Risk Analysis, Vol. 23, No. 1, 2003

A Revised Economic Analysis of Restrictions on the Use of Cell Phones While Driving

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Evidence that cell phone use while driving increases the risk of being involved in a motor vehicle crash has led policymakers to consider prohibitions on this practice. However, while restrictions would reduce property loss, injuries, and fatalities, consumers would lose the convenience of using these devices while driving. Quantifying the risks and benefits associated with cell phone use while driving is complicated by substantial uncertainty in the estimates of several important inputs, including the extent to which cell phone use increases a driver's risk of being involved in a crash, the amount of time drivers spend using cell phones (and hence their aggregate contribution to crashes, injuries, and fatalities), and the incremental value to users of being able to make calls while driving. Two prominent studies that have investigated cell phone use while driving have concluded that the practice should not be banned. One finds that the benefits of calls made while driving substantially exceed their costs while the other finds that other interventions could reduce motor vehicle injuries and fatalities (measured in terms of quality adjusted life years) at a lower cost. Another issue is that cell phone use imposes increased (involuntary) risks on other roadway users. This article revises the assumptions used in the two previous analyses to make them consistent and updates them using recent data. The result is a best estimate of zero for the net benefit of cell phone use while driving, a finding that differs substantially from the previous study. Our revised cost-effectiveness estimate for cell phone use while driving moves in the other direction, finding that the cost per quality adjusted life year increases modestly compared to the previous estimate. Both estimates are very uncertain.

KEY WORDS: Benefit-cost analysis; cost-effectiveness analysis

1. INTRODUCTION

Cellular phones (cell phones) were first introduced in the United States in the mid-1980s, and their use has since experienced dramatic growth. Today, there are more than 128 million subscriptions.(1) This technology has proven to be particularly useful for people on the move; indeed, a majority of cell phone owners report they use the technology while driving.(2,3)

Concerns have been raised that use of a cell phone while driving increases the risk of traffic crashes, property damage, injuries, and fatalities. These safety concerns have also led policymakers to consider whether the use of a cell phone while driving should be regulated or even prohibited. Among 29 developed nations currently belonging to the Organization for Economic Cooperation and Development (OECD), eight countries have enacted legislation that prohibits hand-held usage while driving. In the United States, 36 states considered restrictions on the use of cell phones while driving in 2001.(4) New York banned the use of hand-held phones, although the law allows the use of hands-free devices. Data on the safety of hands-free

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0272-4332/03/1200-0005$22.00/1

devices are limited but do not indicate any safety advantage compared to hand-held phones.(5,6)

Although an extensive literature has empirically documented the risks associated with using a cell phone while driving, restricting this practice has been controversial because of the benefits consumers derive from these calls. Analyses of these risks and benefits have attempted to inform the debate by comparing the monetary value of these benefits to the monetary value of eliminating the associated risks, as in the case of Hahn and Tetlock,(7)[2] or by estimating the monetary value of the benefits foregone by eliminating cell phone calls while driving per quality adjusted life year (QALY)[3] saved, as in the case of Redelmeier and Weinstein.(8) The Hahn and Tetlock benefit-cost analysis estimated that a ban on cell phones would result in a societal loss amounting to a central estimate of \$23 billion annually (costs of \$25 billion and benefits of \$1.2 billion). The Redelmeier and Weinstein cost-effectiveness (CE) analysis estimated that the cost per QALY saved would be \$300,000.

Although both studies reached qualitatively similar conclusions, i.e., that a ban on cell phone use while driving is not economically efficient, some of their key assumptions differed substantially. This article, which is an updated version of Lissy *et al.*,(9) revises the key assumptions for these two assessments so that they are consistent and reflect the best information available.[4] We also update the assumed number of people who use cell phones and the assumed amount of time they spend on the phone while driving. Our revised net benefits estimate for a ban on all cell phone use while driving (i.e., both hand-held and hands-free units) is substantially less unfavorable than the estimate reported by Hahn and Tetlock(7) (i.e., we predict a much smaller net loss). On the other hand, our cost-effectiveness estimate is moderately more unfavorable than the value reported by Redelmeier and Weinstein(8) (i.e., we predict a somewhat higher cost per QALY saved). Our revised net benefits and CE ratio estimates both have a wide range of plausible values, and we identify those assumptions that contribute the most to this uncertainty.

2. METHOD

For the benefit-cost analyses, net benefits are computed by taking the difference between monetized benefits and costs. For the cost-effectiveness analyses, the CE ratio equals net costs divided by QALYs saved. Net costs are the difference between the value of the foregone phone calls and any savings from averted crashes not reflected in the QALYs saved. Consistent with the approach recommended by the Panel on Cost-Effectiveness in Health and Medicine convened by the U.S. Public Health Service,(10) changes in household productivity, market productivity, and other workplace costs are omitted from the monetized savings because they are already reflected in the QALY component of the CE ratio.

Assumptions for this analysis are as follows.

- A ban on all cell phone use while driving would completely eliminate both the costs and benefits associated with such calls. That is, we assume total compliance.
- The proportion of property-damage-only (PDO) crashes, injuries, and fatalities attributable to cell phone use are equal. Data are not available to separately quantify these proportions.
- Incremental crash risk is proportional to time spent on the phone. This assumption is consistent with the hypothesis that mental distraction associated with phone conversation is the main contributor to crash risk, rather than other factors, such as physical interference with the driving task resulting from dialing. The results of Redelmeier and Tibshirani,(5) which did not show hands-free cell phones to be safer than hand-held devices, and experiments conducted by Strayer *et al.*(6) to see how conversation influences performance on simulated driving tasks, support this hypothesis.

