Classics in Risk Management
Volume I

Edited by

W. Kip Viscusi

John F. Cogan Jr. Professor of Law and Economics
Harvard University, USA

and

Ted Gayer

Assistant Professor of Public Policy
Georgetown University, USA

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Cheltenham, UK • Northampton, MA, USA
Introduction

W. Kip Viscusi and Ted Gayer

The management of health and safety risks became a salient policy concern in the 1970s. Since that time the importance of health, safety, and environmental regulations has become so great that they comprise the largest share of all regulatory costs in the United States as well as in many other countries. These regulatory ventures raised new questions for economists as well. If the government is going to intervene, when should it do so and to what extent? Determining the level of stringency has proven to be more problematic than the framers of regulatory policy envisioned in that they failed to recognize that achieving zero risk was not a feasible goal.

The considerable economic literature that has emerged over the era of societal risk management has been stimulated in part by these policy initiatives. Economics in turn has also provided valuable guidance for enhancing the design and performance of regulatory policy. This set of collected papers brings together many of the most influential contributions that have shaped the subsequent economic literature and continue to provide guidance for policy management. Among the key concerns is how the benefits of risk reduction policies should be valued. Given that a zero-risk goal is not feasible, the regulatory process requires that we attach a value to the reduced risks to life and health in order to properly address the tradeoffs inherent in risk reduction decision making. However, the benefit value may also depend – among other things – on the extent of life at risk, raising sensitive issues pertaining to the role of age adjustments. Examination of such benefit assessment issues is the focus of Volume I.

In Volume II we turn to a wide range of issues linked to regulatory performance. Whether risk regulations on balance are in fact health enhancing can be assessed using the tools of risk-risk analysis and by undertaking studies of regulatory performance. The inability of command and control regulations to be effective in some contexts has led to the adoption of warnings policies as a regulatory tool. Informational regulations and the public’s response to situations of risk ambiguity will continue to be critical regulatory concerns as they are closely linked to policy design issues with respect to newly emerging risks. We discuss these issues and how they are addressed within this collection in the sections that follow.

Volume I, Part I

Efficient regulation of health risks is achieved when the net benefits of the risk reduction are maximized. Thus, determining whether a regulation is efficient requires reliable estimates of the costs and benefits of the proposed regulation. Indeed, even policy processes that do not take efficiency as their objective often require that there be an assessment of the benefits and costs of the different policy options. Estimating regulatory costs is straightforward methodologically, though difficulties sometimes arise in projecting future compliance costs. Estimating benefits
is generally believed to be a more difficult two-step process. The first step is to estimate the health effects that would result from the regulation. The second and perhaps more difficult step is to convert the estimated health benefits into dollar values so that they can be compared to the regulatory costs. For example, after estimating the human health effects of different arsenic levels in drinking water by using animal bioassay analysis, one must then calculate the dollar value of these risk reductions to see if the regulatory benefits are commensurate with the costs. Only then can one determine the efficient reduction of arsenic in drinking water.

The value of the benefit for any policy is society’s willingness to pay for these benefits. In the case of risk management efforts this benefit is the value society attaches to the reduced probability of some adverse health outcomes. As a consequence, what is of interest is the value of reduced risks or the statistical lives that will be saved, where this value ideally should be in monetary terms to be commensurate with cost amounts.

Converting risk reductions into monetary values is often a controversial undertaking. However, even if policymakers and regulators were to avoid confronting this task explicitly, any regulation that does not make an unbounded commitment to safety implicitly places a finite value on the risk reduction. Explicitly monetizing the value of risk reduction allows for a reasoned and transparent approach to evaluating and setting risk regulations.

Historically the dominant approach to valuing fatalities for regulations was based on the procedure used to compensate victims in personal injury cases. In particular, the value of life was related to the present value of a person’s earnings. This shortsighted approach may have a reasonable foundation from an insurance standpoint, but it is not linked to the risk-money tradeoff that people have for small risks.

