

MODELO SIMPLE DE VALORACIÓN DE EXTERNALIDADES DE ACCIDENTES DE TRÁNSITO*

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Resumen

En este trabajo se plantea un modelo de accidentes viales que permite calcular los costos externos de los accidentes de tránsito. Tres tipos de externalidades son consideradas. La primera de ellas consiste en el incremento en el nivel de riesgo de accidente para todos los conductores debido a la adición de una unidad de tráfico extra. La segunda se origina en el efecto que una nueva unidad de cierta categoría de tráfico tiene sobre el riesgo de accidente de usuarios de otras categorías. El tercer tipo de externalidad dice relación con el impacto que un accidente tiene sobre el resto de la sociedad. Cada una de estas externalidades es analizada en el contexto del tránsito urbano e interurbano.

El modelo es aplicado para calcular la modificación que el Seguro Obligatorio de Accidentes Personales (SOAP) requeriría si el mismo debiese internalizar los costos en vidas humanas y lesiones graves de los accidentes de tránsito en Chile tomando como valor de referencia la disposición al pago de los individuos por prevención de accidentes de tránsito.

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1. INTRODUCCIÓN

El objetivo de este documento es plantear un modelo económico básico de accidentes viales que permita determinar el costo monetario esperado (o costo ex ante) en términos de víctimas fatales y lesionados graves de los accidentes de tránsito en Chile, a fin de propender a su correcta internalización. Los accidentes de tránsito incluyen tres tipos de externalidades. La primera de ellas consiste en el incremento en el nivel de riesgo de accidente para todos los conductores debido a la adición de una unidad de tráfico extra. La segunda se origina en el efecto que una nueva unidad de cierta categoría de tráfico tiene sobre el riesgo de accidente de usuarios de otras categorías. Estas dos primeras externalidades son internas al sistema de transporte y dan origen a lo que llamaremos costos internos de los accidentes. El tercer tipo de externalidad dice relación con el impacto que un accidente de tránsito tiene sobre el resto de la sociedad y recibe el nombre de externalidad del sistema de transporte y da lugar a los costos externos del sistema de transporte.

Para lograr nuestro objetivo, plantearemos un modelo similar al utilizado por Jansson, 1994; Elvik, 1994; Persson y Ödegaard, 1995; Fridstrøm, 1999 y Lindberg, 2001. Desde el punto de vista teórico haremos una extensión al considerar la distribución de la gravedad de los accidentes en función del volumen de tráfico. Así, se puede valorar de manera explícita el efecto que la congestión puede tener sobre los costos de los accidentes.

Este documento se estructura de la siguiente manera. En la segunda sección, se considera una corriente homogénea de tránsito a fin de estudiar las externalidades ocasionadas por una unidad extra de flujo tanto sobre el resto de los conductores como sobre el resto de la sociedad. En la tercera sección se considera una corriente mixta de tráfico a fin de considerar el efecto que una unidad más de flujo de una corriente de tráfico tiene sobre la otra. En la cuarta sección se estiman los costos externos de los accidentes en Chile, dejándose las conclusiones para la última sección.

2. MODELO CON FLUJO HOMOGÉNEO DE VEHÍCULOS

Se supone una red vial en la que cada vehículo tiene un riesgo r de sufrir un accidente por unidad de distancia. Este riesgo es una función del total de kilómetros – vehículos¹, Q . Así, $r = r(Q)$, con derivada primera no positiva y derivada segunda no negativa. Dado un accidente existe una probabilidad de que el mismo derive en víctimas fatales o víctimas de gravedad. Esta probabilidad está en función del flujo vehicular y de la presencia de un vector de variables cualitativas del sistema (vinculadas al diseño vial y diseño del automóvil), q . Para altos valores de Q el riesgo de una fatalidad disminuye ante aumentos en el valor de Q , debido a la menor intensidad de los choques. Así, la derivada de F con respecto a Q habrá de ser no positiva y $F = F(Q, q)$. El resto de los accidentes son de víctimas graves, $H (= 1 - F)$. A lo largo de este trabajo se asume que el vector q está dado. Para un tratamiento pormenorizado en relación al efecto de la variables cualitativas del sistema, ver Rizzi (2002).

¹ En esta sección, los términos vehículo – kilómetro, flujo vehicular o simplemente flujo se utilizarán indistintamente.

El costo total de un accidente incluye los costos internos al sistema de transporte y los costos externos. Los primeros representan la disposición al pago (DP) en el margen por reducción de riesgos de muerte y riesgos de accidentes graves, a_m y a_g respectivamente. Estos costos incluyen también los costos materiales asumidos por cada víctima. Los costos externos² comprenden daños a la propiedad de terceros, atención médica y hospitalaria, costos de policía, gastos administrativos³ y el valor actual del costo en término de ingresos netos no percibidos por el Estado por incapacidad laboral de las víctimas y los denominaremos c_m y c_g para los casos de accidentes fatales y accidentes con víctimas graves respectivamente.

El modelo planteado es una adaptación de Jansson (1994), donde el costo total se expresa así:

$$CT = \{(a_m + c_m)F + (a_g + c_g)H\}rQ \quad (1)$$

El número total de accidentes, A , es igual a rQ/n , donde n representa el número promedio de automóviles por accidente. Calculemos el costo marginal de accidentes asociado a un kilómetro-vehículo extra:

$$\frac{\partial CT}{\partial Q} = \{(a_m + c_m)F + (a_g + c_g)(1-F)\}r(E_r^Q + 1) + \{(a_m + c_m) - (a_g + c_g)\}rFE_f^Q \quad (2)$$

donde E_r^Q es la elasticidad flujo del riesgo de accidente y E_f^Q es la elasticidad flujo del riesgo fatal. Si al costo marginal se le resta el costo medio percibido por el conductor por kilómetro transitado se obtiene la cuantía de los efectos externos no percibidos por el conductor, diferencia que constituye un cargo a cobrar a los conductores. A continuación mostramos este diferencial, desglosado según se trate de un costo interno o externo.

$$\begin{aligned} \frac{\partial CT}{\partial Q} - CM = & \{a_m F + a_g (1-F)\}rE_r^Q + \{c_m F + c_g (1-F)\}r(E_r^Q + 1) + \\ & + \{a_m - a_g\}rFE_f^Q + \{c_m - c_g\}rFE_f^Q \end{aligned} \quad (3)$$

A priori no puede establecerse el signo de este monto; claramente dependerá del valor de las dos elasticidades mencionadas. En relación a E_r^Q , su valor dice relación entre un mayor nivel de flujo y el riesgo de accidentes. En tráfico interurbano este valor suele ser considerado igual a cero; en tráfico urbano, se lo calcula superior a cero (ver SNRA, 1989). En cuanto a E_f^Q es de esperar que a medida que se incrementa el flujo, sea necesario conducir a una menor velocidad y, en consecuencia, la gravedad de los accidentes disminuirá, con la consiguiente reducción de

² Cada vez que se diga costo interno o costo externo equivaldrá a decir costo interno del sistema de transporte o costo externo del sistema de transporte.

³ Básicamente se trata de los costos administrativos de las compañías de seguro. El resto de los costos de los seguros son internos, aunque puede objetarse que dichos costos no influyen sobre el comportamiento en el margen, ya que las primas no guardan relación con el uso del vehículo.

víctimas fatales; esto sería especialmente cierto cuando la densidad de tráfico es alta. Así, dicha elasticidad sería negativa, especialmente en áreas urbanas⁴.

Si ambas elasticidades fuesen igual a cero, caso probable en tráfico vial interurbano, quedaría sólo el término $\{c_m F + c_g (1 - F)\}r$ y correspondería cobrar una tarifa que cubra los costos esperados ‘externos’ de los accidentes. Para el caso de tráfico urbano, los dos primeros sumandos en la ecuación (3) serían positivos mientras que los últimos dos negativos. En otras palabras, un incremento del flujo vehicular produce un incremento en el nivel de riesgo, pero la peligrosidad de los accidentes disminuye.

Por último, a medida que el flujo se satura, es de esperar que los costos de los accidentes en términos de vidas humanas o de víctimas graves sea cada vez menor debido a las cada vez menores velocidades de circulación. En este caso se tendrían solamente accidentes menores cuyos costos representarían en su mayoría daños a los vehículos como consecuencia de choques menores. En este sentido, la situación difiere respecto a lo que sucede con el costo marginal en los tiempos de viaje, que a flujo de saturación tiende a infinito. Según Fridstrøm (1999), la congestión podría ser un factor que contribuya a las bajas tasas de accidentalidad actuales en el nor-oeste europeo.

3. MODELO CON FLUJO MIXTO DE TRÁFICO

En esta sección analizamos un caso más complejo, la presencia de flujo mixto. Como ejemplo se utiliza el caso de vehículos y bicicletas, aunque es fácil su extensión a otros casos⁵. Se supone que X es el número de accidentes entre vehículos y bicicletas⁶, M el número total de kilómetro – bicicletas. Se supone que en cada accidente participan un ciclista y un automovilista y que por cada accidente entre automóvil y bicicletas habrá sólo una víctima. La víctima (fatal o grave) será un ciclista con una probabilidad θ y será un automovilista (fatal o grave) con una probabilidad $1 - \theta$ ⁷.

