
Deaths by age	*fp*	0.0038	(2.30)
hospitalised non-permanent injury by age	*fp*	0.0004	(1.91)
hospitalised non-permanent injury by male	*fp*	-0.034	(-2.21)
Crossing (None) (1,0)	*rp*	-2.317	(-8.28)
Crossing (Zebra) (1,0)	*rp*	-1.419	(-6.45)
Crossing (Traffic Lights) (1,0)	*rp*	-0.729	(-3.96)
Travel Time (minutes)	*rp*	-0.039	(-4.54)
Traffic Speed Limit (KM per hour)	*rp*	-0.028	(-7.65)
Number of Lanes	*rp*	-0.429	(-1.95)
Cost ($ increase per month)	*rp*	-0.020	(-8.78)
Fixed Parameters			
Constant 1 (SC1)	Mean	9.629	(12.85)
Constant 2 (SC2)	Mean	9.450	(12.75)
Model Fits			
LL(0)		-1087.626	
LL(β)		-751.671	
ρ^2		0.309	
N		990	

The means and spread parameters (equal given the constrained triangular distribution[16]) are all statistically significant and of the expected signs. The relative magnitudes of the spread parameters suggest a significant level of preference heterogeneity resides within the sampled population with regards to these attributes. As would be expected, the mean of the random parameter distribution for the number of deaths is larger than that of the mean of the random parameter distribution for the number of injuries, after accounting for the parameter estimates associated with the interaction of deaths and injuries with the respondents' age and gender, suggesting the sample population has a larger marginal utility for avoiding pedestrian deaths than for avoiding major or minor injuries. Further, the relative magnitude of the minor injury random parameter is such that the number of deaths and major injuries has a larger impact on an individual's preference to use a particular road. We see that, all other influences held constant, as one ages, the marginal disutility of being killed or having a hospitalised non-permanent injury as a pedestrian declines (possibly because one believes this is less likely to occur, given the relatively cautious nature of older folks), however the marginal disutility associated with a hospitalised non-permanent injury is increased for males compared to females. On closer inspection, the magnitude of the parameter estimates (allowing for the scale of the socioeconomic variable) is such that the socioeconomic effect is small relative to the overall impact across all respondents.

With regards to crossing types, the dummy variable for having no-crossing has a larger negative mean than for having a zebra crossing installed, suggesting that having a zebra crossing installed is preferred. A dummy variable for having traffic lights was also tested as part of the experiment, which is also less preferred to having an overpass present when crossing roads. The number of lanes that must be crossed, and the total time spent walking, also have statistically significant and negative mean parameter estimates, suggesting that on average, crossing less lanes and walking shorter distances is preferred to having to cross more lanes and walk greater distances.

Parameters for the speed limit of major roads crossed and the Council rates/housing rent increase used to obtain a cost parameter for the experiment were estimated as random parameters. Both parameters were found to be statistically significant and negative, in line with prior expectations.

7 Deriving WTP to Avoid a Fatality and the value of a Risk Reduction

In this section, we report the empirical findings on the WTP to avoid a fatality and a class of injury in a road environment. Given that the number of deaths and injuries by category were estimated as random parameters, it is necessary to calculate distributions of WTP within the sample data and calculate the mean of the distribution. We use conditional estimates that are based on accounting for the actual choice made and the parameter estimates for the numerator and denominator are randomly assigned

[16] Although not reported herein, using ideas and evidence from Hensher and Greene (*in press*), we estimated the model in WTP space and found an almost identical mean WTP in WTP space and preference space for fatalities. This is the second data set where we have found such close equivalence. Hensher and Greene (*in press*) suggest 'The empirical evidence offers an encouraging sign that constrained distributions on random parameters in preference space 'may' offer a suitable proxy for WTP estimates obtained in WTP space where such constraints are not imposed.'

Table 5: Willingness to Pay Estimates ($/pedestrian activity per month)

Attribute	Average	Std Dev.
Deaths	$15.52	$5.42
Permanent Injuries	$3.23	$1.03
Major injuries (Hospital)	$3.23	$1.03
Minor Injuries	$2.47	$0.84

conditional on the alternative chosen (see Train 2009). The results are presented in Table 5.

The average WTP for a reduction per death is $15.52 per monthly pedestrian activity. For a reduction in the number of permanent severe injuries and major injuries requiring hospitalisation, the average WTP was estimated at $3.23 per monthly pedestrian activity, whereas minor injuries were valued at $2.47 per monthly pedestrian activity.

