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Validating Benefit and Cost Estimates: The Case of Airbag Regulation

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Preregulation estimates of benefits and costs are rarely validated after regulations are implemented. This article performs such a validation for the mandatory automobile airbag requirement. We found that the original 1984 model used to estimate benefits became invalid when 1997 values were input into that 1984 model. However, using a published 1997 cost-effectiveness model, we demonstrate, by replacing the model inputs with the values from 1984, that the 1997 cost-effectiveness ratios, based on real-world crash data and tear-down cost data, are less attractive than what would have been originally anticipated. The three most important errors in the 1984 input values are identified: the overestimation of airbag effectiveness, the overestimation of baseline fatality/injury rates, and the underestimation of manual safety belt use. This case study, which suggests that airbags are a reasonable investment in safety, shows that the regulatory analysis tools do not always produce findings that are biased against health, safety, and environmental regulation. Future validation studies of health, safety, and environmental regulation should focus on validation of benefit and risk estimates, areas where we found significant error, as well as on cost estimates.

KEY WORDS: Cost-benefit analysis; cost-effectiveness analysis; modeling; validation; risk analysis

1. INTRODUCTION

Regulatory agencies are increasingly required to support major regulatory decisions with a comparison of the costs and benefits of alternative strategies (Clinton, 1993; OMB, 1996). Recent studies suggest that the quality of regulatory analysis at agencies is uneven (Hahn *et al.*, 2000) and that the influence of such analysis on the decisions of regulators is sporadic but considerable (Morgenstern, 1997). Since analytical efforts to predict the consequences of a regulation can be challenging, it would be useful to know whether preregulation estimates of benefit and cost are valid and, if errors occur, what types of errors tend to be the most frequent and significant.

Despite the extensive interest in regulatory analysis, the validation literature in this field is quite limited, and the few existing validation studies reveal substantial errors in preregulation estimates of cost. OSHA's early vinyl chloride regulation proved far less expensive to industry than was originally anticipated (OTA, 1995; Mendeloff, 1988). EPA rules phasing out ozone-depleting chemicals (Hammitt, 1997) and reducing sulfur-oxide emissions from stationary sources (Stavins, 1998) have proven to be less costly than expected. In a recent review of 20 or so validation studies, analysts concluded that errors of cost overestimation tend to occur more frequently than errors of cost underestimation (Harrington, Morgenstern, & Nelson, 2000). These findings from retrospective cost studies, coupled with the notion that many regulatory benefits are intangible or not quantifiable, have fostered the view that quantitative economic evaluations

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of health, safety, and environmental regulation tend to be biased against regulation (Tolchin & Tolchin, 1983; NRDC, 1995).

In fact, we are not aware of many published articles that validate preregulation estimates of human health, safety, or environmental benefits, though there have been several agency-sponsored efforts to validate estimates of regulatory benefits. Validation of the cost-effectiveness estimates of some medical interventions showed consistent results in the cases of pertussis vaccination (Hinman & Koplan, 1985) and delivery decisions for mothers with herpes (Binkin & Koplan, 1989).

Our interest in performing a validation analysis of the airbag rule was stimulated by previous work on the airbag rule and the many years of political controversy surrounding it, including several actions by Congress and a pro-airbag decision by the U.S. Supreme Court (Graham, 1989). Technically speaking, the rule in question, Federal Motor Vehicle Safety Standard Number 208 (FMVSS 208), is a performance standard that requires vehicle manufacturers to provide a minimum level of automatic occupant-crash protection to front-seat passengers in frontal crashes. However, Congress ultimately transformed the rule into a design standard that required industry to install airbags that met specified performance criteria. When airbags were mandated in 1984, the true costs and rates of effectiveness of this safety device were uncertain and no hard bases existed for judging what the long-run marginal cost of the device would be once full economies of scale were achieved. Moreover, insufficient real-world data existed to make statistically precise projections of airbag effectiveness and thus the estimated numbers of lives saved and injuries avoided were based primarily on experimental crash tests and engineering judgment. Regulatory analysts nonetheless made estimates in the midst of such scientific uncertainty, estimates that strongly influenced the thinking of academic analysts (Arnould & Grabowski, 1981; Graham & Henrion, 1984). The vehicle manufacturing industry, however, submitted much more pessimistic estimates to the National Highway Traffic Safety Administration (NHTSA) in several rule-making proceedings, estimates that NHTSA chose to discount. For example, in 1977, when NHTSA proposed to require that all new cars be equipped with passive restraints by 1983 based on the results of a cost-benefit analysis that suggested passive restraints (airbags or automatic belts) could prevent on the order of 9,000 fatalities per year, NHTSA noted that General Motors provided comments that suggested a very different estimate of less than 3,000 lives saved by full-front airbags (42FR34292). In this article, we compare what was projected in 1984 by NHTSA (NHTSA, 1984b) to what was known as of 1997 as revealed in a comprehensive cost-effectiveness analysis of airbags published in the peer-reviewed medical literature (Graham *et al.*, 1997).