Based on this last assumption, automobile crash risk due to all causes is the time-weighted average of the baseline risk ($R^{Baseline}$ crashes per minute) and the risk associated with cell phone use ($R^{Baseline} \times RR$, where RR is the relative risk associated with cell phone use). Hence, total crash risk among all drivers (R_{Total}) is:

$$R_{Total} = \frac{(T_{Total} - T_{cp})\, R^{Baseline} + T_{cp} \times RR \times R^{Baseline}}{T_{Total}}, \tag{1}$$

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[2] A summarized and somewhat updated version of Hahn and Tetlock(7) appears in Hahn *et al.*(28)

[3] A quality adjusted life year (QALY) is a year of life in perfect health. An actual year of life is typically worth something less than one QALY because of adverse health conditions.(10) The QALY metric therefore takes into account both longevity and quality of life.

[4] Because this article builds on Lissy *et al.*,(9) we do not directly compare this analysis to that previous work. Section 5 identifies the key differences between the two.

where T_{Total} is total minutes driving among all drivers, and T_{cp} is minutes spent on the phone while driving among all drivers.

Subtracting the baseline risk from the right side of Equation (1) and dividing the result by $R^{Baseline}$ yields the incremental proportion by which cell phone use while driving increases the number of crash events (ΔR). That is,

$$\Delta R = \frac{T_{cp} \times (RR - 1)}{T_{Total}}. \tag{2}$$

The number of crash events avoided by banning cell phone use while driving is the product of ΔR and the baseline number of events. Multiplying this result by the value of each such event (in either dollars or QALYs) yields the value of the resulting benefit.

Hence, net benefits (NB) is computed as:

$$NB = \Delta R\left[\sum_{i=1}^{n} R_i^{Baseline} \times V_i^{Total}\right] - Value_{calls}, \tag{3}$$

where the index i ranges over the types of crash events, V_i^{Total} is the total value of averting each crash event of type i, and $Value_{calls}$ is the value of all phone calls made or received while driving. The CE ratio is computed as:

$$CE = \frac{Value_{calls} - \Delta R\left[\sum_{i=1}^{n} R_i^{Baseline} \times V_i^{Partial}\right]}{\Delta R\left[\sum_{i=1}^{n} R_i^{Baseline} \times QALY_i\right]}, \tag{4}$$

where $QALY_i$ is the number of QALYs lost per crash event of type i, and $V_i^{Partial}$ is the value of averting each crash event of type i, omitting those components of cost reflected in $QALY_i$.

3. PARAMETER ASSUMPTIONS

This section describes the parameter assumptions for Redelemeier and Weinstein,(8) Hahn and Tetlock,(7) and for our revised analysis. Section 3.1 discusses ΔR, Section 3.2 discusses baseline crash-event rates, Section 3.3 quantifies the value of averting each type of crash event, and Section 3.4 quantifies the value of cell phone calls made or received while driving. Tables I and II summarize these assumptions.

3.1. The Incremental Impact of Cell Phone Calls While Driving on Crash Risk (ΔR)

Redelmeier and Weinstein(8) assumed that 20% of all drivers (35 million drivers) use cell phones while driving, and that among these individuals, use averages two minutes per day. They assumed further that average driving time per day is 60 minutes. Finally, they used the central value for RR computed by Redelmeier and Tibshirani(5) ($RR = 4.3$). The corresponding value for ΔR is 0.02.

Hahn and Tetlock(7) computed ΔR in two different ways. They developed their central estimate for this parameter from four sets of police accident reports: (1) reports from Minnesota and Oklahoma for the years 1994–1998 (the only states with provisions on the crash report forms to specify potential cell phone involvement), (2) reports from North Carolina for the years 1989–1995, (3) data extracted from the National Highway Transportation Safety Administration (NHTSA) Fatal Accident Reporting System (FARS) for the years 1994–1997, and (4) the

Table I. Comparison of Assumptions Across Analyses

	Redelmeier and Weinstein(8)	Hahn and Tetlock(7)	This Analysis
Setting	1997	1999	2002
Annual driving time for all drivers (T_{Total})	60 min per driver per day, 175 million drivers yields 3.8×10^{12} min	3.5 trillion miles per year at 25 mph yields 8.4×10^{12} min	2.6 trillion miles at 35 mph, 0.6 trillion miles at 60 mph yields 4×10^{12} min
Annual time on phone while driving (T_{cp})	2 min per day, 35 million users yields 2.5×10^{10} min	2 min per day, 77 million users yields 5.6×10^{10} min	Use from 300–1,200 min per year, 128 million users yields 3.8×10^{10} to 1.5×10^{11}, central estimate of 7.7×10^{10}
Relative crash risk while on phone (RR)	4.3 (3.0–6.5)	1.3 (central) 4.3 (high)	4.3 (3.0–6.5)
Incremental impact of cell phone use on crash rate (ΔR)	0.02	0.002–0.02	Central estimate: 0.06 Range: 0.02–0.21
Annual value of cell phone calls made and received while driving	\$12 billion	\$25 billion	\$43 billion

Table II. Comparison of Crash-Event Assumptions Across Analyses—Baseline Annual Rate, Costs, and QALY Losses

Crash-Event	All Analyses Baseline Annual	Redelmeier and Weinstein(8)		Hahn and Tetlock(7)	This Article		
Type	Frequency	Partial Cost	QALYs Lost[a]	Total Cost ($)[b]	Partial Cost ($)	Total Cost[c]	QALYs Lost[d]
PDO	23,395,971	$1,576	0	$0	$1,900	$2,000	0
AIS-0	3,715,370	$0	0	$0	$1,300	$1,300	0
AIS-1	4,626,495	$5,298	0	$13,000	$6,400	$22,000	0
AIS-2	398,553	$17,799	0	$100,000	$22,000	$150,000	0
AIS-3	166,845	$53,635	3.17	$380,000	$65,000	$510,000	3.17
AIS-4	17,123	$149,170	1.47	$1,200,000	$180,000	$1,600,000	1.47
AIS-5	6,914	$460,326	16.3	$5,000,000	$560,000	$6,000,000	16.3
Fatal	40,676	$115,534	20.2	$6,600,000	$140,000	$7,700,000	20.2

[a] Redelmeier and Weinstein(8) assumed that the AIS-3, AIS-4, and AIS-5 components are uncertain with estimates ranging from zero to approximately four times their central values. They assumed that the QALY loss for fatalities can range from 15–25 QALYs.