The first analysis to put this line of research on sound footing was that by Schelling (Volume I, Chapter 1), who indicated that the value of risk reductions to the individual is the person’s willingness to pay for decreases in risk. Subsequent researchers have generalized this individual value of risk reduction to values that should be applied in the policy realm. Unlike most consumer goods, risks are not traded explicitly in markets. Rather, these health risks are tied to implicit trades as health risks are bundled with other attributes of jobs or consumer products. This aspect of health and safety risks complicates the task of estimating individuals’ willingness to pay for reductions in risk.

The articles in Part I track the initial debate and development of the welfare economic approach to valuing health risks. Schelling’s early paper develops the willingness-to-pay approach in which he describes the difference between the value of preventing a certain individual death versus the value of preventing a statistical death. A statistical death occurs when there is an increase in the risk to a certain population, which leads to the death of one person who is unidentifiable a priori.

Mishan (Volume I, Chapter 2) formalizes the valuation of changes in risk within a welfare-economic framework. He shows that the criterion of achieving a potential Pareto improvement (i.e., a reallocation in which the net gains can be redistributed so that at least one person is made better off with no one being made worse off) would require that a death be valued by reference to the individual’s compensating variation (i.e., the minimum sum the person is prepared to accept for the death). Given that policies deal with statistical risks (and not certain, identifiable deaths), he demonstrates how the pertinent value is the sum of each individual’s compensating variation for avoiding a risk of fatality, which leads to the concept of the value of a statistical life.
Zeckhauser (Volume I, Chapter 3) questions Mishan's reliance on potential Pareto improvement as the guiding criterion. His concern is that this criterion presumes that compensation from the winners to the losers is feasible, thus resulting in an outcome in which no one is made worse off. While Zeckhauser does not specifically propose an alternative model, he does caution against trying to obtain unequivocal answers to the value of health risks; instead, the aim should be for benchmarks and guidelines to help the policy process.

One approach to ascertaining the willingness to pay values for greater safety is to simply ask people what these amounts are. While well-constructed surveys can serve a useful foundation, obtaining meaningful responses requires that the survey reconstruct a simulated market transaction. An alternative approach that has dominated the literature has been to estimate the implicit value of risk reduction that individuals reveal through their own risk-taking decisions. The studies in Part I provide an overview of this approach that is explored with greater specificity in later sections of this volume.

The dominant statistical approach has been to analyze the equilibrium set of tradeoffs observed in the market, where this relationship is known as the hedonic function. These analyses focus on choices made in labor, housing, or product market transactions. The articles in Part II focus on the hedonic wage model of labor markets, which will be extended to other markets in later sections. The articles in Part III rely on housing or product market transactions in order to estimate the benefits of risk reduction. These articles are discussed in more detail below. Other papers included in Part I explore some of the nuances with respect to establishing values of statistical lives. The article by Michael W. Jones-Lee (Volume I, Chapter 6) explores how altruistic concerns with other people's lives should be taken into account in a proper economic analysis. Similarly, the chapter by Johannesson et al. (Volume I, Chapter 8) examines the discrepancy between the private value of safety to the individual versus the value more generally to the public. In each case, the focus is on statistical lives. Why identifiable and statistical lives differ in terms of their valuation is the focus of the paper by Jenni and Lowenstein (Volume I, Chapter 9).

Estimates of the risk-money tradeoff from market decisions may have additional implications as well. In the paper by Viscusi and Moore (Volume I, Chapter 5), they show that the wage-risk tradeoff from the market can be used to determine whether the level of social insurance being provided through workers' compensation is at the optimal level. For example, very low rates of wage offset in response to higher workers' compensation benefits would imply that workers do not value such compensation amounts to the same extent as their actuarial cost, which in turn would imply that benefit levels are too high. Viscusi (Volume I, Chapter 7) offers an overview of the empirical issues surrounding value-of-life studies and reviews the literature of these empirical works.