Una vez más se supone que los accidentes pueden acarrear víctimas fatales o víctimas graves; la distribución de las víctimas entre fatales y no fatales están influenciadas por el vector de variables cualitativas q , supuesto fijo. La función de riesgo de accidente para usuarios de bicicletas es $r_b = r_b(Q, M)$, la función de riesgo de accidente para usuarios de vehículos es $r_v = r_v(Q, M)$, $r_b = X / M$, $r_v = X / Q$ y las funciones de riesgo de accidentes fatales para usuarios de bicicletas y vehículos respectivamente son $F_b = F_b(Q, M, q)$ y $F_v = F_v(Q, M, q)$, donde el vector q se supone fijo una vez más.

⁴ Dicho de otra manera, un aumento en el flujo vehicular produce una disminución de la velocidad que hace disminuir la probabilidad de accidentes fatales.

⁵ Si se consideran las categorías de tráfico z , w , cada vez que dice automóvil se refiere a la categoría z , y cada vez que dice bicicleta, a la categoría w .

⁶ En esta sección cada vez que se mencione la palabra accidente se refiere a accidentes entre automóviles y bicicletas.

⁷ Ver Lindberg (2001) para una referencia sobre posibles valores de θ para distintas categorías de tráfico mixto. En el caso de colisiones entre automóvil y usuarios desprotegidos (categoría que incluye a los ciclistas en Lindberg, 2001, Tabla 4) dicho valor es 0,99.

El costo total de los accidentes está dado por la siguiente expresión:

$$CT = \{(a_m + c_m) F_b + (a_g + c_g) H_b\} r_b M \theta + \{(a_m + c_m) F_v + (a_g + c_g) H_v\} r_v Q (1 - \theta)$$

$$CT = CT^M \theta + CT^Q (1 - \theta) \quad (4)$$

Derivando con respecto a Q y M se obtienen los costos marginales de agregar a la red un kilómetro – automóvil y un kilómetro – bicicleta extra.

$$\frac{\partial CT}{\partial Q} = \frac{CT^M}{Q} E_{r_b}^Q \theta + \{(a_m + c_m) F_v + (a_g + c_g) (H_v)\} r_v (1 + E_{r_v}^Q) (1 - \theta) + \{(a_m + c_m) - (a_g + c_g)\} \left(E_{F_b}^Q r_b F_b \frac{M}{Q} \theta + E_{F_v}^Q r_v F_v (1 - \theta) \right) \quad (5)$$

$$\frac{\partial CT}{\partial M} = \{(a_m + c_m) F_b + (a_g + c_g) (H_b)\} r_b (1 + E_{r_b}^M) \theta + \frac{CT^Q}{M} E_{r_v}^M (1 - \theta) + \{(a_m + c_m) - (a_g + c_g)\} \left(E_{F_b}^M r_b F_b \theta + E_{F_v}^M r_v F_v \frac{Q}{M} (1 - \theta) \right)$$

El costo marginal de adicionar un vehículo - kilómetro a la red está relacionado con tres elementos: a) la elasticidad flujo vehicular del riesgo de accidente para el usuario de bicicleta, b) la elasticidad flujo vehicular del riesgo de accidente para el usuario de automóvil y c) las elasticidades flujo vehicular del riesgo de accidente fatal para el usuario de bicicleta y el usuario de vehículo. El primer elemento dice relación sobre el efecto de adicionar un vehículo - kilómetro a la red sobre el riesgo de accidente entre un automóvil y una bicicleta para los usuarios de bicicleta; el segundo elemento, sobre el efecto de agregar un vehículo - kilómetro sobre el riesgo de accidente entre usuarios de automóvil y de bicicletas para los usuarios de vehículos y el último, sobre el efecto que un vehículo - kilómetro adicional tiene sobre la proporción de accidentes fatales. Con las adecuadas modificaciones, la misma interpretación vale para el cálculo del costo marginal de un kilómetro – bicicleta.

De aquí en adelante se adoptará un valor de θ igual a uno (1), que en nuestro caso particular es acertado según el resultado de la nota a pie de página 7. Además, supondremos independencia de la proporción de accidentes fatales y no fatales respecto a los flujos, tal que $F_b = F_b(q)$ y $F_v = F_v(q)$. Este supuesto implica que el caso de tráfico urbano e interurbano son tratados de manera idéntica. La ecuación (5) se transforma en la ecuación (6):

$$\frac{\partial CT}{\partial Q} = \frac{CT^M}{Q} E_{r_b}^Q \quad (6)$$

$$\frac{\partial CT}{\partial M} = \{(a_m + c_m) F_b + (a_g + c_g) (H_b)\} r_b (1 + E_{r_b}^M)$$

Los conductores de automóvil deberían pagar una tarifa equivalente al diferencial entre el costo marginal y el costo medio percibido. Este último resulta ser cero, ya que ellos no sufren las consecuencias económicas de los accidentes, por lo que la tarifa a cobrarles es igual a $\frac{\partial CT}{\partial Q}$.

Por el contrario, los ciclistas perciben un costo igual a $a_m F_b + a_g H_b$, de manera tal que deberían pagar una tarifa equivalente a

$$\begin{aligned} \frac{\partial CT}{\partial M} - CM &= \left\{ (a_m + c_m) F_b + (a_g + c_g) H_b \right\} r_b E_{r_b}^M + \left\{ c_m F_b + c_g H_b \right\} r_b \\ &= CT^M \frac{E_{r_b}^M}{M} + \left\{ c_m F_b + c_g H_b \right\} r_b \end{aligned} \quad (7)$$

La recaudación total sería entonces igual a la suma de los dos componentes mencionados:

$$RT = CT^M (E_{r_b}^Q + E_{r_b}^M) + \left\{ c_m F_b + c_g H_b \right\} r_b M \quad (8)$$

Esta cifra recaudada tendrá como valor inferior el costo esperado externo de los accidentes, si $(E_{r_b}^Q + E_{r_b}^M)$ es igual a cero. Si la función de accidentes entre vehículos y bicicletas fuese del tipo Cobb-Douglas en el volumen de vehículos kilómetros y vehículos bicicleta y homogénea de grado uno, un caso probable sería aquel en que $E_{r_b}^Q$ y $E_{r_b}^M$ toman valores de 0,5 y -0,5 respectivamente (Jansson, 1994). En este caso, los automovilistas pagan la mitad del costo esperado total de los accidentes y los ciclistas reciben una cantidad igual a diferencia entre la mitad del costo total esperado de los accidentes según sus valoraciones y los costos externos esperados de los accidentes. La diferencia entre el pago de los conductores y el valor que reciben los ciclistas es el valor esperado de los costos externos⁸.

4. TARIFAS PARA LA INTERNALIZACIÓN DE COSTOS DE ACCIDENTES DE TRÁNSITO

En esta sección se muestran algunos cálculos de carácter indicativo para establecer el incremento que debería experimentar el costo del seguro obligatorio de accidentes personales (SOAP) a fin de corregir las distorsiones generadas por las externalidades de accidentes en lo referente a costo en muertes y accidentes graves valorados según la metodología de la disposición al pago (DP). Para los cálculos correspondientes utilizaremos los siguientes valores. El costo de la víctima fatal basado en el método de la disposición al pago se sigue de márgenes un poco más amplios que los obtenidos en Rizzi (2001). Se usa una cota inferior de 200.000US\$⁹ y una cota superior de 1.000.000US\$. Siguiendo a Rizzi (2001) se supone que el costo de una víctima grave representa el ocho por ciento de una víctima fatal¹⁰. En cuanto al costo interno anual total en accidentes viales para el país, utilizando nuestros valores de costos de víctimas, el mismo asciende a 585

⁸ Dado que el valor de la DP es superior a los costos externos en accidentes fatales y graves, es de esperar que los ciclistas sean efectivamente subsidiados. En caso contrario, ellos tendrían que afrontar un cargo positivo.

⁹ Se utilizará la siguiente tasa de conversión 1US\$ = 690\$Ch.

¹⁰ Este valor es transferido de estimaciones correspondientes al Reino Unido.

U\$S millones y 2.924 U\$S millones según se considere un valor por cada muerte según la cota inferior o superior (entre el 0,9% y el 4,5% del PBI). Estos valores no incluyen los costos externos (ni otros costos monetarios a cargo de las víctimas que no sean los relacionados con la DP por disminución de riesgos de accidentes).

El SOAP es de carácter obligatorio en Chile (Ley 18.490) y tiene como finalidad indemnizar a las personas que resulten lesionadas en un accidente en que participen vehículos asegurados o a los beneficiarios de aquellos que perezcan a raíz de un accidente de ese tipo. El pago de las correspondientes indemnizaciones se hace sin investigación previa de culpabilidad, bastando la sola demostración del accidente y de las consecuencias de muerte o lesiones que éste originó a la víctima. El cobro de la indemnización correspondiente no impide el curso de futuras acciones legales que permitan un mayor resarcimiento para las víctimas de los accidentes. El artículo 25 de la Ley 18.490 fija los montos sobre los cuales deben basarse los cálculos para las primas de los seguros. A modo de ejemplo, los beneficiarios de una víctima fatal deben ser resarcidos por una suma aproximada de 3.560U\$S (150UF). En relación al monto del SOAP, la prima promedio por vehículo asciende a 11,5U\$S para un total algo superior a 2.000.000 de vehículos¹¹. De esta manera se recaudan aproximadamente 23M U\$S millones; cifras muy inferiores a los costos en vidas humanas y lesiones graves basados en la disposición al pago.