This analysis also builds on our retrospective analysis of the lifesaving effectiveness of airbags (Thompson *et al.*, 1999) that explored the causes for the overestimation of airbag lifesaving benefits, but did not address the validation of the cost or cost-effectiveness estimates. In this article, we extend prior work by exploring whether preregulation estimates of cost and cost effectiveness of airbags were valid and how these estimates changed over time.

2. ANALYTIC APPROACH

Initially, we sought to update the NHTSA's 1984 model (NHTSA, 1984a), which included more than 50 inputs to validate that model, and compare estimates of airbag costs and benefits using more recent data with the data available in 1984.

2.1. Original 1984 Model

The 1984 model for estimating airbag costs included three components: actual equipment costs, replacement costs, and lifetime energy costs. Using this model, the savings associated with airbags were all computed in terms of reductions in insurance premiums (including medical savings). The estimates of reductions in insurance premiums were based on three components: auto and health insurance savings, auto insurance loss, and life insurance. A preliminary analysis suggested that the life insurance costs and additional auto insurance costs were both relatively small and unchanged in magnitude based on updated inputs, so they are not discussed further.

However, the estimates of auto and health insurance savings in the 1984 model depended on the effectiveness of the airbags. NHTSA (1984a) took the general approach of assessing the average annual premium amount paid per vehicle (AAP) that could be reduced associated with fewer payments due to avoided fatalities and injuries. The model estimated the AAP by dividing the value of passenger car liability premiums by the number of cars with such coverage, and multiplying this by the percent of the premiums associated with personal injury coverage and the percent of the premiums that is associated with claims. NHTSA (1984a) used several equations to estimate "safety factors" for airbags and belts and to find the incremental "increase in safety," which was multiplied by the average annual premium to determine annual savings. NHTSA (1984a) assumed that the proportions of the insurance premiums associated with the different injuries would be 10% for fatalities, 75.6% for Abbreviated Injury Scores (AIS) 2–5, and 14.4% for AIS 1 and weighted effectiveness estimates accordingly. For example, NHTSA used a weighted effectiveness of safety belts of $0.45 * 0.1 + 0.5 * 0.756 + 0.1 * 0.144 = 43.7\%$. Weighted estimates for effectiveness of airbags ranged from low to high values depending on the effectiveness rates used for the airbags. However, using 1997 inputs in this same analysis, we found negative numbers for the incremental airbag safety factor, implying that the presence of airbags would increase insurance premiums because the equations did not work over the entire range of possible effectiveness. We concluded that this approach would not yield a fruitful comparison of cost estimates for this validation effort. Based on this realization, we decided to implement a different approach.

2.2. Using 1984 Inputs in a 1997 Model

Given our inability to apply the original 1984 model forward, we decided to rely on the cost-effectiveness model published in 1997 (Graham *et al.*, 1997) with two sets of input values: those published by NHTSA in 1984 and those published by Graham *et al.* (1997) based on real-world crash data and tear-down engineering cost studies. The deterministic state-transition model is used to track a hypothetical cohort of new vehicles over a 20-year period (representing the assumed maximum life of a vehicle). Three policy options are compared: (1) installation of manual safety belts, (2) installation of driver airbags in addition to safety belts, and (3) installation of passenger airbags in addition to driver airbags and safety belts. We do not address automatic safety belts, which were an option that NHTSA considered in 1984, because Congress ultimately prohibited their use as a method of regulatory compliance.

Our approach estimates net costs (gross capital and operating costs of airbags minus savings in health-related costs in 1993 dollars) and net effectiveness (quality-adjusted life years saved or QALYs). This approach follows the recommendations of a recent Panel on Cost-Effectiveness in Health and Medicine commissioned by the U.S. Department of Health and Human Services (Gold *et al.*, 1996). We take a societal perspective, meaning that all resource costs and safety consequences are counted, regardless of which members of society incur them.