**Volume I, Part II**

The hedonic wage model examines the set of equilibrium outcomes generated by labor supply and labor demand in order to estimate the average rate of tradeoff between wages and job risk, controlling for other aspects of the job. The hedonic wage function is the locus of tangencies formed by the optimizing behavior of both firms and employees. It is consequently incorrect to refer to this relationship as reflecting worker preferences alone. Figure 1 illustrates this
interaction. The curves FF and GG are isoprofit curves, or offer curves, for two different firms. They illustrate the various combinations of job risk and wages that have the same level of profits for the firm. These isoprofit curves rise at an increasing rate as risk levels are reduced. Since reducing risk is costly, wages must be lower at higher levels of safety to keep the firm at the same level of profits. The wage offer curves are consequently increasing functions of risk. Different firms have different production functions, which is why the isoprofit curves differ for the two firms illustrated in the figure. The outer envelope of these offer curves is the market opportunity locus facing workers.

The standard economic model of the supply side is that workers optimize in accordance with a von Neumann-Morgenstern expected utility model with state-dependent utilities. Suppose that utility depends on one’s wages \( w \), and that utility in the unhealthy state \([V(w)]\) occurs with probability \( p \), and utility in the healthy state \([U(w)]\) occurs with probability \( 1 - p \). If there is a workers’ compensation program for the unhealthy state, these payments are typically functions of the wage rate. The functional form for \( V(w) \) captures this influence. The curves \( EU_1 \) and \( EU_2 \) represent indifference curves for two different workers. They are derived by assuming a fixed level of expected utility, \( Z \), and by then tracing out various combinations of \( p \) and \( w \) that keep utility constant at \( Z \). This set of combinations satisfies the following equation:

\[
Z = (1 - p)U(w) + pV(w).
\]  (1)

The wage-risk tradeoff along this curve is given by the following equation:
\[
\frac{\partial w}{\partial p} = \frac{U(w) - V(w)}{(1 - p)U'(w) + pV'(w)}
\]  

(2)

If we assume that individuals prefer being healthy to being unhealthy \([U(w) > V(w)]\) and that the marginal utility of income is positive \([U'(w) > 0, V'(w) > 0]\), then equation (2) is positive, indicating a positive slope of the expected utility functions diagramed in Figure 1. The two different expected utility curves in the figure differ due to different preferences of the two workers.

The hedonic wage function is formed by the tangencies of the firms’ offer functions and the workers’ constant expected utility loci. The workers each select the available risk-wage bundle that maximizes their expected utility. Firms, on the other hand, select the available risk-wage bundle that maximizes their profits. The firms’ offer functions serve as a constraint on the workers’ expected utility optimization decision, and the workers’ bid functions serve as a constraint on the firms’ profit optimization decision. Each hired employee therefore represents the tangency of a bid and an offer function, and the locus of these tangencies forms the hedonic wage function, depicted as XX in the figure. The points \((p_1, w_1)\) and \((p_2, w_2)\) represent two such points along the hedonic wage function.

In an empirical hedonic analysis, the economist only observes points on the hedonic wage function, not the points on the expected utility functions. Since the latter reflect individual preferences, one would ideally want to estimate the structural expected utility functions in order to obtain accurate welfare measures of changes in risk. For example, suppose that the risk to the first worker changes from \(p_1\) to \(p_2\). The wage increase the worker requires to accept this risk increase is \(w_1(p_2) - w_1(p_1)\). However, applying the hedonic price function to this change in risk yields an estimate of \(w_1(p_2) - w_1(p_1)\), which underestimates the worker’s true willingness to accept. By fitting a curve through the wage and risk data, the economist estimates the hedonic wage function, which provides estimates of the local willingness to pay values for marginal changes in job risk (which will also equal the willingness to accept values for small changes in risk). These wage-risk tradeoffs serve as the basis for estimates of the value of statistical life, since such estimates are based on marginal changes in risk.

In the special case where all workers had the same preferences, then there would be only one expected utility curve in Figure 1, and the observable points on the hedonic wage function would be the same as the points on the expected utility curve. Such a situation would generate empirical estimates that would provide information on valuations of both marginal and infra-marginal changes in risk. Likewise, if each firm had the same production function, then the hedonic price function would be the same as each firm’s offer curve, and one could easily estimate the costs to the firm of marginal and infra-marginal changes in risk. Unfortunately, the typical (yet more realistic) assumption is that workers and firms are heterogeneous. Therefore, in order to estimate infra-marginal changes, one would need to estimate the expected utility functions, which is a considerably more difficult task.