Los datos sobre accidentes que se utilizan han sido redondeados para facilitar los cálculos y se basan en datos reales de CONASET¹² sobre números de accidentes, número de fatalidades, número de heridos graves (agrupándose víctimas graves y muy graves), y proporción de peatones víctimas. Del total de 1700 muertes consideradas, un 40 por ciento corresponde a peatones y ciclistas. En base a lo dicho en la sección 3 (ver ecuación (8) y párrafo siguiente), los conductores deben pagar la mitad de los costos totales esperados de los accidentes de estas personas. Consideremos sólo los costos internos: suponiendo un costo por muerte igual a 200.000U\$S por este concepto la prima promedio debería ascender a 34U\$S. A esto hay que adicionar otros 25U\$S para el caso de las lesiones graves suponiendo que el 40% son de peatones y ciclistas.

El resto de las muertes son de personas viajando en vehículo de las que suponemos un 50% en áreas urbanas y otro 50% en áreas no urbanas. En cuanto a los últimos según nuestros supuestos de la sección 2, no hay costo interno alguno (ver ecuación (3) y párrafos siguientes); en cuanto a las muertes urbanas se hace el siguiente cálculo. Asumiendo unas 510 muertes y una elasticidad flujo riesgo de muerte 0,20 deben adicionarse 10U\$S de prima. Faltan aún los costos internos por víctimas graves. Bajo idénticos supuestos (4590 heridos graves en zonas urbanas), la prima ha de aumentar otros 7U\$S. En total debería cobrarse una prima promedio por vehículo de 76U\$S¹³, totalizando una recaudación de 152MU\$S. Esto supondría incrementar el valor de la prima de los SOAP en 6,6 veces, sin considerar los costos externos. Esto se traduce en un costo por vehículo

¹¹ <http://www.aach.cl/BOLETIN%20SOAP.pdf>, boletín estadístico SOAP 1991 – 2001. De aquí en más utilizaremos como referente un parque de 2.000.000 de vehículos.

¹² <http://www.conaset.cl/>, sección Estadísticas.

¹³ No se ha considerado el efecto que la congestión puede tener sobre la disminución de las consecuencias negativas de los accidentes debido a la falta de un estimador confiable, una limitación más de este trabajo. A fin de brindar una idea, si la elasticidad flujo del riesgo de muerte fuese igual a $-0,1$, la prima debería descender casi 5U\$S para arrojar un valor de 71U\$S.

kilómetro de 2,1\$Ch. Todos estos valores deben multiplicarse por cinco para obtener su cota superior (prima promedio de 380US\$) y han de ser considerados como indicativos¹⁴.

Este supuesto de internalización de costos no supone que las compensaciones a las víctimas deban ser realizadas por el equivalente al costo del accidente en términos de la DP (excepto en el caso de peatones y ciclistas, ver ecuación (7)). La teoría económica sostiene que quienes originan una externalidad deben pagar su costo marginal, pero no que las víctimas deban recibir compensación. Desafortunadamente, la teoría no es clara en cuanto al destino de los montos recaudados. Suele mencionarse la posibilidad de transferencias de sumas fijas que no afecten conductas en el margen. Adicionalmente, si se cobrase el cargo marginal por externalidad, no debería continuarse con ninguna instancia judicial contra ninguna de las partes involucradas excepto que hubiese negligencia de alguna de ellas.

Como precaución, debe tenerse en cuenta que se ha estimado un cargo anual promedio para un vehículo promedio (que no existe). El cálculo del SOAP debería considerar la historia del conductor, el modelo del vehículo y el uso que se hace del mismo (es decir, kilómetros circulados, tipo de vía en la que se conduce y la hora de conducción). En otras palabras, este valor tiene que estar computado de manera tal que su impacto en el margen afecte el comportamiento de los conductores en la dirección deseada.

A estos cálculos faltan agregar los costos externos y otros costos internos no incluidos en la DP. En este sentido vale aclarar que en Chile se recaudan anualmente unos 193M US\$ en concepto de primas de seguros por daños materiales y responsabilidad civil de vehículos motorizados. Estos seguros no son de carácter obligatorio; aproximadamente el 25% del parque vehicular dispone de un seguro por daños materiales.

Para concluir esta sección, procedamos con los mismos cálculos, pero considerando los valores monetarios asignados por el Ministerio de Obras Públicas a una muerte de tránsito y a un herido grave de tránsito actualmente. Dichos valores son 1250UF por muerte y de 398UF por lesionado (ver CITRA, 1996)¹⁵ y así el costo del SOAP debería aumentar a 25US\$, es decir, el doble del valor actual.

5. CONCLUSIONES

En este artículo se presentó un modelo simple de accidentes para el análisis de los costos externos de los accidentes. Se analizaron dos casos: tráfico homogéneo y tráfico mixto. En ambos se detectó la presencia de externalidades y la necesidad de establecer algún tipo de cargo para su internalización. Se vio en particular que el elemento más importante para calcular la magnitud de los costos externos es la elasticidad flujo del riesgo de accidentes. Dado este valor, determinar los costos es sencillo.

¹⁴ En el ejemplo desarrollado, todo costo externo de los accidentes fue internalizado mediante el SOAP. También podría pensarse en una tarifa vial como alternativa.

¹⁵ El valor de 398UF es el valor promedio correspondiente a las lesiones graves y lesiones menos graves según CITRA (1996). El total aproximado de 15.300 víctimas no fatales graves se divide en partes iguales entre lesiones graves y lesiones no graves.

Cuando se considera el tráfico homogéneo interurbano, la única externalidad de los accidentes es el costo externo de los mismos suponiendo que la elasticidad flujo del riesgo de accidentes es cero. En tráfico homogéneo urbano, esta elasticidad parece ser superior a cero; en otras palabras, al agregarse una unidad de flujo, se incrementa el riesgo de accidentes para todos los demás conductores, por lo que se tienen una externalidad. Cuando se consideran corrientes de tráfico mixto, suele ser una la categoría que sufre todo el peso de los accidentes que involucran un participante de cada corriente de tráfico. Esto se puede explicar físicamente: existe una relación de peso y potencia tan dispar entre ambas categorías que la más débil sale siempre perjudicada y la más fuerte indemne. De esta manera, la categoría más fuerte produce una externalidad, que requiere de una tarifa para ser corregida. Por otro lado, el usuario de la categoría más débil debe ser subsidiado (o compensado): una unidad más de flujo de la categoría débil contribuye a disminuir los costos totales de los accidentes entre distintas corrientes de flujo.

El modelo planteado arrojó un beneficio asociado a la presencia de congestión en corrientes homogéneas de tráfico: si a altos niveles de densidad vehicular disminuye la intensidad de los accidentes, la externalidad podría volverse positiva: una mayor unidad de flujo contribuye a una mayor seguridad para todos los vehículos. En el caso que existiese tarificación vial, en secciones de tráfico muy denso, la misma tendría dos componentes, una positivo vinculado a los costos en tiempo y otra negativa debido a los accidentes. Dependiendo de la magnitud de cada una, resultaría un cargo a pagar o un subsidio a cobrar por los conductores. Desafortunadamente, este efecto no pudo ser considerado en los cálculos realizados en la sección 4 por no tenerse un estimador del mismo.

Se hizo un ejercicio de internalización de los costos de accidentes en Chile mediante la adecuación del valor del seguro obligatorio de accidentes personales (SOAP), requerido por la ley Chilena. Si la Ley 18490 fuese modificada de manera tal que el SOAP tuviese que corregir las externalidades de accidentes, considerando un costo por cada muerte ocurrida basado en una DP de 200.000 US\$, la prima promedio del sistema pasaría de los actuales 11,5 US\$ a 76 US\$. Actualmente hay una propuesta para modificar la Ley 18.490 a fin de incrementar la cobertura del seguro en caso de accidentes: se duplicaría la cobertura de beneficios de 90 a 180 UF, en gastos de hospitalización, y de 150 a 300 UF en caso de muerte o invalidez permanente y total. Si esto lograrse hacer que se incremente el valor de la prima de los seguros, se daría un paso en la dirección correcta. Sin embargo, tal como se vio en la sección anterior, debe tenerse en cuenta que lo importante es el cobro de cargos óptimos más que la compensación de las víctimas.

Finalmente, algunas palabras sobre en qué direcciones debería seguir avanzándose para una mejor comprensión del fenómeno estudiado. Desde el punto de vista empírico, deberían estimarse con datos locales las elasticidades flujo del riesgo de accidentes, la elasticidad flujo del riesgo de accidente fatal y el valor de la disposición al pago por reducción de accidentes graves (todos valores que han debido ser transferidos). Es de esperar que estos valores puedan diferir sensiblemente de los valores calculados en Europa. Desde el punto de vista teórico, debería avanzarse en el desarrollo de modelos que permitan estudiar los fenómenos de congestión y accidentes de manera conjunta, así como el desarrollo de un enfoque de comportamiento que permita estudiar con mayor detalle el rol que la percepción de riesgo tiene sobre la elección de modos de transporte.