[b] Hahn and Tetlock(7) added to these values the cost component borne by others, amounting to $140 billion annually for all crashes, but did not detail how that cost is divided among different types of event. They estimated that the total value of the cost component not borne by others is $490 billion annually. Hahn and Tetlock assumed that this component of total cost is uncertain, with all estimates ranging from 55–145% of their central values.

[c] We assume that the cost component not borne by others is uncertain to the same degree as the estimates made by Hahn and Tetlock(7) (i.e., ranging from 55–145% of the central values).

[d] We assume the same uncertainty as that assumed by Redelmeier and Weinstein.(8)

same data with reports from Oklahoma excluded because of doubts as to its accuracy. Estimates for the cell phone involvement rate for these data sets (adjusted to reflect 1999 cell phone subscription rates) were 3 per 1,000, 3 per 10,000, 3 per 1,000, and 1 per 1,000, respectively, yielding an average for ΔR of approximately 0.002.

Hahn and Tetlock(7) also estimated ΔR using the Redelmeier and Tibshirani(5) cell phone relative crash risk value of 4.3, an estimate they viewed as an upper bound for reasons discussed in Section 3.1.2. They assumed further that there are 77 million cell phone users, each of whom uses the phone while driving for an average of 12 hours per year. Finally, they assumed that total driving time for all U.S. drivers amounts to 140 billion hours annually. These assumptions correspond to a value of 0.02 for ΔR. We note that the Hahn and Tetlock(7) central estimate for ΔR of 0.002, along with their assumptions for T_{cp} and T_{Total} described in this paragraph, correspond to an RR value of 1.3.

The remainder of Section 3.1 describes our derivation of a value for ΔR. The key factor explaining why the Hahn and Tetlock(7) central estimate value for ΔR is an order of magnitude lower than both their high-end value and the Redelmeier and Weinstein(8) value for this parameter is the use of the police crash data to estimate ΔR directly rather than the use of the RR value from Redelmeier and Tibshirani(5) of 4.3 and Equation (2) above. Section 3.1.1 argues that because of factors compromising the utility of police accident reports to estimate the impact of cell phone use on crash risk, the central estimate developed by Hahn and Tetlock(7) should be disregarded. Section 3.1.2 reviews three epidemiological studies that estimate values for RR and concludes that one, conducted by Redelmeier and Tibshirani,(5) provides the best information for this purpose. Section 3.1.3 revises estimates for total driving time (T_{Total}) and cell phone usage while driving (T_{cp}). Finally, Section 3.1.4 uses the information in Sections 3.1.2 and 3.1.3 to develop our value for ΔR.

3.1.1. Police Accident Reports

Although studies of crash case reports are consistent with the hypothesis that cell phone use while driving elevates crash risk, quantitative inferences are limited by two factors that probably result in the substantial underestimation of cell phone involvement. First, until 2001, only three states (Oklahoma, Minnesota, and Tennessee) specifically required police to specify the presence or potential involvement of cell phones on crash report forms. Because of other police priorities at the site of a crash, such as tending to the injured, restoring traffic flow, and issuing citations for legal infractions,(11) it is plausible that in other states police often do not record the potential involvement of a cell phone in many crashes even if the evidence is available. A NHTSA review(11) of the North Carolina data cited by Hahn and Tetlock(7) indicated that the extent of the underreporting might be substantial. In particular, NHTSA pointed out that the identified proportion of crashes caused by inattention (1.5%), which often plays a role in crashes associated with cell phone use, was substantially less than the proportion of such crashes identified in more comprehensive crash analysis studies (30–50%).

Second, even if collection of this information is required, it may not be accurate because drivers involved in a crash may be reluctant to report use of a cell phone to police. Concealment of such use can occur unless the cell phone user is severely or fatally injured. NHTSA noted that "culpable drivers may be less inclined to admit that they were using their cellular telephones at the time of the crash."(11:Ch.3,p.9) NHTSA added that even though witnesses can help fill in gaps, "Witness testimony is often not available, however, and can be unreliable."(11:Ch.3,p.9)

3.1.2. Estimating Relative Crash Risk from Epidemiological Studies

We identified three epidemiological studies that measure crash incidence and cell phone usage among drivers. One approach to the synthesis of these findings would be to compute some type of weighted average based on the different study findings. However, our review concludes that only the study conducted by Redelmeier and Tibshirani(5) provides useful information for the purpose of quantifying the impact of cell phone use while driving on crash risk. The other two studies(12,13) do not control for potentially critical confounders. Moreover, the odds ratios (OR) for the Violanti and Marshall study is based on a relatively small sample and hence has a wide confidence interval. Finally, there is no straightforward way to estimate the relative crash risk while using a cell phone and driving from the results of either Vialanti and Marshall(13) or Dreyer *et al.*(12)

Using a case cross-over design Redelmeier and Tibshirani(5) evaluated cell phone usage patterns among 699 drivers in metropolitan Toronto, Canada involved in PDO crashes. In particular, the authors compared usage during the 10-minute period just prior to the crash to the same period on a comparable recent preceding day. An analysis adjusted to account for the possibility that the subject was not driving at that time on the preceding day revealed that cell phone activity was associated with a relative crash risk of 4.3 (95% CI 3.0–6.5). Because the case cross-over design compares drivers directly to themselves, it automatically controls for many potential confounders, such as driver characteristics, distance traveled, and so forth. Moreover, the Redelmeier and Tibshirani study had sufficient statistical power to provide a reasonably precise risk estimate.