Each policy option is evaluated using an incremental cost-effectiveness ratio, where the key summary figure is the net cost of the policy option per QALY saved compared to the next best alternative option. The reader is left to make his or her own determination about whether the resulting cost-effectiveness ratios represent a reasonable societal investment in safety. We do compare the estimated cost-effectiveness ratios for airbags to the ratios reported in the medical literature for several commonly accepted public health and clinical measures. We also cite, from the economics literature, estimates of what informed consumers might be willing to pay to enhance their level of safety, although our analysis does not apply a strict dollar value to each QALY saved. Since the early 1980s, NHTSA has not used cost-benefit analysis due to the significant ethical and scientific controversy about the monetization of lives saved and injuries avoided.

The cost-effectiveness model requires about 50 input values, approximately 30 of which are explicitly reported in NHTSA's 1984 regulatory impact analysis. For the remaining 20 input values, we apply the same values in 1997 and 1984 since NHTSA made no estimate in 1984 that can be subject to validation. For example, in 1984 NHTSA did not collapse fatalities and injuries into a unitary measure of effectiveness and thus the assumptions we make about the relative valuation of nonfatal injuries and fatalities (QALYs) are the same in 1984 and 1997. Moreover, vehicle lifetimes and scrappage rates are assumed to be the same in 1984 and 1997, even though they may have changed. Another important behavioral assumption that is maintained in both analyses is that the presence of an airbag does not alter driving behaviors or crash frequencies. Some economists and psychologists question this assumption, but no conclusive evidence exists to support the theory of offsetting risk-taking behaviors in the case of airbags. If such risk compensation is occurring, however, this behavior change could lead to errors in estimating the benefits of the safety device.

Our approach focuses on generating two sets of cost-effectiveness ratios, one using the 1997 inputs and the other using the 1984 inputs, and explores the differences between these using single-variable sensitivity analysis. This sensitivity analysis approach relies on changing one input at a time to its 1997 value while all other variables are held constant at their 1984 values and assessing the change in the cost-effectiveness ratio. Through this approach, we identify which 1984 inputs, when used in this model, induced the most significant errors in estimation of the costs and benefits of airbags using a cost-effectiveness ratio when compared to the 1997 estimates.

Our analysis considers only state-of-the-art airbag designs marketed to consumers from model years 1987 to 1997. Beginning in model year 1998, many airbag systems were depowered to reduce risks to children, small-statured adults, and any out-of-position occupants. Insufficient data exist to assess the benefits, risks, and costs of depowered airbags. Second-generation, "smart" airbags are not analyzed due to insufficient real-world experience. Consumers have also been offered the option of disconnecting their airbag systems if the consumers fall into specified at-risk groups, but few consumers have requested such permission. Thus, for both 1984 and 1997 we assume that 100% of airbag systems will be "fully powered" and armed to deploy in frontal crashes as designed by vehicle manufacturers in accordance with FMVSS 208. Because there is considerable variation in airbag design among manufacturers, we interpret the 1984 and 1997 estimates to be representative of the average airbag design installed in new vehicles from model year 1987 to model year 1997.

3. INPUT VALUES

Table I reports the model inputs for 1984 and 1997 that are used to compute costs, effectiveness (QALYs saved), and cost-effectiveness ratios. Numerous differences exist between the 1984 and 1997 values but only some of them prove to be important in the cost-effectiveness analysis. In this article, all estimates of costs and cost effectiveness are expressed in 1993 U.S. dollars.

Airbag costs include three components: actual equipment costs for high-volume production, replacement costs (after a crash that deploys the airbag), and maintenance costs (an inspection after 10 years to make sure the airbag is operational). Estimates of actual equipment costs, based on tear-down studies, are slightly smaller than what NHTSA projected in 1984. Airbag replacement costs are in the same ballpark as projected. The observed airbag-deployment rate is about double what NHTSA projected in 1984, which influences the magnitude of the airbag-replacement costs. No inspection costs were quantified in 1984.

Savings in health-care costs attributable to airbags are based on airbag-effectiveness estimates (discussed below), associated consumption of health-care resources, and charges for physician, hospital, and long-term care services estimated in NHTSA's cost-of-injury studies published in 1983 and 1996 (Blincoe & Luchter, 1983; Blincoe, 1996). Health-care cost inputs are disaggregated by injury severity using the American Association for Automotive Medicine's Abbreviated Injury Scale. Health-care costs of treating injuries were underestimated in 1984, but this may reflect vagaries in the Consumer Price Index for medical care (Newhouse, 1992), as well as actual resource consumption. We used a real rate of discount of 3% in the 1997 cost-effectiveness analysis to express future costs in terms of present value, following the recommendation of Gold *et al.* (1996). We note, however, that in 1984 NHTSA used a discount rate of 5%, and this is reflected in Table I.