Si hubiese voluntad política de diseñar el SOAP tal que se internalicen los costos (al menos los costos en términos de disposición al pago) de los accidentes, habría que pensar la manera adecuada de hacerlo. Si las víctimas no fueran a ser compensadas según el valor de la DP, no sería justo que ese excedente quedase en poder de las compañías de seguros. El exceso entre el recaudado por el SOAP y la compensación pagada (deducidos los costos administrativos y el margen de ganancia) debería ser apropiado por el Estado o reinvertido en seguridad.

REFERENCIAS

- CITRA (1996) *Investigación Diseño de Programa de Seguridad Vial Nacional*, para el Ministerio de Transportes y Telecomunicaciones y Ministerio de Obras Públicas.
- Elvik, R. (1994) The external costs of traffic injury: definition, estimation, and possibilities for internalization. *Accident Analysis and Prevention*, 26, 719-732.
- Fridstrøm, L. (1999) *Econometric Models of Road Use, Accident, and Road Investment Decisions*. Tesis de Doctorado, Institute of Transport Economics, TØI report 457/1999, University of Oslo, Oslo.
- Jansson, J.O. (1994) Accident externality charges. *Journal of Transport Economics and Policy*, 28, 31-43
- Lindberg, G. (2001) Traffic insurance and accident externality charges. *Journal of Transport Economics and Policy*, 35, 399-416.
- Persson, U. y Ödegaard, K. (1995) External cost estimates of road traffic accidents. *Journal of Transport Economics and Policy*, 29, 291-304.
- Rizzi, L.I. (2001) *Economía de los Accidentes Fatales: una Aplicación al Caso de la Seguridad Vial Urbana*. Tesis de Doctorado, Departamento de Ingeniería de Transporte, Pontificia Universidad Católica de Chile.
- Rizzi, L.I. (2002) Accidentes de tránsito y externalidades de diseño. Documento presentado para su revisión al Primer Congreso Chileno de Seguridad de Tránsito.

Road Safety Valuation under a Stated Choice Framework*

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ABSTRACT

The value of fatal risk reductions is a vital input for road safety cost-benefit analysis and has been traditionally estimated by means of contingent valuation. However, many scholars believe that risk-money trade-offs are not well understood due to the difficulty in internalizing tiny risks. In recent studies we have succeeded in applying the Stated Choice (SC) approach to tackle this problem. An SC survey requires respondents to choose among different hypothetical alternatives, characterized by a set of relevant attributes. To assess the robustness of SC, we conducted an external validity test based on the results of three different studies. We investigated if preferences in terms of number of accidents were well defined according to economic theory postulates. We also addressed an issue usually ignored in transport theory and practice: should there be a unique value of fatal risk reductions for road safety?

We found that people can internalize fatal accidents in a consistent way from both the economic and the psychological points of view so that it can be considered a good proxy for the level of risk. On the second question, although each sample yields different values of risk reductions, we were able to establish a relationship between the level of risk and the value of risk reductions.

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1. INTRODUCTION

The value of road safety has been estimated traditionally by means of contingent valuation, standard gamble or the chain method (Viscusi *et al*, 1991; Jones Lee *et al*, 1993; Beattie *et al*, 1998; Carthy *et al*, 1998). In almost all these cases, people are confronted with situations expressing risks as tiny probabilities and involving a trade-off between risk and money, to come up with a monetary value¹. This kind of context simulation may not bear upon actual choices where individuals have to consider a bundle of attributes of a particular good in a given choice context.

A different approach was used recently by Rizzi and Ortúzar (2003) and Iragüen and Ortúzar (2003), and followed by de Blaeij *et al* (2002); it is based on Stated Choice (SC) or conjoint analysis techniques. A SC survey asks individuals to choose among different alternatives, the attribute levels of which vary according to a statistical design aimed at maximizing the precision of the estimates. SC allows the analyst to characterize the choice situation context as much as he pleases so that it can mimic actual choices with a high degree of realism.

Rizzi and Ortúzar (2003) defined a particular kind of trip on a particular road for two reasons. First, the choice context must be replicated accurately to derive meaningful results (Ampt *et al*; 2000, Louviere *et al*, 2000). Second, from a theoretical point of view different risks may be valued differently because of different risk perceptions. Dread, knowledge of risks and personal benefits from exposure, all factors contribute to risk perception and eventually to different Willingness to Pay (WTP) for reducing it (Slovic *et al*, 1985). Hence, it is crucial to define a specific risk context. For example, private motoring is a risk well understood by most people in Santiago de Chile: it is under their control and yields great personal benefit (Bronfman and Cifuentes, 2003).

As another feature, instead of providing a probability of fatal risk for each alternative, we decided to use the number of fatal accidents as a risk proxy. Jones Lee *et al* (1993), Krupnik *et al* (1997) and O'Brien *et al* (1998) provide evidence of people having difficulties in dealing with

¹ Some of these studies posed a risk – risk trade-off. However, in order to arrive to a monetary value, a risk – money trade off is necessary sooner or later.

probabilities. In a contingent valuation survey conducted by the latter, many people were unable to tell that an event with a probability of one in a hundred ($1 / 100$) was more likely to occur than an event with a probability of 1 in two hundred ($1 / 200$). Based on this evidence, we decided that the level of risk should be expressed in another fashion.

Although SC applied to risk analysis seems promising, its reliability remains to be tested. According to theory, we expect that the more risky a road context is and/or the higher the risk reduction offered, the higher should be the WTP. In this analysis, external validity tests are essential. By external validity we mean confronting the results of different SC surveys applied to different road contexts to assess the sensitivity of WTP to the initial risk level.

In addition, we would like to treat variability explicitly in determining the Value of Risk Reduction (VRR)² and go one step beyond to say that cost-benefit analysis of road safety projects should incorporate it. The few countries that do assign a VRR to safety improvements in road project appraisal use only one figure, irrespective of the level of safety of the road (Trawen et al, 2002). We would like to challenge this stance and show, at least methodologically, that a simple alternative works well with our data sets.

The objective of this paper is twofold. First, we address some subtle issues concerning the way the VRR is defined for different road contexts and how this can be incorporated in an evaluation framework. Second, we investigate to what extent SC constitutes a reliable method for eliciting road safety preferences, which are not derived from people's valuation of risk reductions but from people's valuation of accident reductions. To this end, we analyze three experimental studies concerning the valuation of risk reductions in different road contexts: two interurban ones and an urban one.

The rest of the paper is organized as follows. Section 2 analyzes how the VRR is derived in the context of road safety and what sort of particular demand structure is implied by a unique VRR. Section 3 comments briefly on the three surveys and Section 4 presents the econometric analysis. Finally, Section 5 closes the paper with a discussion.

² Also termed the value of a statistical life, but we would rather avoid this term.

2. THE VALUE OF FATAL RISK REDUCTIONS (VRR)

Assume a route is used by M users. If a person travels more than once in a reference period, say n_m times, we can say that she gives rise to n_m pseudo-members totaling a population of $N = M n_m$ observations; from now on these will be called the individuals of a population. This population exactly amounts to the flow on a route in a given period (say a year)³. We define a route as a path connecting one origin-destination pair. A trip on a route provides a level of dissatisfaction given by the following deterministic indirect utility function V :

$$V = V(r, c, t) \quad (1)$$

where r stands for risk of a fatal accident, c for the cost of the route and t for travel time. A formal definition of the VRR is the following (Jones Lee, 1994). Provided there is no correlation between WTP and risk, the VRR is equal to the value of avoiding one expected death and is given by the population (or sample) average of the marginal rate of substitution between income and risk of death for member j (MRS_j):

$$MRS_j = \frac{\partial V_j / \partial r}{\partial V_j / \partial c |_{V=\bar{V}}} \quad (2)$$

$$VRR = \frac{1}{N} \sum_{j=1}^N MRS_j \quad (3)$$

Equation (3) gives the definition of WTP for a public good, road safety in this case. The MRS can be interpreted as an implicit value for the own life and averaging it over all individuals traveling on the route yields the VRR. The MRS clearly depends on personal risk perceptions according to the functional form of equation (1). If another route is considered, flow and risk figures are likely to be different but one would expect that a relationship between risk and the MRS should follow certain patterns. For instance, one would expect that the WTP for risk

³ Actually, a population is a stock variable whereas a flow is not. The reader should bear this in mind.

reduction should increase with the risk of death and/or with the risk reduction offered, as shown in Figure 1 by the full line curve.

[Figure 1. approximately here]

The same analysis can be carried out in terms of fatal accidents, a , instead of risks, r . However, in this case the VRR is derived differently (but yielding obviously the same value):

$$VRR = \frac{1}{e} \sum_{j=1}^N \frac{\partial V_j / \partial a}{\partial c|_{v=\bar{v}}} = \frac{1}{e} \sum_{j=1}^N SVAR_j, \quad (4)$$

This is the more traditional way to define the WTP for a public good, where e represents the number of fatal victims per fatal accident and the subjective value of fatal accident reductions (SVAR) is interpreted as a Lindahl price. Thinking in terms of a tolled route, for example, the SVAR would be the maximum toll increase for individual j , due to a safety improvement, such that she is as well-off as before the improvement. In real life, however, this value is unique and can be computed as the average or the median SVAR.