The Redelmeier and Tibshirani(5) study provides results that are more useful for quantifying risk than the two other epidemiological studies. The first, a case-control study of New York drivers conducted by Violanti and Marshall,(13) concluded that cell phone use while driving for more than 50 minutes per month was associated with involvement in a traffic crash (OR = 5.59, 95% CI = 1.19–37.33). However, the study's usefulness is limited by its small sample size and resulting lack of precision, and by the fact that it does not appear to have controlled for potentially important confounders, such as distance driven per year. Finally, because study subjects were dichotomously categorized (cell phone use < 50 minutes per month or >50 minutes per month), it is not possible to tell from this study how much cell phone use contributes to crash risk per minute of use.

The second study, conducted by Dreyer *et al.*,(12) extended work conducted by Rothman *et al.*(14) and tracked the mortality experience for a large cohort of cell phone users in the United States. Based on billing records, the authors reported motor vehicle mortality rates were 5, 10, and 12 per 100,000 for subscribers using their phones <1 min/day, 1–3 min/day, and >3 min/day, respectively. This study's usefulness for the purpose of quantifying risk is limited because the exposure metric did not distinguish between cell phone use while driving and use while not driving, and because it did not control for distance driven annually.

Despite the strength of the Redelmeier and Tibshirani(5) study, Hahn and Tetlock(7) noted two factors that may bias its risk estimate upward. First, the reported association may not be causal because circumstances (e.g., congestion, poor weather, a delay that motivates the driver to go faster) might contribute to both the exposure (cell phone use) and the outcome (crashes). It is not clear how large this effect might be.

Second, Redelmeier and Tibshirani(5) may have misclassified calls made for emergency assistance after the crash occurred as calls that occurred before the crash. However, Redelmeier and Tibshirani(15) have pointed out that the relative risk was similar ($RR =$ 4.0, 95% CI = 2.2–11.0) in those cases for which the exact collision time was known. Moreover, they noted that the relative risk was similar when their analysis was restricted to incoming calls.

A third factor may bias the results in either direction. In particular, the Redelmeier and Tibshirani(5) study was limited to accidents not resulting in either injury or fatality, and it is not clear if cell phones would contribute more or less to more serious accidents. For example, unpublished data collected by Cohen *et al.*(16) indicate cell phone use while driving tends to be underrepresented during late night hours when crashes tend to be most fatal. On the other hand, they are overrepresented on roads with high speed limits, where crashes are often more fatal. We use the *RR* value from Redelmeier and Tibshirani (4.3) and assume that its 95% confidence interval (3.0–6.5) characterizes its bounds.

3.1.3. Revised Estimates for Time on Phone While Driving (T_{cp}) and Total Driving Time (T_{Total})

T_{Total}: Assuming 6.3×10^{11} miles per year highway travel and 2.6×10^{12} miles per year traveled on other roads (1998 values),(17:Table 1-30) an average highway speed of 60 mph (estimate) and an average speed on other roads of 35 mph (estimate), total travel time per year is approximately 4×10^{12} minutes.

T_{cp}: Two empirical estimates of cell phone use while driving have become available since the Redelmeier and Tibshirani(5) and Hahn and Tetlock(7) analyses were conducted. First, a telephone survey conducted by PCIA(3) asked respondents to quantify the time they spend per month using their phone while driving. Responses were: no use (10%), 0–10 minutes (39%), 10–30 minutes (20%), 30–60 minutes (15%), and greater than one hour (15%). Using the midpoint for each range and assuming that average use for the last category was 90 minutes per month, the survey suggests that use while driving averages around 300 minutes per year.

NHTSA(18) estimated cell phone use while driving based on a nationally weighted sample of roadside observations made as part of the fall 2000 National Occupant Protection Use Survey. The survey found that 3.0% of all observed drivers were using a cell phone. Assuming 100 million cell phone users (the approximate number of users at the time the NHTSA survey was conducted), average cell phone use while driving is 4×10^{12} minutes per year × 3.0% ÷ 100 million cell phone users, or approximately 1,200 minutes per year per cell phone user.

The two estimates just described differ by a factor of four. The accuracy of the PCIA survey, which is based on 971 telephone interviews with cell phone users, is difficult to gauge in large part because it is not clear if individuals have an accurate impression of the amount of time they spend on the phone while driving. In another survey conducted by telephone, Cohen *et al.*(16) found that responses to questions on this issue failed internal consistency checks. The NHTSA(18) findings are based on a stratified observational survey of driver vehicle occupant behavior at 640 intersections. Although the results are nationally representative, it is possible that they overstate cell phone use if users are more likely to make or answer calls when stopped at an intersection. Surveillance was also limited to daytime hours, although it is not immediately clear that this restriction would introduce a bias.

We take the two estimates as bounds on this parameter (300–1,200 minutes/year), with their geometric mean (600 minutes/year) as a central estimate. The number of drivers who use cell phones while driving is 128 million,(1) yielding a central estimate for T_{cp} of 77 billion minutes per year, and a range from 38–150 billion minutes per year.

3.1.4. Proportion of Crash Events Attributable to Cell Phone Use While Driving (ΔR)

The central estimate for ΔR is 0.06 (7.7×10^{10} minutes phone use $\times (4.3 - 1) \div 4 \times 10^{12}$ minutes driving). The low-end estimate is $3.8 \times 10^{10} \times (3.0 - 1) \div 4 \times 10^{12}$, or 0.02; the high-end estimate is $1.5 \times 10^{11} \times (6.5 - 1) \div 4 \times 10^{12}$, or 0.21.