While some studies have attempted to estimate the structural expected utility equations, the more frequent approach is to estimate the first-stage hedonic wage function. Most policies aim to reduce health risks by small amounts so that the marginal willingness to pay derived from a hedonic price function serves a useful purpose of estimating welfare effects and deriving the value of a statistical life. The value of a statistical life is given by equation (2) and is the average willingness to pay for a reduction in risk divided by the risk reduction. Therefore, if a
policy would reduce risk by 1 in a million, and the affected population is willing to pay an average $6 for this risk reduction, then the value of a statistical life is $6 million. By using actual labor market decisions to estimate the hedonic wage function, one can then use the estimated changes in wages due to a small change in risk in order to estimate the value of a statistical life.

Each of the articles in Part II uses labor market data to estimate the hedonic wage function. The paper by Thaler and Rosen (Volume I, Chapter 10) was one of the early empirical analyses to estimate the compensating differentials for risk using individual data. They use risk data from the 1967 Occupation Study of the Society of Actuaries. These data measure risks associated with very high-risk occupations. To the extent that people more willing to bear risk tend to select into such occupations, the empirical results will underestimate the population-wide wage-risk tradeoff. Their estimates suggest a value of a statistical life of $16,000 to $260,000 (1967 dollars).

Viscusi (Volume I, Chapter 11) uses a more representative sample taken from the 1969–1970 University of Michigan Survey of Working Conditions and couples it with different risk measures in order to estimate compensating differentials for risk. His analysis also uses a self-assessed measure of whether the worker believes the job to be dangerous. The advantage of this measure over an objective measure of job risk is that it reflects the subjective beliefs of the workers, which is the pertinent measure that motivates individual behavior. The analysis also estimates separate specifications in which the variable of interest is the number of disabling injuries per million hours worked in the worker's industry. The results suggest that workers who perceive their job as dangerous earn an annual premium of $375, and they receive an additional $26 each year for a one-point increase in the frequency of disabling injury per million hours worked. That paper also explores the negative relationship between worker wealth and risk levels, which is a relationship that comprises the key component of the risk-risk analyses discussed in Volume II, Part V.

Estimates of the value of statistical life may vary intentionally because of differences in worker wealth and preferences as well as different offer curves from the demand side of the market. If the hedonic function is nonlinear over income, then heterogeneity of income across countries would lead to different estimates of the marginal willingness to pay for risk reduction. Moreover, institutional labor market differences across countries, such as the level of unionization and government involvement in setting wages, could generate structural differences in the hedonic wage functions across these countries. The article by Kniesner and Leeth (Volume I, Chapter 12) examines whether compensating differentials vary across Australia, Japan, and the United States. They find that workers exposed to the average Japanese manufacturing fatality rate receive only 0 per cent to 1.4 per cent higher pay than they would in a perfectly safe Japanese manufacturing industry. However, their small sample limits the precision of the estimates. They find a rather robust compensating differential of 2.5 per cent for Australian workers. They have a considerably larger sample for their U.S. estimates, and they find a 1 per cent compensating differential for risks in the manufacturing industries.

The value of a statistical life is also likely to vary across different sub-populations. Thus, a benefit-cost analysis of a risk-reducing policy aimed at a certain sub-population would need a reliable estimate of the risk-dollar tradeoff for that group, assuming one wanted to assess population-specific benefit values. Disaggregating differences in risk valuations is difficult to
accomplish, especially since most risk and wage data aggregate across sub-populations. For example, most wage hedonics studies rely on industry-level risk data; however, if women tend to select safer jobs within industries, then matching industry risk to female workers’ wages will lead to misleading estimates of the risk-dollar tradeoff. Hersch (Volume I, Chapter 13) uses gender-specific estimates of injury and illness on an occupational level in order to estimate the compensating differentials for women. She finds that women are in fact exposed to substantial risks of injury and that the value of a statistical injury or illness for women ranges between $20,000 and $30,000.