The relationship between risk and WTP is less transparent when working with the SVAR. Assume one tries to determine a unique value of the VRR for every route, as done by Jones Lee et al (1993) and de Blaeij et al (2002), and wants to translate this into a SVAR. If flows vary between routes, clearly the SVAR should be different; in other words, if the toll were to be increased in order to finance safety improvements, the increase would vary with the route flow in a unique way: simply dividing the VRR by the flow route. Clearly, this would only be true if the value of identical risk reductions is the same, independently of the initial risk level. This is a very restrictive assumption on risk preferences, as it implies a constant marginal WTP for safety (see the horizontal dashed light gray line in Figure 1). For cost benefit analysis, considering only one VRR for every road context may give rise to a non-optimal allocation of resources; for instance, less safer routes may be likely to suffer under-investment.

Equation (1) can be made operational within a binary choice context in this way:

$$V_{ij} = \left(\alpha_0 + \sum_l \alpha_l s_{lj} \right) a_{ij} + \beta c_{ij} + \lambda t_{ij} \quad (i = 1, 2) \quad (5)$$

The binary variable s_{lj} represents the socio-economic (SE) characteristic l of individual j , and i represents the choice alternatives. This is an interesting way of incorporating SE variables, with the advantage that the information can be used to estimate, for instance, the SVAR. Equation (5) states that given the characteristics of the individual there may be different coefficients for each attribute. The SE variable could enter each of the three coefficient expressions. This form of introducing SE data allows estimating models that are almost unique for each individual. The VRR is computed by applying equation (4), which requires the SVAR for each individual. If SE variables are excluded, equation (5) becomes a simple linear utility function and the SVAR is just α_0 / β for every individual. Also note that by computing λ / β , the subjective value of time (SVT) is obtained. For the rest of the paper we will use this more simply utility function.

3. THE SURVEYS

In this section we describe the surveys that provided the data for our external validity analysis. First of all we concentrate on the two interurban surveys and next move on to the urban one. We then proceed to explain how we defined the risk variable in all three surveys.

3.1 Interurban surveys

Rizzi and Ortúzar (2003) conducted a survey in order to elicit drivers' valuation of fatal accident reductions for Route 68, linking the cities of Santiago and Viña del Mar/ Valparaíso in Chile. This route is approximately 120 km long. The survey was responded by 342 interviewees during the austral summer (1999/2000). Later on, during the austral autumn of 2000 another survey of very similar characteristics was administered to drivers on a 100 km section of Route 5, a stretch of the Pan American Highway linking Santiago and Rancagua, (Galilea et al, 2000). This second survey was answered by 94 respondents. In both cases, individuals had to choose among two different routes (binary choice).

The experimental design was the same for both routes and although there were changes in the level of the attributes, their differences were exactly the same as shown in Table 1. Three variables were considered: toll value, number of fatal accidents, and en-route travel time. Route 5 had a higher number of accidents and lesser travel time than Route 68⁴. Toll levels were identical, the only difference being if it was a week-end or a week-day toll. For full details of the experimental design see Rizzi and Ortúzar (2003).

Table 1. Attribute differences levels

Week-end toll (Ch\$)*	Week-day toll (Ch\$)*	Fatal accidents per year	Travel time (min)
1,500	1,200	-4	-30
-1,000	-800	8	-15
500	400	-12	-45

*In 2000, 1US\$ equaled CH\$ 500

Both samples are similar in terms of three basic socio-economic variables: income, gender and age. Family income was remarkably the same (no differences at the 0.05 level); these are samples of basically high income individuals (the reader should bear in mind that car ownership in Chile is highly correlated with income). Women account for 29% and 30% of the respondents in Route 5 and Route 68 respectively, the difference not being statistically different at the 0.05 level. We only found differences in the age profile of the samples; the Route 5 sample included a greater proportion of individuals under 30 and a lesser one of individuals among 30 and 49. But all in all, from these results we believe that it is possible to consider these two samples as coming roughly from the same population.

3.2 Urban survey

Iragüen and Ortúzar (2003) conducted a third survey in order to come up with the VRR for a work related trip in an urban road context in the 2002 austral autumn. The statistical design was the same as before, but the attribute levels were adapted to the trip under consideration (the survey format can be seen at www.ing.puc.cl/~piraguen). This survey was answered by a higher

⁴ There were approximately 11 and 36 annual accidents on Route 68 and Route 5 respectively; the average travel time for Route 68 was one hour and forty minutes and for the Route 5 section considered it was just one hour.

proportion of both females and young people in comparison with the two other surveys. We will see later what kind of bias this may introduce in terms of the VRR.

3.3 The definition of the risk variable

We now turn to explain why we decided to use the number of fatal accidents as a proxy for the risk of death in our surveys. The main reason is that we do not believe that people consider risk as an objective probability (i.e. as derived by the safety engineer), but as an entity which is the result of complex mental processes where risk perceptions and risk attitudes play an important role. Most people develop an idea about the level of safety of a given route through their personal risk perception when driving and through information mostly coming from the media. When there is a road crash the information on the media is stated in terms of number of accidents, number of fatalities, number of seriously injured victims and so on. Besides, the frequency with which a certain road is involved in accidents helps to get an idea of how dangerous it is.

Of course, we do not pretend to say that people keep mental accounts of the number of accidents on each route they (may) travel. However, we strongly believe that if they care about safety, the idea “of how much safe a route is” is derived from the above facts and not from probabilities of accidents. Following the finding of Bronfman and Cifuentes (2003), that private motoring is perceived as a well understood risk, we believe that a road accident is a familiar concept and, therefore, we argue that most people may have already arrived to some sort of well defined and stable preferences about this concept (Nash, 1990). Thus we decided to use the number of fatal accidents as a risk proxy variable, and this proved satisfactory in practice.

4. MODELLING RESULTS

In this section we present our econometric analysis. First we considered jointly the Rizzi and Ortúzar (2003) and Galilea et al (2000) surveys. We tried a variety of model specifications and also considered unobserved heterogeneity. Then we proceeded with the analysis of the Iragüen and Ortúzar (2003) data set. The outcome of this analysis provides the basis for our external validity test. Ideally, the same persons should have been subject to the different SC surveys in

order to carry out this test, but this was impossible. Hence, the external validity test will just consist in analyzing how the VRR varies according to different risk levels in different samples.

4.1 Interurban road safety models

To give an idea of the approximate magnitudes of risk for both routes, the flows for Route 68 and Route 5 are of the order of 3,700,000 and 5,785,000 vehicles/year respectively; the average number of accidents between 1998-2000 was around 11,3 and 35,6 respectively. Finally, the average number of deaths per accident was 1.66 and 1.30 for routes 68 and 5.

Traditional estimation

Binary logit models for the data from these two surveys were first estimated separately assuming each individual observation was uncorrelated with the other observations coming from the same individual. This is the traditional way SC data is modelled in practice. Results are displayed in Table 2. The combined log likelihood is the sum of the log likelihood values of the models for each sample.

Table 2. Separate binary logit models⁵

Parameters	Route 68	Route 5	Parameter ratios
Toll (10^{-3})*	-0.7449	-0.62695	1.188
Travel time (10^{-1})*	-0.3908	-0.4780	0.818
Accidents*	-0.1027	-0.1054	0.974
SVT (Ch\$/min)	52	76	-
SVAR (Ch\$/acc)	138	168	-
VRR (US\$/risk)	612,146	1,491,168	-
Combined log-likelihood	-2,244.728		-

* All estimated values are significant at $p=0.05$. In 2000, 1US\$ equaled Ch\$ 500

⁵ In this and following tables the subjective values can not be reproduced exactly from the reported parameter estimates due to rounding approximations.

From this model we can see that the point estimates for both the subjective value of accident reductions (SVAR) as well as the value of risk reductions (VRR) are higher for Route 5. Following Armstrong *et al* (2000) we computed the 95 percent confidence interval for both the SVAR and the VRR. The SVAR interval for Route 68 ranges from 118 to 169 Ch\$/accident and for Route 5 from 121 to 326. Interestingly, this last interval almost completely includes the first one. Turning now to the VRR, we obtained the following intervals expressed in US\$/risk [522,726; 750,430] for Route 68 and [1,075,307; 2,897,026] for Route 5. Clearly, this time both intervals do not overlap at all.

We now want to examine if the VRR complies with the expected *a priori* pattern. The risks of death in routes 68 and 5 are respectively 5.09^{E-06} and 8.02^{E-06} , whereas the magnitudes of the risk reduction brought about by one less expected death are respectively 4.5^{E-07} and 2.25^{E-07} . Figure 2 illustrates the shape of the marginal WTP curve for risk reductions associated with these results, a pattern that seems quite plausible: the value of fatal risk reductions depends not only on the value of risk reduction offered but also on the initial risk level. The shaded areas in light and heavy gray represent the SVAR for routes 68 and 5 respectively: SVAR is the VRR times the magnitude of risk reduction. This shows diagrammatically how the two concepts interact.