3.2. Baseline Crash-Event Rates

Redelmeier and Weinstein(8) divided crash events into six categories and used 1994 statistics from Blincoe(19:Table 3) to quantify baseline annual rates for each type of event. The categories considered were as follows, with annual rates in parentheses: (1) PDO ($n = 23{,}395{,}971$); (2) injuries with AIS (abbreviated injury severity) scores of 1 (minor) or 2 (moderate) ($n = 5{,}025{,}048$); (3) injuries with AIS scores of 3 (serious) ($n = 166{,}845$); (4) injuries with AIS scores of 4 (severe) ($n = 17{,}123$); (5) injuries with AIS scores of 5 (critical) ($n = 6{,}914$); and fatalities ($n = 40{,}676$). We note that Blincoe(19) estimated the number of AIS-1 injuries to be 4,626,495, and the number of AIS-2 injuries to be 398,553.

Although they did not describe these values in the same level of detail, it is evident that Hahn and Tetlock used the same baseline crash-event rates.(7,12) They also pointed out that the total numbers of crashes and fatalities in 1994 were similar to the corresponding 1999 figures.

The analysis developed here also uses the Blincoe(19) statistics. However, in addition to considering injured individuals, we also consider individuals who were involved in a crash causing injuries to others but who were not injured themselves. Because these uninjured individuals may receive medical attention, and because of the logistics involved in dealing with a crash (e.g., filing insurance claims, etc.), there are costs associated with this group. Blincoe(19) estimated that there were 3,715,370 such individuals in 1994.

We note that although annually published crash statistics are available for more recent years, the Blincoe(19) statistics are of greater value because they reflect both events reported to the police and the estimated number of events not reported. The proportion of events not reported can be substantial for both PDO crashes (48%) and for minor and moderate injuries (23% for AIS-1 injuries and 16% for AIS-2 injuries).

3.3. Valuation of Crash Events

3.3.1. Monetized Crash-Event Costs

Hahn and Tetlock(7) calculated the total cost of all crashes as the sum of those costs borne by individuals involved in the crash and those costs borne by others (e.g., insurance companies). They started with the NHTSA(20) estimate for total economic costs (i.e., costs excluding those associated exclusively with pain and suffering) and subtracted the $30 billion in costs incurred directly by dead and injured individuals. To the remaining $140 billion, which represents costs borne by others, they added the amount individuals would be willing to pay to avoid both the economic costs and the pain and suffering associated with injuries and fatalities. That is, they assumed that the willingness to pay (WTP) values subsume the $30 billion in economic costs directly borne by dead and injured individuals.

Hahn and Tetlock(7) assumed that the pain and suffering (noneconomic) costs for various levels of injury severity are proportional to the value of a statistical life (VSL), for which Hahn and Tetlock assumed a central value of $6.6 million (range of $3.6–9.6 million) (1999 dollars). In particular, they assumed central estimates for pain and suffering costs of $13,000, $100,000, $380,000, $1,200,000, and $5,000,000 for AIS-1 through AIS-5 injuries, respectively. However, although Hahn and Tetlock detailed the noneconomic component of total costs on a per-event basis, they did not detail the per-event economic costs that produced the $140 billion economic cost component.

Redelmeier and Weinstein(8) developed their monetary cost estimates from the per-event crash costs reported by Blincoe.(19) However, consistent with the approach recommended by the Panel on Cost-Effectiveness in Health and Medicine convened by the U.S. Public Health Service,(10) they omitted that portion of these costs reflecting changes in household productivity, market productivity, and other workplace costs. Cost components that were retained included medical, funeral, emergency medical services, vocational rehabilitation, insurance administration, and legal costs. From Table 2 in Blincoe,(19) we get totals for these costs of $5,298 (AIS-1), $17,799 (AIS-2), $53,635 (AIS-3), $149,170 (AIS-4), and $460,326 (AIS-5) (1994 dollars). The corresponding cost total for fatalities was $115,534. For PDO crashes, the cost used was $1,576.

For our analysis, we specify two sets of costs. The values used to estimate net benefits reflect all cost components (V_i^{Total}), while the values used to estimate the CE ratio omit the components omitted by Redelmeier and Weinstein(8) ($V_i^{Partial}$).

Net benefits costs (V_i^{Total}): We use the WTP values estimated by Hahn and Tetlock(7) (adjusted upwards by 4.1% to convert them from 1999 to 2002 dollars) to estimate total costs (both economic and pain and suffering) borne by affected individuals, yielding: $0 (PDO and AIS-0), $14,000 (AIS-1), $110,000 (AIS-2), $400,000 (AIS-3), $1,300,000 (AIS-4), $5,200,000 (AIS-5), and $6,900,000 (fatal). We assume that these values are uncertain because the VSL has plausible values ranging from $3.7–10 million (2002 dollars). For the economic costs borne by others, we use the estimates from Blincoe(19) (adjusted upward by 21.1% to convert from 1994 to 2002 dollars) but omit household productivity costs on the assumption that these costs are reflected in the WTP values. The resulting costs are $2,000 (PDO), $1,300 (AIS-0), $8,300 (AIS-1), $38,000 (AIS-2), $110,000 (AIS-3), $260,000 (AIS-4), $790,000 (AIS-5), $850,000 (fatal).

Cost-effectiveness costs not accounted for by changes in lost QALYs ($V_i^{Partial}$): Adjusting for inflation (converting from 1994 dollars to 2002 dollars), the Blincoe(19) values used by Redelmeier and Weinstein(8) amounted to the following: $1,900 (PDO), $1,300 (AIS-0), $6,400 (AIS-1), $22,000

(AIS-2), $65,000 (AIS-3), $180,000 (AIS-4), $560,000 (AIS-5), and $140,000 (fatal).