The pedestrian WTP values are calculated per month. Thus, it is necessary to convert the pedestrian WTP from a per month basis to a per trip basis given that the exposure rate relates to trips. For example, if we assumed an average of 20 walking trips per month, the average WTP per trip for walking trips is calculated as $0.776 to avoid fatal accidents, $0.162 to avoid severe accidents resulting in permanent injury or hospitalisation, and $0.124 to avoid minor injuries. The data suggests that the average number of one-way pedestrian trips per month is close to 30, or 1 per day, with a mean distance close to 1 kilometre. The average of 1 km was based on advice from the NSW Transport Data Centre (now the NSW Bureau of Transport Statistics) who advised us, from their household travel surveys and GIS mapping of trips, that 1 km is the best mean representation.

8 Deriving the value of risk reduction (VRR)

The WTP estimates are a 'per person per trip' valuation for an individual in a household. To obtain the value of a reduction in risk of one fatality and one injury, we have to convert the WTP per person per trip to a WTP per person per kilometre, and then multiply by the inverse of the chance of death or injury class to obtain an aggregated VRR[17]. The data required to identify the chance of death or injury has been obtained from a variety of sources. We need exposure data measured in terms of annual kilometres walked by pedestrians, and risk data in terms of the numbers of fatalities and injuries in each class per annum for persons walking. All the evidence is in Aud$2007.

The presentation of the evidence has been stratified by urban and non-urban travel. Given the problems in disaggregating data beyond the Sydney Statistical

[17] In our approach we are not assuming anything with respect to the respondents' estimations of flows. That is the advantage of the method; risk is a subjective assessment, and we should not care whether or not respondents correctly estimate flows, furthermore we do not need to know what measure of risk they have in mind (risk could be something very fuzzy from respondents' point of view, we only need them to believe that there is a risk of an accident). We then convert WTP per fatalities to WTP per kilometre to add WTP and be able to value total WTP for the public good 'road safety'.

Division (SD) (i.e., Metropolitan Sydney and the Central Coast)[18] and the rest of NSW, we have defined the Sydney SD as urban and the rest of NSW as non-urban. We can classify the urban road environment in terms of a road hierarchy represented by four categories of Freeways/Motorways, State Highways, Other Classified Roads, and Unclassified (Local) Roads. This classification, while applicable in the non-urban context, does not provide data on exposure and risk, and hence the best we can do in the non-urban context is to treat the network as one. We have adopted the same strategy for the urban jurisdiction.

Data on fatalities and injuries for urban and non-urban jurisdictions were sourced from the Road Safety Branch of the Roads and Traffic Authority (RTA) of NSW. The source we have available is referred to as the *Accident and Casualty statistics*. These data cover accidents and casualties included in the RTA's Traffic Accident Database (TADS) for the five year period 2001 to 2005 and updated to 2007. The accidents in TADS are confined to those accidents which conform to the national guidelines for reporting and classifying road-related accidents. The main criteria are:

(i) The accident was reported to the police;
(ii) The accident occurred on a road open to the public;
(iii) The accident involved at least one moving road vehicle; and
(iv) The accident involved at least one person being killed or injured or at least one motor vehicle being towed away.

A pedestrian accident is any accident which involves at least one pedestrian where a pedestrian is any person who is not in, on, boarding, entering, alight or falling from a road vehicle at the time of the accident. We had to establish the average number of fatalities per accident and average number of injuries in each class per accident to obtain the relevant number of fatalities and injured persons.

Given that injury data does not distinguish classes of injuries, a formula had to be implemented to apportion injuries to the three categories. The great majority of injuries are not serious, and do not require hospitalisation. This can be estimated using the NTID serious injury data set for the land transport (traffic accident indicated) category. Although it may not be strictly comparable with the RTA definition of road traffic accidents; for example, it may include accidents outside the road reserve such as car parks and driveways, it is the only source available. The proportional distribution of severe permanent injuries/hospitalised non-permanent injuries/other injuries is based on a range of data sources given the difficulties in obtaining a single source of data that presents the three levels of injury. The final number of injuries in each class is given in Table 6.