The baseline fatality and injury rates in 1984 and 1997 are based on actuarial data reported by NHTSA's national fatality and injury data systems. They are lower in 1997 than in 1984. Safety-belt use rates in 1997 are much higher than NHTSA assumed in 1984. When airbags were mandated in 1984, NHTSA was not optimistic that rates of manual safety-belt use, then hovering near 10%, could be increased.

Estimates of safety belt and airbag effectiveness in 1997 are based on real-world crash data and an analytic method called double-pair comparison. Evans (1986a, 1986b) present the analytic basis for the double-pair comparison method, which is now well accepted in the field of traffic safety, and estimates that safety belts are about 45% effective in reducing fatalities. This method, in the case of driver airbags, compares the ratio of driver to passenger fatalities in vehicles with driver-only airbags (where both front seats are occupied) to the same ratio in vehicles with safety belts only. If the fatality ratios are equal, it is assumed that the driver airbag is 0% effective. In fact, the ratios are statistically smaller in cars with driver-only airbags, suggesting that the driver airbag is about 10% effective in reducing fatality risk (Kahane, 1996).

Between 1984 and 1997, the different interactions between children and adults with airbags became clear and necessitated different estimates of effectiveness as a function of age. Effectiveness estimates published for the passenger airbag show that children under age nine appear to be at increased risk of death due to airbag installation (Kahane, 1996; Braver *et al.*, 1997; Graham *et al.*, 1998a). As Table I

Table I. Inputs for 1984 and 1997

Variable	Inputs for 1997	Inputs for 1984	Source for 1984 Input
Event rates			
Fatality rate per million vehicle-yrs, No.			
Driver	115	197	NHTSA, 1984b
Dual	36	74	NHTSA, 1984b
Ratio of MAIS 2–5 injuries to fatalities	16.8	14	NHTSA, 1984a:VII-9
Airbag deployment rate per 1,000 vehicle-yrs	4	8	NHTSA, 1984a:VII-24
Percent of MAIS 2–5 by			
MAIS 2	777.6	64.7	NHTSA, 1984a:II-2
MAIS 3	18.6	28.6	NHTSA, 1984a:II-2
MAIS 4	3.0	5.0	NHTSA, 1984a:II-2
MAIS 5	0.8	1.7	NHTSA, 1984a:II-2
Target population, %			
Drivers > 64 yr	16.2	16.1	NHTSA, 1984b
Front passengers < 10 yr	5.3	9.9	NHTSA, 1984b
Front passengers > 10 yr	21.6	16.3	NHTSA, 1984b
Intervention effectiveness rate, %			
Occupant safety belt use	50	12.5	NHTSA, 1984a:V-47
Safety belts	45	43.7	NHTSA, 1984a:VII-11
Airbags for adults 10–64 yr	13	31	NHTSA, 1984a:VII-10 (excludes AIS1)
Airbags for adults > 64 yr	5	31	NHTSA, 1984a:VII-10 (excludes AIS1)
Airbags for children < 10 yr	−21	31	NHTSA, 1984a:VII-10 (excludes AIS1)
Costs (1993 $)			
Safety belt	57	39	NHTSA, 1984a:VIII-25
Airbag installation driver	278	330	NHTSA, 1984a:VIII-2, 33
Dual	410	465	NHTSA, 1984a:VIII-2, 33
Airbag replacement driver	664	825	NHTSA, 1984a:VII-31
Dual	1452	1163	NHTSA, 1984a:VII-31
Airbag maintenance driver	25	0	Not considered
Dual	50	0	Not considered
Fatality, total cost (1993 $)	99,992	48,260	Blincoe, 1983:8
Injury, lifetime costs (1993 $)			
MAIS 2	13,884	4,564	Blincoe, 1983:8
MAIS 3	46,469	11,344	Blincoe, 1983:8
MAIS 4	137,116	48,071	Blincoe, 1983:8
MAIS 5	440,802	205,909	Blincoe, 1983:8
Weighted average	27,057	12,101	
Discount rate (%)	3	5	NHTSA, 1984b:VIII-25
Quality-of-life weights	Same values as used by Graham *et al.* (1997)		

Note: 1997 inputs listed for comparison only, taken directly from Graham *et al.*, 1997.

reveals, airbag-effectiveness estimates are smaller in 1997 than projected in 1984.