[Figure 2. approximately here]

We also ran a model forcing the VRR to be identical across both routes, yielding a value of US\$ 759,837 and values of time for routes 68 and 5 of 59 and 80 Ch\$/min respectively. Under this assumption, the marginal WTP curve for risk reductions should be horizontal (the dashed light gray line in Figure 2) and equal risk reductions would be equally valued independently of the initial risk level. This last VRR would imply SVARs of 171 and 85 Ch\$/accident for routes 68 and 5 respectively. As this model implies a constant marginal WTP for safety, the SVAR is higher in Route 68 because it entails a higher risk reduction: as one expected death is avoided on each route, the risk reduction will naturally be higher, the lowest the flow of the route is. The reader should note that these last values are not supported by the models estimated in Table 2. The log-likelihood of this model amounts to 2262.76, indicating that it is statistically inferior to the model presented in Table 2 (likelihood ratio test of 36.07 against the critical value $\chi^2_{2; 0.95} = 7.81$), so it should be discarded.

We also wished to investigate if the SVAR was stable across both samples. To accomplish this we first tested the hypothesis of equal taste parameters for both surveys constraining them to be the same (the results are shown in column two of Table 3). If we perform a likelihood-ratio test, we can reject the null hypothesis of equal parameters with confidence (17.63 against a critical value $\chi^2_{3; 0.95} = 5.99$)⁶.

Then we examined the more sensible hypothesis of equal parameters but different scale values. The difference in this case is directly related to the error variances in both samples; the lower the scale parameter, the higher the variance for Gumbel distributions. For a logit model the probability of choosing option i is given by the following formula:

$$\text{Prob}(i) = \frac{e^{\mu V_i}}{\sum_l e^{\mu V_l}} \quad (6)$$

where μ is the scale parameter. As this parameter can not be identified, it is normalized (i.e. assumed equal to one). However, when two different samples are considered the ratio μ_1 / μ_2 can be estimated as only one parameter needs to be normalized (Carrasco and Ortúzar, 2002), in our case μ_2 corresponding to the Route 5 sample. If the ratio is higher than one, it implies that the variance of the first sample is lower than the variance of the second survey and vice versa.

Different variances could be attributed to various reasons. First, there could be an unobservable context whose influence is percolated through the scale parameter. Second, as the survey for Route 68 was answered by more individuals it is reasonable to expect higher precision. However, if we have a look at the parameter ratios in Table 2, we can see that whilst one ratio is greater than one the others are smaller than one; this led us to believe that the hypothesis of equal parameters and different scale should also be rejected and it was indeed (6.13 against a critical value of $\chi^2_{2; 0.95} = 5.99$). The value of the scale factor in Table 3 does not lend support to our *a priori* ideas; apparently there is more variance in the Route 68 survey.

⁶ Even at the $p=0,005$ level it would be rejected.

Table 3. Binary logit models testing for equality of parameters

Parameters	Route 68 / Route 5	Route 68 / Route 5
	Equal parameters and scale	Equal parameters, different scale
Toll (10^{-3})*	-0.6961	-0.8802
Travel time (10^{-1})*	-0.4024	-0.5141
Accidents*	-0.1018	-0.1285
SVT (Ch\$/min)	58	58
SVAR (Ch\$/acc)	146	146
VRR (US\$/risk)	649,320 / 1,297,867	648,193 / 1,295,614
Scale factor (μ_1 / μ_2)	-	0.7351**
Log-likelihood	-2,253.542	-2,247.794

* All estimated values are significant at $p=0.05$. **Statistically different from one (1) at $p=0.05$. In 2000, 1US\$ equaled CH\$500

Having completely discarded parameter equality, we decided to examine the potential equality of only one of the parameters, defining a specification which statistically was equal to that of Table 2. This specification, which assumes equality of the risk parameters (see Table 4) by restricting the accident coefficient to be the same in both surveys, yielded a model statistically equivalent to the first one (0.028 against $\chi^2_{2; 0.95} = 5.99$). Although, we would have expected exactly the opposite (i.e. more stable toll or travel time parameters rather than the accident one⁷), results are very similar to those shown in Table 2 when considering both the SVAR and the VRR.

Table 4. Models with equal risk parameter

Parameters	Route 68	Route 5	Parameter Ratios
Toll (10^{-3})*	-0.7499	-0.6059	1,238
Travel time (10^{-1})*	-0.392	-0.472	0,831
Accidents*	-0.1032	-0.1032	1,000
SVT (Ch\$/min)	52	78	-
SVAR (Ch\$/acc)	138	170	-
VRR (US\$/risk)	611,025	1,511,585	-
Combined Log-likelihood	-2,244.742		-

* All estimated values are significant at $p=0.05$. In 2000, 1US\$ equaled CH\$500

⁷ We thought that time and money perceptions could be route-independent, whereas fatal risk would not.

We finally computed confidence intervals for the models in Table 4. First, the 95% confidence interval in Ch\$/min for the SVAR on routes 68 and 5 are respectively [118; 168] and [122; 290]. Once again, the second interval almost completely contains the first one. If we consider the VRR, however, the 95% confidence intervals in US\$/risk turned to be [518,796; 752,821] and [966,002; 3,422,446] for routes 68 and 5 respectively, not overlapping at all. The confidence interval for the Route 5 model is now wider when compared to that of the models in Table 2, but it does still not overlap with the interval for Route 68.

Contemporary estimation

So far our models have not allowed for unobserved heterogeneity among different individuals. Heterogeneity arises from the fact that as each respondent answered nine choice situations, her answers are likely to be correlated. When this fact is taken into account fits usually improve. Unobserved heterogeneity was modelled using uniformly distributed random taste parameters (α_0 , β and γ in equation 1) within a Mixed Logit framework (Train, 2002). Table 5 shows the results. The VRR is now somewhat higher for both samples, especially for Route 68, but still within the confidence intervals associated to the models in Table 2 and Table 4.

Table 5. Mixed logit models

Parameters	Route 68	Route 5
Toll (10^{-2})*	-0.00239	-0.001655
Std. dev. (10^{-2})*	0.4499	0.3212
Travel time *	-0.1191	-0.1186
Std. dev.*	0.1361	0.1221
Accidents*	-0.3617	-0.2828
Std. dev.*	0.57	0.4234
SVT (Ch\$/min)	50	72
SVAR (Ch\$/acc)	151	171
VRR (US\$/risk)	671,909	1,516,690
Combined Log-likelihood	-1,608,973	

*All values significant at $p=0.05$.

4.2 Urban road safety model

We now turn to analyze the results obtained by Iragüen and Ortúzar (2003) for the avoidance of fatal accidents in urban areas (Table 6). The magnitudes of risks in this case are in the order of $1,85^{E-06}$ and that of risk reductions of $3,09^{E-07}$; i.e. in comparison to the previously reported figures these are safer roads, as expected. The SVAR amounts to 48 Ch\$/min with a 95% confidence interval between 40 and 58. In order to obtain the VRR we had to amend the figures presented by Iragüen and Ortúzar (2003). The reason is that the US dollar appreciated considerably with respect to the Chilean peso between the time of occurrence of the first two surveys and the urban SC survey (it went from Ch\$ 500 to Ch\$ 650, a 30% increase). On the other hand, local prices (measured in terms of Unidades de Fomento, UF, a unit which considers Chilean inflation⁸) only went up by 7,5%. Thus, considering a dollar value of Ch\$ 537.5, the VRR estimated from a simple logit model amounts to 290,009 US\$/risk within a 95% confidence interval ranging from 241,171 to 349,699.

Table 6. Results for the Urban Case

Parameters	Logit Model	Mixed Logit Model
Cost (10^{-2})*	-0.304	-1.190
Std. Dev. (10^{-1})*	-	0.107
Travel time (10^{-1})*	-0.1307	-4.047
Std. Dev.(10^{-1})*	-	2.582
Accidents*	-0.1468	-0.5973
Std. Dev.*	-	0.576
SVT (Ch\$/min)	43.04	34.04
SVAR (Ch\$/acc)	48.1	50.24
VRR (US\$/risk)	290,009	302,911
Log-likelihood	-1183.870	-890.390

*All values significant at $p=0.05$

For the simple binary logit model (column 2 of Table 6), both the SVAR and the VRR go down in relation to the interurban models, a result that seems once again eminently plausible (Figure 2).

⁸ The UF takes into account the increase in the price of the US dollar as long as it impacts on the inflation index.

In fact, a focus group revealed that for most people driving in urban environments is perceived to be safer than driving on interurban roads. If we also take into account that most trips under consideration are made during peak-hours, this result turns out to be even more credible. As Gaudry and Lasarre (2000) assert, road congestion is probably one of the two main causes helping to reduce fatal accidents within advanced western nations and it is very likely that congestion induces people to have a higher feeling of security (Hauer, 1997). This phenomenon would apply for people living in Santiago de Chile and, hence, it is reasonable to expect that these facts translate into a smaller VRR. Lastly, column 3 of Table 6 displays results for the mixed logit model. Although, there is a clear improvement in fit, the subjective values remain very similar.