The final estimates of VRR are summarised in Table 7, based on equations (11) and (12). Some observations can be made about the findings in Tables 6 and 7. Pedestrian deaths are less in the non-urban context, as might be expected (ratio 0.429), as is the chance of a pedestrian being killed (0.743). For injuries, the incidence is higher for the urban setting (i.e., ratio of non-urban to urban is 0.294) with the chance of a serious injury being lower in the non-urban context as well (i.e., 0.404). Importantly, we expect the WTP for a given reduction in probability of a fatality or a class of injury to be an increasing function of the initial risk level. If we compare the

[18] The Sydney Region is defined as the Sydney ABS Region and covers the area bounded by the Wyong, Gosford, Hawkesbury, Blue Mountains, Wollondilly and Sutherland local government areas.

Table 6: Chance of Death and Injury Estimates
Injury: SI = Severe, HI = Hospital, MI = Minor

	Degree of Casualty						Ave per crash				Exposure	Chance of:			
	Fatality	*Injured*	*SI*	*HI*	*MI*	*Total*	*Fat*	*SI*	*HI*	*MI*		*Fatality*	*SI*	*HI*	*MI*
Urban											VKT PA				
Pedestrian (2007 est)															
TOTAL	*62*	*1603*	160	481	962	1665	1	1	1	1	1,601,600,000	3.86E-08	1.0008E-07	3.0024E-07	6.0049E-07
Non-Urban															
Pedestrian (2007 est)															
TOTAL	*26.64*	*470.7*	38	104	329	497	1	1	1	1	928,200,000	2.87E-08	4.0569E-08	1.1156E-07	3.5498E-07

mean estimates for urban and non-urban pedestrian activity, our evidence is completely consistent with this.

To establish some confidence in the evidence, albeit for fatalities only, we draw on a review of the value of a statistical life by Access Economics (2007). VSL estimates were identified from 244 'western' studies between 1973 and 2007, primarily in health, occupational safety, transport, and environment. Estimates were converted to 2006 Australian dollars. A meta-analysis was performed of the higher quality studies (i.e., more recent studies that had either a midpoint and standard deviation or other minimum-maximum range). The meta-analysis yielded an average VSL of $6.0 million in 2006 Australian dollars with a range of $5.0 million to $7.1 million. Another source of evidence for VSL is de Blaeij et al. (2003). The majority of the so called stated preference studies cited in de Blaeij et al. are contingent valuation studies and related to car occupants; however with this caveat, we note a mean in $US1997 of four. million, which in the currency of our study year is close to AUS2009 $8m. Hence our estimates for loss of life, while closer to this estimate than the current estimates for VSL used in Australia (around $1.5m), are below the mean in some countries such as the US, UK, and France, but are not substantially lower than others (i.e., those in Chile for example). For pedestrians, the comparisons have to be qualified. Why would these values have to be equal in magnitude to the quite different WTP for avoiding car driver fatalities? Maybe as a pedestrian one has different perceptions than as a driver, and also for some pedestrians the income constraint might be more severe. When aggregating WTP across pedestrians their total number is not very high, so we are adding fewer people, and thus we get a lower VRR as a community value. Hence the mean estimate for pedestrian fatalities of AU2009 $5.32m seems plausible.

Table 7: Summary of Major Findings ($2007)

VRR ($) per:	Fatality	SI	HI	MI
urban	5,352,140	429,458	143,153	54,735
urban all injuries		118,732		
non-urban	4,244,530	290,221	105,535	33,168
non-urban all injuries		69,653		
Urban plus non-urban	4,879,699	370,068	127,107	45,536
		81,235		

9 Conclusions

This study has presented a method to obtain empirical estimates in the Australian context of the ex ante WTP by individuals who are pedestrians to avoid being killed or injured in the road environment, to varying degrees of severity and permanence. The *WTP* is the pedestrian's marginal rate of substitution between income and the number of annual pedestrian fatalities or number of injuries in the road environment; and *VRR* is the summation of *WTP (separately for fatalities and classes of injuries on a specific route)* over all pedestrians that traverse a specific road in a given year. Summing *WTP* values over all pedestrians (annual flow) on each route, we obtain four values - the value of fatality risk reductions and the value of injury class risk reductions for each of severe permanent injury (or serious), injuries requiring hospitalisation, and minor injury.