4. RESULTS

In both analyses, safety belts are an attractive investment: only $1,800 per QALY saved based on 1984 inputs; belts are actually cost saving using the 1997 inputs. Table II reports the total and incremental costs and QALYs saved, in addition to the cost-effectiveness ratios, for the airbag policy options compared to the *status quo* of safety belts. The incremental cost-effectiveness ratios for driver and "dual" (passenger plus driver) airbags are $10,000 and $11,000, respectively, based on the 1984 inputs. The corresponding ratios are $24,000 and $61,000, respectively, using the 1997 inputs.

Although the updated ratios based on real-world data are less attractive than the 1984 ratios, they are comparable to or less than the cost/QALY ratios reported for many well-accepted medical and public health interventions. For comparative purposes, Table III provides a summary of some ratios reported by Graham *et al.* (1998b). Note that these comparisons

Table II. Estimated Cost-Effectiveness Ratios (1993 $/QALY) Using the 1997 and 1984 Inputs from Table I for a Cohort of 10 Million Vehicles

Intervention	Total Cost ($)	Total Effectiveness (QALYs Saved)	Incremental Cost ($)	Incremental Effectiveness (QALYs Saved)	Incremental Cost/Effectiveness ($/QALY)
1997 Inputs, 3% Discount Rate (Results from Graham *et al.*, 1997)					
Belts	($1,356,809,000)	219,629			
Driver airbag	$853,135,000	312,735	$2,209,944,000	93,106	$24,000
Dual airbags	$2,184,474,000	334,531	$1,331,339,000	21,796	$61,000
1984 Inputs, 5% Discount Rate					
Belts	$104,529,000	56,165			
Driver airbag	$2,386,983,000	286,107	$2,282,454,000	229,942	$10,000
Dual airbags	$3,360,212,000	374,902	$973,229,000	88,795	$11,000

do not explicitly factor in other attributes that might be important in the context of such comparisons, including the voluntary and/or controllable nature of the risk, etc. The airbag-investment ratios are also reasonable when compared to published values of a statistical life year derived from economic studies of consumer and worker willingness to pay for safety (Viscusi, 1998). This literature suggests that investments of $100,000–500,000 per life year saved are compatible with consumer willingness to pay for safety. Although preregulation estimates of cost-effectiveness ratios now appear optimistic, the magnitude of the errors does not appear to be large enough to call into question the policy determination about economic efficiency.

The errors in preregulation estimates were, however, large enough to generate interest in what caused the errors. The single-variable sensitivity analysis reported in Table IV indicates that errors in economic estimation and selection of the discount rate are not responsible for most of the change in ratios from 1984 to 1997. The three largest contributors to error were (1) the overestimation of airbag effectiveness, (2) the overestimation of baseline fatality and injury rates, and (3) the underestimation of safety-belt-use rates. The first error, discussed in detail by Thompson *et al.* (1999), reflects the difficulty of making engineering judgments about the outcomes of real-world crashes based on experimental crash testing. In particular, the consequences (risks and benefits) of deploying airbags for some adults (unbelted, out-of-position, small statured) and children were not analyzed properly. The second error represents a failure to predict the progress in highway safety that has arisen from a series of unrelated improvements in highways, vehicles, drivers, and medicine (Graham, 1993). The third error reflects a miscalculation of the political feasibility of mandatory safety-belt-use laws in the

Table III. Estimated Cost-Effectiveness Ratios (1993 $/QALY) for Selected Public Health and Clinical Interventions (Graham *et al.*, 1998)

Intervention	Comparator	Target Population	Net Cost/QALY Saved
Compulsory helmet use	Voluntary helmet use	Motorcyclists	<0
Behavioral intervention to increase condom usage to prevent HIV transmission	No program	Self-identified gay men	<0
Restriction of cigarette sales to minors	No restriction	Children < 18	900
Percutaneous coronary angioplasty	No revascularization	Patients with severe angina and one-vessel disease	7,300–9,500
Pap smear every four years	No screening	Women 20–75	15,200
Mitigation of radon in homes	No testing or mitigation	Residents of homes with radon > 20 pCi/liter	54,000
55-mph speed limit	65-mph limit	Rural interstate travelers	78,000
Annual mammography	Annual clinical breast exam	Women 40–50	227,000
Screening to prevent HIV transmission to patients	Universal precautions	Health-care workers in an acute-care setting	465,000