In section 3 we mentioned that this last survey was answered by a higher proportion of females and young people. The first tend to have a higher WTP for safety and the latter a lower WTP for safety (see Rizzi and Ortúzar, 2003; Iragüen and Ortúzar, 2003). Comparatively though, there is a higher proportion of young people than females in the sample, so these figures could be somewhat downward biased in comparison to the first two surveys.

We did not attempt to pool the three data sets. From visual inspection, it is clear that the parameters in Table 6 are in a different, higher, scale than the parameters corresponding to the surveys described in section 4.1. Thus, the interurban models are subject to greater variance than the urban model.

4.3 Deriving a general relationship for the VRR

The estimated VRRs for each survey can be considered valid only within a neighborhood of the risk measure for each particular road. However, its is apparent from the outcome of each survey (see Figure 1) that there exists a global relationship between the level of risk and the VRR and we will now proceed to estimate it.

First of all, we have to decide what values should we consider for this task. Mixed logit models are superior for predicting market shares and for computing individual WTP values (Train, 2003, Sillano and Ortúzar, 2002); however, our main concern is with mean sample WTP values, the

figure to be used in a potential cost-benefit analysis, and with regard to these estimates logit models are known to perform well. In addition, logit models and their confidence intervals provide us with a range of values that includes all mean sample values estimated with the mixed logit models. Hence, we decided to base our analysis on the logit model results. For the interurban case, we will consider results from Table 4 and for the urban case results from Table 6.

Based on our observations about three different levels of fatal risks and their respective VRRs, we approximated this relationship by two straight lines. Unfortunately, there are not enough degrees of freedom to test the validity of the fit, but at least it can suggest how the VRR may vary according with different levels of risks associated to different road environments. The following two equations establish the sought after relationship:

$$\begin{aligned}
 VRR &= 3,07 * 10^{16} * (risk\ level) - 9.52 * 10^5 && \text{if } risk > 5,09 * 10^{-6} \\
 VRR &= 9,91 * 10^{10} * (risk\ level) + 1.07 * 10^5 && \text{if } risk < 5,09 * 10^{-6}
 \end{aligned}
 \tag{7}$$

These equations reveal that the WTP curve for safety is indeed of the form shown in Figure 1; as the initial risk level decreases, willingness to pay also decreases but at a decreasing rate. It is reassuring to observe that in spite of our limited data we were able to establish empirically the correct expected theoretical pattern. This equation can only be considered indicative within the range of the data and we do not suggest to apply it outside its range. Table 7, column 2 (see also Figure 3) gives an approximate idea of the values implied by equation (7). Columns 3 and 4 display the inferior and superior limits of the 95% confidence intervals⁹. We can appreciate that these intervals tends to narrow as the risk of death diminishes.

Although our estimates are of a preliminary nature, we believe that this approach is superior to one based in a unique VRR irrespective of the initial level of risk and should lead to better resource allocation for safety improvements. For instance, some actions could be too costly for the safest roads, but may be justified for more dangerous roads, thus preventing safety over-investment in certain routes at the expense of under-investment in less safer routes.

⁹ The equation for the upper and lower bounds can be obtained upon request. The upper bound is represented by two straight lines in a similar fashion to the VRR curve; the lower bound curve is given by a second order polynomial.

[Figure 2. approximately here]

As an application of the above equation, imagine major safety public works on Route 5 in order to improve safety up to the level of Route 68; that is, a reduction of risk of $2.9 \cdot 10^{-6}$ or 17 fatal victims (i.e. a 63% reduction in fatalities) . According to equation (7), the toll could be increased by Ch\$ 1,556. The toll for the Santiago – Rancagua trip in 2000 amounted to Ch\$ 3,100, so the above figure would imply an increment of roughly 50%, which appears to be sensible.

Table 7. Implied VRR as a function of initial risk

Level of risk	VRR(US\$*10 ³ /risk)	95% Confidence interval (US\$*10 ³ /risk)	
8 ^{E-06}	1,505	962	3,402
7 ^{E-06}	1,197	789	2,491
6 ^{E-06}	890	638	1,581
5 ^{E-06}	602	508	742
4 ^{E-06}	503	400	617
3 ^{E-06}	403	314	492
2 ^{E-06}	304	249	368

5. DISCUSSION

Based on the definition of the VRR we have shown that the value of road safety may differ between different routes. This should prevent the use of a unique VRR for different road contexts. Although this fact complicates matters a simple way to overcome this difficulty is to attempt to establish a relationship between the risk level of a route and the VRR. This relationship should comply with economic theory in the sense that the higher the initial risk level and/or the higher the risk reduction offered, the higher the VRR should be.

Based on three different data sets we were able to establish the required relationship. These data sets consisted of three different SC surveys aimed at estimating the value of road safety in different road contexts. Thus the VRRs obtained gave us an opportunity to perform an external validity test of the SC method. As we observed the expected theoretical relationship between the

level of risk and the VRR, we concluded that the external validity test yielded a positive result¹⁰. From this we reaffirmed our belief that SC is a powerful technique for estimating the VRR.

We presented the risk information to respondents as numbers of fatal accidents and not as probabilities. This variable was correctly interpreted by them and when we translated results in terms of probabilities we found the correct economic outcome. On this issue we concluded that fatal accidents are a good risk proxy that can be easily interpreted by most people who *have* driving experience on the actual roads defining the SC surveys¹¹.

As caveats to our results three facts should be borne in mind. First, we are still developing the technique of SC applied to road safety and some improvements are being considered in ongoing research. Second, our samples are not strictly of a random nature, so our values may not be truly representative of population values. For example, we believe that all these figures may be upward biased since the average income of our samples is higher than that of the total population of road users. However, with proper adjustment these values could be used in Chile and could also be transferred to other Latin American countries (and even other second world countries) with more confidence than values transferred from the developed world.

The third point to consider is the definition of risk itself. There are many definitions of risk and it is difficult to decide which one is superior (see Shalom-Hakkert et al, 2002, for an interesting discussion). We consider risk as the probability of a car trip ending with a fatality: thus, to derive the VRR we need the number of fatal victims per accident and this value is highly variable. We decided against considering just the number of fatalities, since this number is much more variable than the number of accidents with fatalities (Fridstrom, 1999, chapter 6), but may be considered in future work.

When comparing the VRR obtained within Chilean road contexts with international values, it is not easy to draw a definite conclusion. We have observed that the VRR tends to be related to the level of risk and differences can be important. We can only say that for the safest Chilean roads -

¹⁰ Even the values within the 95% confidence interval for each sample comply with the expected theoretical pattern.

¹¹ As a caution, we do not recommend to interview people who can not figure out how dangerous the specific road is; in that case the number of accidents would be a figure devoid of any contextual meaning.

Route 68 and the urban case - our values tend to be much lower than those found for (even safer) roads in the developed world. For instance, our VRR estimates (considering confidence intervals) from these two surveys are lower than a set of values provided by Evans (1994) for the UK (US\$ 1,000,000 to over US\$ 3,100,000). On the other hand, VRR estimates for the more dangerous Route 5 span an interval even wider than the UK one. As another yardstick, de Blaeij et al (2002) obtained a point estimate slightly superior to US\$ 2,000,000 for Dutch interurban roads (among the safest in the world) using SC; once again a value superior to all our point estimates.

Consider now the meta-analysis by Miller (2000) from which one can obtain the VRR for any country by transferring values based on a 1995 GDP/capita adjustment. He derived values for the Chilean case ranging from US\$ 600,000 to US\$ 900,000. These values could be roughly compared to the ones for the VRR (in US\$) for Route 68 [518,796; 752,821], but in our opinion this is just sheer luck, as the per capita income of our sample is much higher than the Chilean 1995 GDP/capita computed by Miller. We should also note that Miller's values are not sensitive to initial risk levels, so we do not know whether or not it is appropriate to apply his transfer function to different road environments. In particular we suspect his transfer function could not be applied to a route as unsafe as Route 5.

Taking all these facts into account, we observe that Chilean VRRs are comparatively lower than VRRs estimated in developed countries (even after adjusting by income). In order to account for this difference, we can suggest two reasons. First, we believe there are differences related to idiosyncratic risk perceptions. Unfortunately, road risk consciousness is not as high in Chile as in first world countries and many tend to believe that accidents simply occur and can not be prevented. Hence, there is a lower WTP for risk reduction road safety measures. This finding will never show up if a meta-analysis does not include VRRs from developing countries and/or variables related to risk perception.

Second, the high VRR obtained in developed countries may be due to biases introduced by the extensive use of the contingent valuation (CV) technique. CV usually implies a trade off between probabilities of risk and money in a context not completely specified. Thus, it is not rare at all that very high VRR could be obtained. The context in which we set up the choice situations is well defined, easily understood by most people and real market restrictions are introduced to

prevent respondents producing unlikely responses. This has the effect of tempering responses, and precluding people to produce “outliers”. De Baleij et al (2002) also reported a similar finding¹².

To wrap up, we conclude that (a) SC is a promising questionnaire technique in order to elicit VRR; (b) accidents are better understood than probabilities of risk; (c) the VRR for road contexts should include a range of likely values depending of the risk level of each route and (d) our findings provide a set of figures for road safety planners in Latin American and other developing countries, which are superior (more credible) to simple transfer from industrialized nations.