3.3.2. *Lost QALYs per Crash Event*

Based on the Beaver Dam Health Outcomes Study,(21) Redelmeier and Weinstein(8) estimated that a vehicle crash fatality would result in the loss of 20.2 QALYs (range of 15–25 QALYs). They omitted consideration of potential QALY losses for PDO crashes, uninjured individuals (AIS-0), and individuals sustaining either minor (AIS-1) or moderate (AIS-2) injuries, effectively assuming these events did not result in any loss of QALYs. Based on the findings of Graham *et al.*(22) and MacKenzie *et al.*,(23) they assumed more severe injuries resulted in the loss of 3.17 QALYs (AIS-3), 1.47 QALYs (AIS-4), or 16.3 QALYs (AIS-5). Based on these assumptions, each crash event resulting in a nonfatal injury amounted to an average loss of 0.127 QALYs. For the purpose of evaluating the impact of uncertainty, Redelmeier and Weinstein(8) assumed that this average ranges from 0–0.5. We use these assumptions in our analysis as well.

3.4. The Value of Cell Phone Calls Made and Received While Driving

Hahn and Tetlock(7) updated the Hausman(24) consumer surplus value estimate for cell phone service in 1994. The Hausman study was based on U.S. industry data and controlled for numerous factors that shift either the demand or supply curve for this service, including changes in population, income, the price of service, and the price of substitutes. Hahn and Tetlock noted that between 1994 and 1999, subscription rates increased five-fold to 77 million, and estimated that consumer surplus increased from $27 billion to $41 billion during the same period. Based on the assumption that 60% of cell phone calls are made while driving and that each call has the same value regardless of whether it is made while driving, Hahn and Tetlock concluded that the economic cost of banning such calls would be approximately $25 billion. Finally, they noted that the elasticity of demand (-0.17 to -0.84) and the proportion of cell phone time reflecting use while driving (40–70%) yield consumer surplus values ranging from approximately $10–87 billion.

Redelmeier and Weinstein(8) estimated the value of cell phone calls as the area under the demand curve for this service between zero demand and the level of demand at the time of their study. They characterized the demand curve using data from a large Canadian cell phone service provider. At the then-current price per minute of $0.38 (1997 U.S. dollars), Redelmeier and Weinstein estimated an average per minute value of $0.47, suggesting a consumer surplus value of $0.09 per minute. Based on the assumption that 35 million individuals each make two minutes of calls while driving each day, Redelmeier and Weinstein(8) estimated the total value of calls (rather than the consumer surplus value) made while driving to be 35 million drivers × 2 minutes/driver-day × 365 days/year × $0.47/minute, or around $12 billion annually.

We use the Hahn and Tetlock(7) result ($25 billion annually, range of $10–87 billion) as the basis for our estimate of the value of cell phone calls made while driving because the methodology they used to extend the Hausman(24) study ensured control for shifts in the demand and supply curves over time. We update the Hahn and Tetlock(7) estimate by adjusting it for inflation (1999 to 2002) and by scaling it proportionally by the increase in the number of cell phone users during the same period (77 million in 1999 to 128 million presently). These adjustments produce a central estimate value of $43 billion annually (range of $17–151 billion annually) and correspond to an annual consumer surplus value per cell phone user of $340 (range: $130–1,200).

Scaling by the number of users assumes that the surplus value per incremental user is the same as the average surplus value for users in 1999. There are a number of reasons to believe this is not the case. For example, marginal users who adopt the technology last are likely to have the lowest surplus value, which is why they did not adopt the technology earlier. However, if the new users adopted the technology because of a drop in prices, the surplus value for the preexisting users will increase. Finally, there may have been a shift in the demand for the technology. The availability of substitute technologies would tend to move the demand curve down, decreasing consumer surplus. On the other hand, technological improvements (e.g., increased geographical coverage, clearer calls due to the introduction of digital services) and complementary technologies (e.g., computers that can communicate via cell phone) would tend to shift the demand curve up. Although we do not treat these sources of uncertainty quantitatively, we note that the range of plausible values already spans nearly an order of magnitude due to other sources of uncertainty.

4. ESTIMATES OF ECONOMIC EFFICIENCY AND RISK

4.1. Economic Efficiency

The annual value of the benefits gained by eliminating crashes caused by cell phone use would amount to \$43 billion (range: \$9–193 billion). The value of the eliminated calls would also amount to \$43 billion (range: \$17–150 billion). Hence, net benefits would amount to a loss of \$220 million (range: loss of \$142 billion to a gain of \$175 billion). The central estimate result suggests that banning cell phone use while driving is virtually a break-even proposition, with the net loss per user amounting to less than \$2 per year. However, the plausible range of values for this result is large, with annual net benefits ranging from a loss of \$1,100 per user to a gain of \$1,400 per user.

The annual value of the benefits gained that are not reflected in the prevention of lost QALYs would amount to \$7.0 billion (range: \$2.1–23 billion). Per cell phone user, this estimate amounts to \$55 annually (range: \$17–180). The number of QALYs saved annually would amount to 94,000 (range: 12,000–770,000), which corresponds to 7.3×10^{-4} per cell phone user (range: 9.4×10^{-5} to 6.0×10^{-3}). The central estimate for the CE ratio is \$380,000 per QALY (range: less than zero to \$13,000,000 per QALY).

4.2. Risk

The revised analysis estimates that eliminating the use of cell phones while driving would reduce the number of crash events by approximately 6% (range: 2–21%). In particular, the central estimate changes would translate into the annual prevention of 330,000 total injuries, 12,000 serious to critical injuries (AIS-3 to AIS-5), and 2,600 fatalities. We further characterize the nature of the fatality risk by quantifying its voluntary and involuntary components.

4.2.1. Voluntary Fatality Risk

We define the voluntary fatality risk associated with cell phone use to be the amount by which the average cell phone user increases his or her risk of being killed in a motor vehicle crash. The value of ΔR for these individuals can be calculated using Equation (2). The value of T_{cp} (from Section 3.1.3) is 77 billion minutes per year (range from 38–150 billion minutes per year). The value of T_{Total} must be reduced to reflect time driven only by drivers with cell phones. Because cell phone users represent 128 million individuals and there are 191 million licensed drivers in the United States,(25:back cover) we assume T_{Total} for this population is (128 million $\div$ 191 million) $\times\ 4 \times 10^{12}$ minutes, or 2.7×10^{12} minutes. The baseline annual fatality risk for drivers is 25,492(25:Table 19) divided by 191 million drivers, or 1.3×10^{-4}. Hence, the incremental annual fatality risk is 13 per million cell phone users (range: 4–42 per million). Of course, the risk will be greater for individuals who spend more time on the phone while driving than average and smaller for individuals who spend less time on the phone while driving.