The value of a statistical life will also differ across groups that value risk differently. That is, people who are relatively more risk loving will select different risk levels along the hedonic wage function, and they are likely to have differences in their wage-risk tradeoff. If different preferences for risk affect workers’ behavior, then the nature of the labor market opportunities may differ as well. Viscusi and Hersch (Volume I, Chapter 14) test this hypothesis using smoking behavior as a proxy for risk preferences. They find that smokers choose jobs in higher risk industries as one might expect, but that they have a sufficiently lower wage-risk tradeoff so their total risk compensation is less than that of non-smokers in safer jobs. The set of results for smokers and non-smokers is inconsistent with the standard model of compensation differentials in which workers select different points off a common offer curve. What these findings suggest is that there are distinct labor market equilibria for smokers and non-smokers, as these two groups are selecting jobs from different opportunity loci. Thus, the standard theory of compensating differentials must be generalized to take into account that different segments of the population may be selecting jobs from quite different labor market offer curves.

Volume I, Part III

The value-of-statistical life estimates obtained from labor market studies are pertinent when considering health-reducing policies in the labor market. For example, a benefit-cost analysis of a job safety policy that reduces the on-the-job risk of asbestos exposure may rely on labor market studies in order to estimate the benefits of the policy. However, it is not always warranted to use labor market estimates of the value of a statistical life to estimate the benefits of non-labor market risk reductions, such as environmental protection or transportation safety. For any individual, the marginal value of a statistical life should be equalized across different domains of choice. However, the preferences of people bearing the risk may differ depending on differences in the exposed populations. The ideal approach is to use market transactions of the affected population in order to estimate the risk-dollar tradeoff. Some researchers also suggest that the character of the fatal events may differ, which in turn will affect risk valuations. Fatal job accidents may not be tantamount to environmentally induced cancers.

For reductions in environmental health risks, studies typically rely on hedonic property models, which are analogous to wage hedonic studies. The logic behind such models is that, all things equal, houses that have higher exposure to environmental risks will have lower equilibrium prices. Figure 2 is similar to Figure 1, except that it shows the market relationship between housing price, \( h \), and household environmental risk exposure, \( p \). In this case, the firms are the suppliers of the houses, whereas the residents are the demanders of the houses. If we
assume that the representative consumer purchases one house, then the consumer maximizes the following expected utility function:

\[ \text{Max } Z = (1 - p)U(x, s) + pV(x, s), \]

where \( p \) is the health risk, \( U \) is utility in the healthy state, \( V \) is utility in the unhealthy state, \( s \) is a vector of characteristics of the house, and \( x \) is a composite good. The consumer is constrained by the following equation, in which \( y \) is the consumer’s income and \( h \) is the price of the house:

\[ y = x + h(p, s). \]

The price-risk tradeoff along the expected utility curves is given by the following equation:

\[ \frac{\partial h}{\partial p} = \frac{V(x, s) - U(x, s)}{(1 - p)U'(x) + pV'(x)}. \]

Given the assumptions that for any given level of income people prefer being healthy \([U(w) > V(w)]\) and that marginal utility of income is positive \([U'(w) > 0, V'(w) > 0]\), this equation indicates that the price-risk tradeoff is negative, as illustrated in Figure 2.

As with the labor market hedonic model, hedonic property model studies estimate the locus of tangencies formed by the optimizing behavior of sellers and buyers of houses. For an increase in risk from \( p_1 \) to \( p_2 \), the appropriate willingness to accept measure is \( h_1(p_2) - h_1(p_1) \).
However, the hedonic price function underestimates this value by estimating \( h_2(p_2) - h_1(p_2) \). Again, the hedonic property model does provide accurate welfare estimates for marginal changes in risk.

One of the primary difficulties of estimating hedonic property models is the problem with obtaining measures of the health risks to each of the pertinent households. In contrast, the Bureau of Labor Statistics, the Society of Actuaries, and the National Institute for Occupational Safety and Health regularly publish estimates of various job risks. No such data sets are readily available for household exposure to environmental risks. As a result, hedonic property models typically rely on distance to the environmental disamenity as a proxy for the health risk. The distance proxy is an imperfect measure for a number of reasons: it does not consider weather patterns and geographical contributors to risk exposure; it does not allow for a straightforward aggregation of risk from multiple sources; it conflates health risk with other disamenities associated with the environmental problem, such as aesthetic problems; and it does not consider variations in exposure pathways that are only weakly correlated with distance.