Table IV. Single-Variable Sensitivity Analyses: Incremental Cost-Effectiveness Ratios (1993 $/QALY) Associated with Correctly Projecting the 1997 Value in 1984 (Holding All Other Inputs Constant at 1984 Values)

Input	Driver Ratio	Dual Ratio
1984 Estimates (for comparison)	$10,000	$11,000
Airbag effectiveness all	$33,000	$58,000
Airbag effectiveness ages 10–64	$27,000	$24,000
Airbag effectiveness for ages < 10	$10,000	$15,000
Airbag effectiveness for ages > 64	$11,000	$12,000
Fatality rates	$21,000	$28,000
Safety-belt-usage rates	$18,000	$20,000
Discount rate	$6,000	$7,000
Injury, lifetime costs	$2,000	$3,000
Fatality, total costs	$9,000	$10,000
Ratio of injuries to fatalities	$8,000	$9,000
Breakdown of MAIS	$11,000	$12,000
Airbag deployment rates	$9,000	$10,000
Airbag installation costs	$8,000	$11,000
Airbag maintenance costs	$10,000	$12,000
Airbag replacement costs	$10,000	$12,000
Target population	$10,000	$11,000

Note: By comparing the ratio with the 1997 to the 1984 estimates, this table shows which differences had the largest individual impacts on the cost-effectiveness ratio (i.e., a larger deviation suggests an error in the input estimate with a relatively larger impact on the results).

United States and the growth in safety-belt use that such laws stimulated (Graham, 1989).

5. DISCUSSION

This case study of the airbag mandate raises a variety of broader considerations that we believe should influence how the quality of regulatory analysis is assessed and how future validation studies are designed. We offer several propositions on these matters for consideration, recognizing that a single case study can only present ideas for testing by future studies and does not provide a basis for sweeping conclusions.

5.1. Proposition 1: Quality of Regulatory Analysis Might be Judged on Basis of Whether Decision-Analytic Conclusions Regarding Alternatives were Valid Rather than on Whether Particular Estimates of Input Values or Even Overall Benefit or Cost Estimates were Accurate

The airbag case study revealed numerous errors in regulatory analysis but these errors, taken together, did not challenge the central finding of the 1984 analysis: in the end airbags do appear to be a reasonable investment in safety based on their cost-effectiveness. Many of the errors uncovered (e.g., the underestimation of the airbag-deployment rate) did not have any significant consequence for the cost-effectiveness ratios and, from a policy perspective, one might defend the position that the right decision was made to mandate airbags, even if some of the model inputs were not correct. However, while the overall policy might not have changed, using this criterion requires that policymakers assume that errors will cancel out, an assumption that might not bear out in other cases, and that only the study conclusions matter, not information about the particular inputs. This could be problematic given Proposition 2, even though Proposition 1 is very attractive from an overall policy level.

5.2. Proposition 2: Ignoring Variability and Uncertainty in Regulatory Estimates can Lead to Missed Opportunities for Targeting Risk Reduction Strategies and Research

The airbag case study shows that by focusing on quantification of the net costs and benefits (which is required for proper economic analysis) and by implicitly ignoring variability in the population, decisionmakers may not sufficiently detect or address potential problems that might ultimately undermine the decision. In the case of airbags, NHTSA was aware of the use of rear-facing child-safety seats in the front seats of vehicles as early as 1984 (NHTSA, 1984b:VIII-11). However, the potentially deadly interaction between these seats and airbags was not anticipated or detected in the regulatory analysis. Similarly, the deaths of older children (ages five through nine) that have been attributed to airbags were not anticipated by experts, who assigned the same net airbag-effectiveness numbers to all members of the population. In 1997, estimates suggested that (on net) passenger airbags kill one child under age 10 for every five to 10 adults they save (Braver *et al.*, 1997; Graham *et al.*, 1997). The fact that airbags could cause injuries (as well as prevent them) and did so disproportionately for younger and smaller members of the population was at least partially responsible for the NHTSA's decision to allow manufacturers to depower airbags in 1997. Ignoring variability in the population clearly contributed to the overestimation of airbag effectiveness, and led to missed opportunities to inform passengers about risks (i.e., particularly risks for children and small adults).

From a risk-analytic perspective, the airbag case study also reveals the importance of considering the degree of uncertainty in estimates of risk and benefit (Thompson & Graham, 1996). The large amount of uncertainty associated with airbag-effectiveness estimates did not appear to be fully appreciated in this case. Consequently, opportunities to perform additional research on the effectiveness of airbags prior to their introduction in the entire vehicle fleet may not have been recognized, even though there were proposals to study demonstration fleets of cars with airbags prior to a fleetwide mandate (Graham, 1989). Neither regulatory nor academic analysts formally assessed the value of information from a demonstration fleet.