Table III. Cost-Effectiveness Ratios for Selected Highway Safety Investments[a]

Intervention	Target Population	Net Cost per Life-Year Saved[b]
Daytime running lights	All motor vehicles	<\$0[c]
Side door beams	Light trucks	\$53,000
55 mph speed limit	Rural interstate travelers	\$82,000
Add shoulder belts to lap belts (assuming 9% use) for rear outboard seats	Passengers using rear outboard seats	\$160,000
Cell phone restrictions	All drivers	\$380,000 (range: net savings to \$13,000,000)
Add shoulder belts to lap belts (assuming 9% use) for rear center seats	Passengers using rear center seats	>\$2,400,000

[a] For technical details on assumptions, input data, and primary references regarding specific interventions, see Graham *et al.*(27)

[b] Life-years saved have been adjusted to account for both enhanced life expectancy and improvements in quality of life due to reductions in morbidity and functional impairment due to trauma. The adjustments are based on the quality adjusted life year (QALY), a preference-based system that accounts for trauma severity and the health preferences of consumers for quality of life.

[c] In this case, the CE ratio is less than zero because the intervention both reduces the number of life years lost and saves money.

4.2.2. *Involuntary Fatality Risk*

We define involuntary fatalities to include nonmotorists and individuals not riding with the cell phone user (referred to here as "other-vehicle" fatalities). We exclude from this category passengers who ride with a driver who uses a cell phone based on the assumption that many of these individuals assume the attendant risk knowingly and voluntarily. On the other hand, some passengers may not be aware beforehand that the driver may use a cell phone, or may have no choice about riding with the driver (e.g., children). The number of such fatalities can be estimated as the product of ΔR (central estimate of 6% and range from 2–21%) and the number of baseline fatalities among nonmotorists and other-vehicle passengers.

We estimate that other-vehicle fatalities account for one-half of the fatalities resulting from multiple vehicle collisions. Evans(26) reported that in 1988 this proportion was 55%, suggesting that the baseline rate for other-vehicle fatalities is one-half of 55% × 40,676, or approximately 11,000. Nonmotorist fatalities accounted for 13.3% of all motor vehicle fatalities in 2000,(25:Table 53) suggesting that the baseline rate for this category is 5,400 per year. The total baseline fatality rate for other-vehicle passengers and nonmotorists is therefore 16,000. Multiplying by ΔR and dividing by the total population size (275 million) yields a risk ranging from 1 per million to 12 per million with a central estimate of 4 per million.

5. DISCUSSION

Unlike Hahn and Tetlock,(7) this analysis found that the central estimate for the net benefits of a ban on cell phone use while driving was close to zero and hence that the value of preventing crashes caused by cell phone use while driving is approximately equal to the value of the calls that would be eliminated by a ban. Our revision of the Hahn and Tetlock net benefit estimate was most influenced by two factors. First, we used Equation (2) and the relative risk estimate from Redelmeier and Tibshirani(8) in place of the crash contribution they had calculated using police crash report compilations. Although there are limitations to the Redelmeier and Tibshirani study, the police accident reports appear to suffer from more serious problems for the purpose of estimating risk (Section 3.1.1). Second, we increased the assumed consumer surplus value of the calls made while driving from \$25 billion to \$43 billion annually. This revision is based on several uncertain assumptions that may bias our estimate in either direction (Section 3.4), but was made in order to account for the increase in the number of cell phone users during the last several years. The total impact of our revisions on the net benefit estimate was large because we increased ΔR by a factor of 30 (from a central estimate of 0.002 to 0.06, see Table I) but increased the value of the foregone phone calls by less than a factor of two.

The CE ratio we calculated using central estimate values (\$380,000 per QALY saved) differed only moderately from the central estimate calculated by Redelmeier and Weinstein(8) (\$300,000 per QALY). Our revision of the Redelmeier and Weinstein(8) CE ratio was most influenced by two factors. First, we used the Hahn and Tetlock(7) scaled consumer surplus value (central estimate of \$43 billion) in place of the Redelmeier and Weinstein estimate of \$12 billion annually. The superior methodology of the Hausman(24) study that underlies the Hahn and Tetlock consumer surplus estimate (Section 3.4), and the fact that the Redelmeier and Weinstein cell phone usage estimates

Table IV. Voluntary Risk Factors Affecting Driver Fatality Rates[a]

Risk Factor	Annual Time or Miles During Which Risk Factor is Applicable	Annual Fatalities per Million Drivers
Driving while using a cell phone	600 minutes (range: 300–1,200)	13 (range: 4–44)
Driving with a blood alcohol concentration at the legal limit of 0.10% for one-half hour, 12 times per year (hypothetical)	360 minutes	31
Driving without wearing a lap and shoulder belt (assumes vehicle has airbags)	Always	49
Driving in a small car instead of a large car (1,000-pound difference in weight)	Always	15
Driving 60 miles once per year on a noninterstate rural roadway rather than on a rural interstate highway	one hour (60 miles)	1.5

[a] Technical details for the computation of all entries except the first row are provided in Lissy *et al.*(9)

Table V. Involuntary Risk Factors Affecting Fatality Risks

Risk Factor	Annual Fatalities per Million Individuals in the U.S. Population
Motorist struck and killed by driver using cell phone	4 (range: 1–12)
Sober driver struck and killed by driver with a nonzero blood alcohol concentration	18
Motorist and other roadway users struck and killed in crash involving large truck	17
Person struck and killed on ground by accidental airplane crash	0.013
Pedestrian struck and killed in motor vehicle crash	22

Note: Technical details for the computation of all entries except the first row are provided in Lissy *et al.*(9)

are now substantially out of date, makes us confident that our revised estimate is an improvement. However, we note the uncertainties described in the preceding paragraph. The second influential factor is our assumed increase in time spent on the phone while driving (central estimate of 77 billion minutes annually vs. 26 billion minutes annually). Although the absolute magnitude of this parameter is highly uncertain, it is virtually certain that it has increased substantially since 1997 (the timeframe reflected in the Redelmeier and Weinstein analysis). These two revisions influence the CE ratio in the opposite direction, a factor that helps to explain why the overall impact of our revisions was modest.