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REFERENCES

- Ampt, E.S., Swanson, J. and Pearmain, D. (2000). Stated preference: too much deference? In J. de D. Ortúzar (ed.), *Stated Preference Modelling Techniques*, 191-203. Perspectives 4, PTRC, London.
- Armstrong, P., Garrido, R. and Ortúzar, J. de D. (2001). Confidence intervals to bound the value of time. *Transportation Research* **37E**, 143-161.
- 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**, 5-25.

¹² They state among other reasons for this phenomenon (a) the public good nature of the risk under analysis and (b) the definition of the payment mechanisms. However, they do not attempt any explanation on whether or not the survey instrument could affect the outcome of the experiment.

- Bronfman, N. and Cifuentes, L. (2003) Risk perception in a developing country: the case of Chile. *Risk Analysis* (under review).
- 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**, 187-214.
- Carrasco, J.A. and Ortúzar, J.deD. (2002) Review and assessment of the nested logit model. *Transport Reviews* **22**, 197-218.
- 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. *Proceedings 30th European Transport Forum*. PTRC, London.
- Evans, A.W. (1994) Evaluating public transport and road safety measures. *Accident Analysis and Prevention* **26**, 411-428.
- Fridstrøm, L. (1999) *Econometric Models of Road Use, Accidents and Road Investments Decisions*. Ph.D. Thesis, Institute of Economics, University of Oslo.
- Galilea, P., Norambuena, I. Dueñas, F. and Ortúzar, J. de D. (2000) Validación externa del diseño experimental de PD para accidentes fatales interurbanos. *Working Paper 81*, Department of Transport Engineering, Pontificia Universidad Católica de Chile (in Spanish).
- Gaudry, M.J.I. and Lassarre, S. (eds.) (2000) *Structural Road Accident Models*. Pergamon, Amsterdam.
- Hauer, E. (1997) *Observational Before-After Studies in Road Safety*. Pergamon, Oxford.
- Iragüen, P. and Ortúzar, J. de D. (2003) Willingness-to-pay for reducing fatal accident risk in urban areas: an internet-based web page stated preference survey. *Accident Analysis and Prevention* (in press).
- 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., 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.
- Krupnick, A., Alberini, A., Belli, R., Cropper, M. and Simon, N. (1997) New directions in mortality risk valuation and stated preference methods: preliminary results. *Working Paper*, Resources for the Future, Washington, D.C.
- Louviere, J.J., Hensher, D.A. and Swait, J.D. (2000) *Stated Choice Methods: Analysis and Application*. Cambridge University Press, Cambridge.

- Miller, T. (2000) Variations between countries in values of statistical life. *Journal of Transport Economics and Policy* **34**, 169-188.
- Nash, C.A. (1990) Appraising the environmental effects of road schemes, *Working Paper*, Institute for Transport Studies, University of Leeds.
- O'Brien, B., Goeree, R., Gafni, A., Torrance, G., Pauly, M., Erder, H., Rusthoven, J., Weeks, J., Cahill, M. and LaMont, B. (1998) Assessing the value of a new pharmaceutical: a feasibility study of contingent valuation in managed care. *Medical Care* **36**, 370-384.
- 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.
- Train, K (2003) *Discrete Choice Methods with Simulation* Cambridge University Press, Cambridge.
- Shalom-Hakkert, A., Braimaister, L. and van Schagen, I. (2002) The uses of exposure and risk in road safety studies. *Proceedings 30th European Transport Forum*. PTRC, London.
- Sillano, M. and Ortúzar, J. de D. (2002) WTP estimation with random parameter logit models: some new evidence. Mimeo, Department of Transport Engineering, Pontificia Universidad Católica de Chile.
- Slovic, P., Fischhoff, B. and Lichtenstein, S. (1985) Characterizing perceived risk. In J. Kasperson (ed.), *Perilous Progress: Managing the Hazards of Technology*. Colorado Westview Press, Boulder.
- 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**, 32-51.

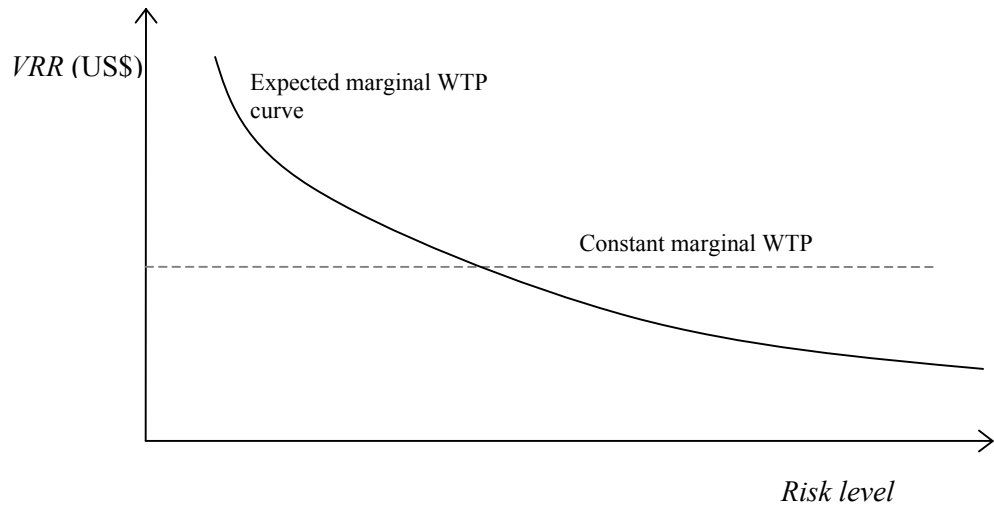


Figure 1. Expected VRR pattern as a function of initial risk

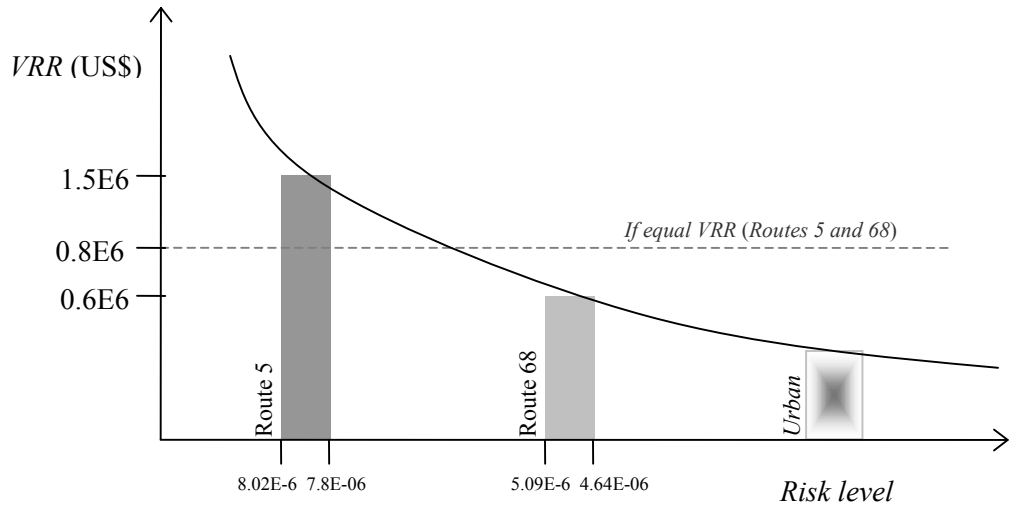


Figure 2. Implied VRR curve from our three data sets (un-scaled values).

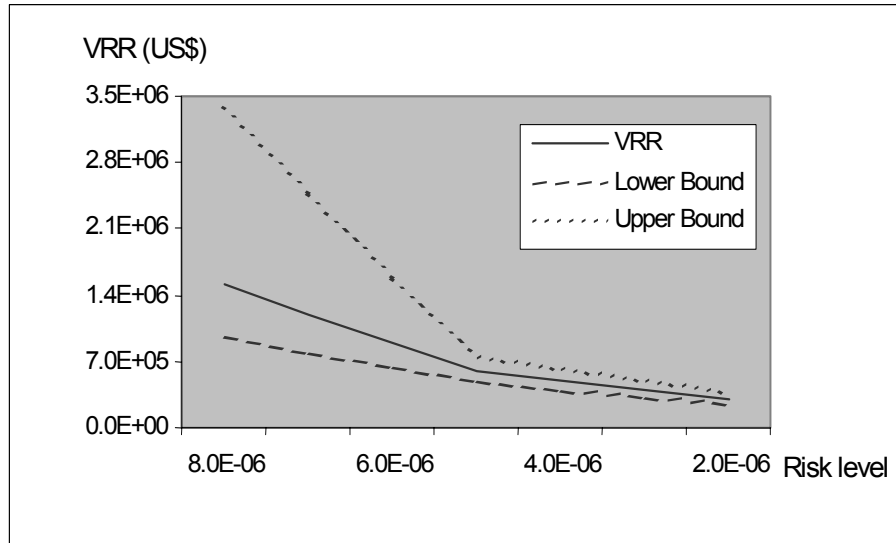


Figure 3. The VRR and its 95% confidence interval