5.3. Proposition 3: Consistent with Findings in Other Analyses, it is Feasible for Regulators to Obtain Reasonably Accurate Estimates of Costs of Regulation to Industry and Consumers

The airbag case study did not uncover large errors in cost estimation. We suspect this is largely because NHTSA relied on cost information from airbag suppliers and from its own tear-down studies. Estimating the costs of airbag technology is not as simple as some people might think because of (1) the large economies achieved with mass versus limited production and (2) the progress achieved in reducing the cost of airbag inflators once a market was assured by regulation. Despite these complexities, NHTSA made reasonably accurate cost estimates. Cost estimation was simplified some in this case because Congress made the regulation a design standard by requiring airbag technology to be the sole compliance strategy. The economic complications associated with predicting firm-by-firm compliance with a performance standard were thereby removed, though the flexibility benefits of a performance standard were also removed. This case provides one more data point in a growing body of evidence on the accuracy of cost estimates (see Harrington, Morgenstern, & Nelson, 2000 for a review of 28 cases).

5.4. Proposition 4: Future Validation Literature Should Explore Potential Errors in Risk and Benefit Estimation, as Well as Cost Estimation

Instead of saving 9,000 lives per year as originally estimated, airbags may save 3,000 lives per year if all passenger vehicles are equipped with the first-generation device (Thompson *et al.*, 1999). This is certainly a nontrivial error in benefit estimation and it suggests that the public should not necessarily accept the accuracy of preregulation estimates of benefit. In future analyses, we believe that the risks induced by the regulation should also be considered. Preregulation estimates indicated that airbags would reduce fatality risk to children by 30% (the same effectiveness rate as adults). Yet recent real-world crash data indicate that passenger airbags are increasing net mortality risk among children. The potential for large errors suggests that it would be useful for future validation studies to consider the accuracy of preregulation estimates of benefit and risk as well as cost.

5.5. Proposition 5: Preregulation Findings of Economic Analysis Not Necessarily or Always Biased Against Health, Safety, and Environmental Regulation

In the recent legislative debate on regulatory reform, concern was frequently expressed that preregulation estimates of benefits and costs would typically be biased against health, safety, and environmental regulation (NRDC, 1995). This perception was rooted in part in concern that costs to industry would be exaggerated but also in concern that the benefits of regulations could not be quantified.

The airbag case study provides an important example where preregulation estimates of benefit and cost were quantified and led to a pro-regulation decision that has been validated based on real-world data. The evidence from the validation study suggests that the original analysis was biased in favor of mandatory airbags due to overly optimistic benefit estimates. Biases in regulatory analyses can be in either direction and we need a much larger sample of validation studies to draw any general conclusions about whether cost-benefit analysis is biased for or against health, safety, and environmental regulation.

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REFERENCES

Arnould, R. J., & Grabowski, H. (1981). Auto safety regulation: An analysis of market failure. *Bell Journal of Economics*, *12*, 27.

Binkin, N. J., & Koplan, J. P. (1989). The high cost and low efficacy of weekly viral cultures for pregnant women with recurrent genital herpes: A reappraisal. *Medical Decision Making*, *9*, 225–230.

Blincoe, L. J. (1996). *The economic cost of motor vehicle crashes*. Washington, DC: U.S. Department of Transportation.

Blincoe, L. J., & Luchter, S. (1983). *The economic cost of motor vehicle crashes*. Washington, DC: U.S. Department of Transportation, NHTSA.

Braver, E. R., Ferguson, S. A., Greene, M. A., & Lund, A. K. (1997). Reductions in deaths in frontal crashes among right-front passengers in vehicles equipped with passenger airbags. *Journal of the American Medical Association*, *278*, 1437–1439.

Clinton, W. (1993). Executive Order 12866: Regulatory planning and review. *Federal Register*, *58*, 51735.

Evans, L. (1986a). Double-pair comparison—A new method to determine how occupant characteristics affect fatality risks in traffic crashes. *Accident Analysis and Prevention*, *18*, 217.

Evans, L. (1986b). The effectiveness of safety belts in preventing fatalities. *Accident Analysis and Prevention*, *18*, 229–241.

Gold, M. R., Siegel, J. E., Russel, L. B., & Weinstein, M.C. (1996).*Cost-effectiveness in health and medicine*. New York: Oxford University Press.