Our revised CE ratio of $380,000 per QALY is also somewhat lower than the $700,000 per QALY CE ratio that we reported in an earlier version of this analysis described by Lissy *et al.*(9) That value was also calculated by revising assumptions made by Redelmeier and Weinstein.(8) There are three differences between the revisions in this article and the Lissy *et al.* revision. First, this article updated the Hahn and Tetlock(7) consumer surplus value. Second, we incorporated the Blincoe(19) injury and crash estimates, which are adjusted to account for unreported crash events and are therefore less likely to be biased downward. Third, we took into account the NHTSA(18) survey findings (which had not yet been published when Lissy *et al.* was released) to estimate time spent on the phone while driving. This direct observation study may be biased but does not suffer from the problems that complicate recall surveys such as the PCIA(3) study relied on by Lissy *et al.*

Whereas the sign of the net benefits calculation provides an indication of a policy's desirability (in terms of economic efficiency), there is no direct way to determine if a CE ratio is large or small without comparing it to other CE ratios. Although the CE ratios listed in Table III(27) for other injury prevention programs are also highly uncertain, they suggest that there are actions that could be taken that would save lives lost in motor vehicle crashes at a lower economic cost than a ban on cell phones. This finding is consistent with the conclusion reached by Redelmeier and Weinstein that "Regulations restricting cellular telephone usage while driving are less cost-effective for society than other safety measures."(8:1) The fact that the net benefits of the ban are close to zero and yet there are other more efficient motor vehicle safety

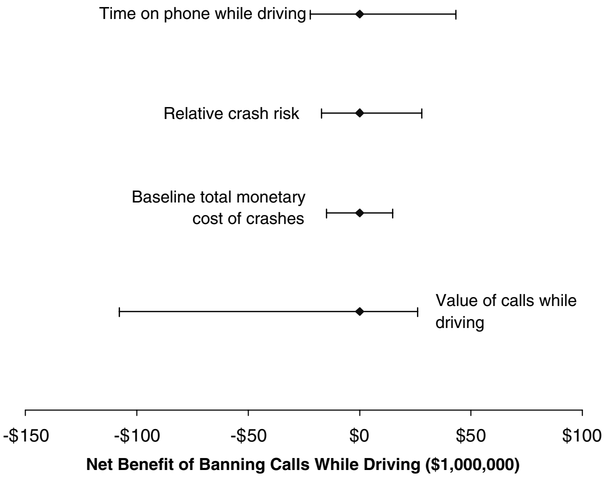

Fig. 1. Sensitivity analysis for the net benefits calculation.

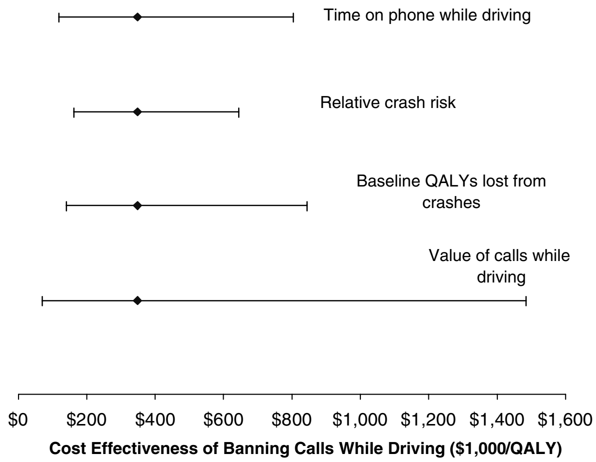

Fig. 2. Sensitivity analysis for the CE ratio.

measures that are not yet implemented indicates that as a society we are underinvesting in motor vehicle safety.

Just as the CE ratio for a particular intervention must be compared to other CE ratios, the magnitude of the voluntary and involuntary risks must be compared to other risk values to provide context. Table IV compares the risks assumed by the average cell phone user to the risks associated with other hypothetical voluntary behaviors. Lissy *et al.*(9) detailed the calculation of these other risk estimates. We note that these other behaviors are subjectively defined, as is the assumed amount of time spent for each behavior (also reported in Table IV). Table V (based on calculations in Lissy *et al.*(9)) compares involuntary risks averaged over the entire population.

The analysis here also indicates that both the benefit-cost estimate and the CE ratio are very uncertain (net benefits ranging from a loss of $142 billion annually to a gain of $175 billion annually, and CE ratio ranging from as high as $13 million per QALY saved to negative values indicating savings of both resources and QALYs). Univariate sensitivity analysis for the net-benefits estimate and CE ratio (Figs. 1 and 2, respectively) indicates that the most influential parameter in both cases is the assumed consumer surplus value of the calls made while driving. For the CE analysis, the next two most influential parameters are the assumed time spent on the phone while driving and the baseline value for QALYs lost due to all automobile crashes. For the net-benefits estimate, the relative importance of the other assumptions is smaller. For both estimates, the risk parameter (which reflects only stochastic factors) is the least influential parameter.

ACKNOWLEDGMENTS

This study was funded by unrestricted grants made to the Harvard Center for Risk Analysis (HCRA). Earlier work on this topic by HCRA was funded by a grant from AT&T Wireless Services (Redmond, WA).

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