The empirical evidence herein has been developed using the ex ante WTP method in contrast to an ex post human capital approach which is the source of the currently available evidence in Australia. Although we believe the evidence has empirical merit (given a previous unpublished study found similar evidence for fatalities and serious injuries), the relatively small sample size necessitates placing a caveat on the findings as having unambiguous implications in drawing a link with policy

Importantly, we expect the VRR for a given reduction in probability of a fatality is an increasing function of the initial risk level. If we compare the mean estimates for urban and non-urban pedestrian activity, our evidence is completely consistent with this. It is important to recognize that one should not assume similar relativities and directions when moving from an *ex post* to an *ex ante* method. The improvement in roads is linked to improving safety for each kilometre walked, and hence the metric used to obtain VRR is the appropriate one for economic analysis of the safety benefits of improvements in the road environment.

In future research, the evidence herein can be disaggregated by road type and distance travelled, subject to data availability, to provide project-specific inputs for benefit-cost analysis, in contrast to the aggregated findings presented herein. We would recommend a larger sample size than used herein, and hence we see the current study as exploratory.

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References

Access Economics, 2007. *The Health of Nations: The Value of a Statistical Life*, Report prepared for the Office of the Australian Safety and Compensation Council, Canberra, August.

Ashenfelter, O., 2006 Measuring the value of a statistical life: problems and prospects, *The Economic Journal*, 116(510), C10-C23.

Beattie, J., Covey, J., Dolan, P., Hopkins, L., Jones-Lee, M., Loomes, G., Pidgeon, N., Robinson, A. and Spencer, A., 1998. On the contingent valuation of safety and the safety of contingent valuation: Part 1 - caveat investigator. *Journal of Risk and Uncertainty*, 17(1), 5-25.

Bonsall, P., Wardman, M., Nash, C. and Hopkinson, P., 1992. Development of a survey instrument to measure subjective valuations of non-use benefits of local public transport services. In E. Ampt, A.J. Richardson and A. Meyburg (eds.),, *Selected Readings in Transport Survey Methodology*. Eucalyptus Press, Melbourne, 71-87.

Bliemer, M. C. J. and Rose, J. M., 2009. Designing stated choice experiments: state-of-the-art. In R. Kitamura, T. Yoshii and T. Yamamoto (eds.), *The Expanding Sphere of Travel Behaviour Research*, Emerald, Bingley, 499-532.

Carthy, T., Chilton, S., Covey, J., Hopkins, L., Jones-Lee, M., Loomes, G., Pidgeon, N. and Spencer, A., 1998. On the contingent valuation of safety and the safety of contingent valuation: Part 2 - The CV/SG "chained" approach. *Journal of Risk and Uncertainty* 17(3), 187-214.

De Blaeij, A. T., Rietveld, P., Verhoef, E. T. and Nijkamp, P., 2002. The valuation of a statistical life in road safety: a stated preference approach, *30th European Transport Forum*. London, UK.

De Blaeij, A. T., Florax, R. J., Rietveld, P. and Verhoef, E. T., 2003. The valuation of a statistical life in road safety: a meta analysis, *Accident Analysis and Prevention* 35(6), 973-986.

Ferrini, S. and Scarpa, R., 2007. Designs with a-priori information for nonmarket valuation with choice-experiments: a Monte Carlo study, *Journal of Environmental Economics and Management*, 5393), 342-363.

Greene, W. H. and Hensher, D. A., 2010. Does scale heterogeneity matter? a comparative assessment of logit models, *Transportation*, 37(3), 413-428

Hensher, D. A. and Greene, W. H., 2003, Mixed logit models: the state of practice, *Transportation*, 30(2), 133-176.

Hensher, D. A. and Greene, W. H., *in press*. Valuation of Travel Time Savings in WTP and Preference Space in the Presence of Taste and Scale Heterogeneity, *Journal of Transport Economics and Policy*.

Hensher, D. A., Rose, J. M. and Greene, W. H., 2005. *Applied Choice Analysis: A Primer.* Cambridge University Press, Cambridge.

Hensher, D. A., Rose, J. M., Ortúzar, J. de D., and Rizzi, L. I., 2009. Risk reduction for car occupants in the road environment, *Transportation Research part A*, 43(7), 692-707

Hess, S. and Rose, J. M., 2011. Disentangling scale and preference heterogeneity in random coefficients models: an exercise in futility, *working paper*.

Hojman, P., Ortúzar, J. de D. and Rizzi, L. I., 2005. On the joint valuation of averting fatal victims and serious injuries in highway accidents, *Journal of Safety Research*, 36(4), 337-386.

Huber, J. and Zwerina, K., 1996. The importance of utility balance and efficient choice designs, *Journal of Marketing Research*, 33, 307-317.