Graham, J. D. (1989). *Auto safety: Assessing America's performance*. Westport, CT: Praeger.

Graham, J. D. (1993). Injuries from traffic crashes: Meeting the challenge. *Annual Review of Public Health*, *14*, 515–543.

Graham, J. D., Corso, P. S., Morris, J. M., Segui-Gomez, M., & Weinstein, M. C. (1998a). Evaluating the cost-effectiveness of clinical and public health measures. *Annual Review of Public Health*, *19*, 125–152.

Graham, J. D., Goldie, S. J., Segui-Gomez, M., Thompson, K. M., Nelson, T., Glass, R., Simpson, A., & Woerner, L. (1998b). Reducing risks to children in vehicles with passenger airbags. *Pediatrics*, *102*(1), e3.

Graham, J. D., & Henrion, M. A. (1984). A probabilistic analysis of the passive-restraint question. *Risk Analysis*, *4*, 25–40.

Graham, J. D., Thompson, K. M., Goldie, S. J., Segui-Gomez, M., & Weinstein, M. C. (1997). The cost-effectiveness of airbags by seating position. *Journal of the American Medical Association*, *278*, 1418–1425.

Hahn, R. W., Burnett, J. K., Chan, Y. I., Mader, E. A., & Moyle, P. R. (2000). *Assessing the quality of regulatory impact analyses*. Working paper 00–01. Washington, DC: AEI-Brookings Center for Regulatory Studies.

Hammitt, J. K. (1997). Stratospheric-ozone depletion. In R. D. Morgenstern (Ed.), *Economic analyses at EPA: Assessing regulatory impact, resources for the future* (ch. 6, pp. 131–169). Washington, DC: RFF Press.

Harrington, W., Morgenstern, R. D., & Nelson, P. (2000). On the accuracy of regulatory cost estimates. *Journal of Policy Analysis and Management*, *19*(2), 297–322.

Hinman, A. R., & Koplan, J. P. (1985). Pertussis and pertussis vaccine: Further analysis of benefits, risks, and costs. *Development of Biological Standards*, *61*, 429–437.

Kahane, C. J. (1996). *Fatality reduction by air bags: Analyses of accident data through early 1996*. Washington, DC: U.S. Department of Transporation, NHTSA.

Mendeloff, J. (1988). *The dilemma of toxic substance regulation: How overregulation causes underregulation*. Cambridge, MA: MIT Press.

Morgenstern, R. D. (1997). *Economic analyses at EPA: Assessing regulatory impact*. Washington, DC: Resources for the Future.

National Highway Traffic Safety Administration (NHTSA). (1984a). *Amendment to Federal Motor Vehicle Safety Standard 208 Passenger Car Front Seat Occupant Protection, Federal Regulatory Impact Analysis*. Washington, DC: U.S. Department of Transportation.

National Highway Traffic Safety Administration (NHTSA). (1984b). *Traffic safety facts 1983*. Washington, DC: U.S. Department of Transportation.

Natural Resources Defense Council (NRDC). (1995). *Breach of faith: How the contract's fine print undermines America's environmental success*. Washington, DC: Natural Resources Defense Council.

Newhouse, J. P. (1992). Medical care costs: How much welfare loss? *Journal of Economic Literature*, *6*, 3–21.

Office of Management and Budget (OMB). (1996). *Economic analysis of federal regulations under Executive Order 12866*. Washington, DC: Executive Office of the President.

Office of Technology Assessment (OTA). (1995). *Gauging control technology and regulatory impacts in occupational safety and health: An appraisal of OSHA's analytic approach*. Washington, DC: OTA.

Stavins, R. N. (1998). What can we learn from the grand policy experiment? Lessons from SO_2 allowance trading. *Journal of Economic Perspectives*, *12*(3), 69–88.

Thompson, K. M., & Graham, J. D. (1996). Going beyond the single number: Using probabilistic risk assessment to improve risk management. *Human and Ecological Risk Assessment*, *2*(4), 1008–1034.

Thompson, K. M., Segui-Gomez, M., & Graham, J. D. (1999). Validating analytical judgments: The case of the airbag's lifesaving effectiveness. *Reliability Engineering and System Safety*, *66*(1), 57–68.

Tolchin, S. J., & Tolchin, M. (1983). *Dismantling America: The rush to deregulate*. Boston, MA: Houghton Mifflin Co.

Viscusi, W. K. (1998). *Rational risk policy*. Oxford: Clarendon Press.