Iragüen, P. and Ortúzar, J. de D. 2004. Willingness-to-pay for reducing fatal accident risk in urban areas: an internet-based web page stated preference survey. *Accident Analysis and Prevention*, 36(4), 513-524.

Jones-Lee, M., 1994. Safety and the savings of life. In R. Layard and S. Glaister (eds.), *Cost-Benefit Analysis.* Cambridge University Press, Cambridge.

Jones-Lee, M. and Loomes, G., 2003. Valuation of safety. In D.A. Hensher and K.J. Button (eds.), *Handbook of Transport and the Environment*, Vol. 4, Handbooks in Transport, Elsevier, Oxford, 451-462.

Jones Lee, M., O'Reilly, D. and Philips, P., 1993. The value of preventing non-fatal road injuries: findings of a willingness-to-pay national sample survey, *TRL Working Paper WPSRC2*, Transport Research Laboratory, Crowthorne.

Kanninen, B. J., 2002. Optimal design for multinomial choice experiments, *Journal of Marketing Research*, 39, 214-217.

Kessels, R., Goos, P. and Vandebroek, M., 2006. A comparison of criteria to design efficient choice experiments, *Journal of Marketing Research*, 43, 409-419.

Louviere, J. J., Hensher, D. A. and Swait, J. D., 2000. *Stated Choice Methods: Analysis and Application*, Cambridge University Press, Cambridge.

McFadden, D., 1998. Measuring willingness-to-pay for transportation improvements. In T. Gärling, T. Laitila and K. Westin (eds.), *Theoretical Foundations of Travel Choice Modelling*. Elsevier Science, Amsterdam, 339-364.

Ortúzar, J. de D. and Rizzi, L. I., 2000. Valuing accidents using stated preference methods. *Second International Conference on Traffic and Transportation Studies* (ICTTS-2000), Beijing, China, 31 July-2 August.

Ortúzar, J. de D. and Rizzi, L. I., 2001. Valuation of road fatalities: a stated preference approach. In D. Hensher (ed.), *Travel Behaviour Research: The Leading Edge*. Elsevier, Amsterdam, 855-868.

Ortúzar, J. de D. and Willumsen, L. G., 2001. *Modelling Transport*. Third Edition, John Wiley and Sons, Chichester.

Rizzi, L.I. and Ortúzar, J. de D., 2003. Stated preference in the valuation of interurban road safety. *Accident Analysis and Prevention*, 35, 9-22.

Sándor, Z. and Wedel, M., 2001. Designing conjoint choice experiments using managers' prior beliefs, *Journal of Marketing Research*, 38, 430-444.

Sándor, Z. and Wedel, M., 2002. Profile construction in experimental choice designs for mixed logit models, *Marketing Science*, 21(4), 455–475.

Sándor, Z. and Wedel, M., 2005. Heterogeneous conjoint choice designs. *Journal of Marketing Research*, 42, 210-218.

Sillano, M. and Ortúzar, J. de D., 2005. Willingness-to-pay estimation with mixed logit models: some new evidence, *Environment and Planning A*, 37(3), 525-550.

Toner, J.P., Clark, S.D., Grant-Muller, S.M. and Fowkes, A. S., 1999. Anything you can do, we can do better: a provocative introduction to a new approach to stated preference design, *WCTR Proceedings*, 3, Antwerp, 107-120.

Train, K., 2009. *Discrete Choice Methods with Simulation.* 2nd edition, Cambridge University Press, Cambridge.

Vermeulen, B., Goos, P. and Vandeboek, M., 2008. Models and optimal designs for conjoint choice experiments including a no-choice option, *International Journal of Research in Marketing*, 25(2), 94-103.

Viscusi, W. K., Magat, W. A. and Hube, J., 1991. Pricing environmental health risks: surveys assessments of risk-risk and risk-dollar trade offs for chronic bronchitis, *Journal of Environmental Economics and Management*, 21(1), 32-51.

Watson, S. M., Toner, J. P., Fowkes, A. S. and Wardman, M. R. 2000. Efficiency properties of orthogonal stated preference designs, in Ortúzar, J de D. (ed.), *Stated Preference Modelling Techniques*, PTRC Education and Research Services Ltd, 91-101.

Yu, J., Goos, P. and Vandeboek, M., 2009. Efficient conjoint choice designs in the presence of respondent heterogeneity, *Marketing Science*, 28(1), 122-135.