What's more, an estimation of the price-distance relationship does not lend itself to estimates of the value of a statistical life. It therefore is more difficult to use such studies in a benefit-cost analysis of a proposed reduction of environmental risk.

Nonetheless, if the objective is to estimate the benefits of removing a neighborhood disamenity, such as a hazardous waste site, the use of the distance proxy can be very useful. Smith and Desvousges (Volume I, Chapter 20) estimate a partial equilibrium model of demand for distance from a landfill with hazardous wastes. Since they use a survey instrument, they are able to estimate the structural willingness to pay function, rather than the approximation of the hedonic price function. They find that the average household would gain a consumer surplus between $330 and $495 (1984 dollars) annually for each additional mile their house is from the landfill. McClelland, Schulze and Hurd (Volume I, Chapter 22) also survey residents near a landfill; however, they solicit opinions on the subjective neighborhood risk and residents' perceptions of such things as the odor of the site. They find that subjective risk differs from the expert assessments, and that the housing market decreased in value by about $40.2 million (1984 dollars) from the landfill.

Portney (Volume I, Chapter 16) devised a creative way of estimating the hedonic property function with respect to air pollution risk by coupling together estimates from previous studies. He starts by assuming a simple model in which housing price, \( h \), is a function of (among other things) the risk of death from air pollution \( R \), which in turn is a function of air quality, \( Q \). That is, \( h = h[R(Q)] \). Differentiating and rearranging terms leads to the following hedonic price function: \( \partial h / \partial R = (\partial h / \partial Q) / (\partial R / \partial Q) \). In other words, the price gradient with respect to risk is equal to the effect of air quality on price divided by the effect of air quality on health risk. He obtains estimates of each of these terms on the right-hand side of the equation from different studies and combines them to find that the implied value of a statistical life for people under 45 is between $377,000 and $567,000 (1978 dollars).

Gayer, Hamilton and Viscusi (Volume I, Chapter 24) were the first to incorporate explicit measures of household environmental risk within the hedonic property model. They examine the housing market in greater Grand Rapids, Michigan – a housing market that contains a number of hazardous waste sites. By calculating the excess cancer risk to each household and aggregating risks across hazardous waste sites, they estimate a hedonic property model that yields estimates of the price-risk tradeoff. They find that after being informed of the risks from
the hazardous waste sites, the implicit value placed on avoiding a statistical cancer case was approximately $4 million. This finding is consistent with estimates of the value of a statistical life derived from labor market studies.

The study by Brookshire et al. (Volume I, Chapter 18) also analyzes a hedonic property model, although they focus on the price effects due to risks from earthquakes. The independent variable of interest in their hedonic model is whether the house is located in a Special Studies Zone (SSZ), which is an area designated by the state as having elevated relative earthquake risk determined by potentially and recently active earthquake fault traces. They find that housing prices increase by $4650 (1978 dollars) in Los Angeles County if a house is located outside of the SSZ, and housing prices increase by $2490 in the Bay Area if a house is located outside of the SSZ. They use these estimates to make a strong case that residents engage in self-insuring behavior that is consistent with the expected utility model.

The other papers presented in Part III of Volume I estimate hedonic models for a variety of product markets. The underlying model behind these studies is similar to the labor and housing hedonic models. Blomquist (Volume I, Chapter 15), Atkinson and Halvorsen (Volume I, Chapter 21), and Dreyfus and Viscusi (Volume I, Chapter 23) use measures linked to motor-vehicle safety decisions in order to estimate the value of a statistical life. They find estimated values consistent with those found in labor market studies. Ippolito and Ippolito (Volume I, Chapter 17) use changes in consumption of cigarettes over time as the risk information changes in order to estimate the price-risk tradeoff. They estimate a value of a statistical life of $300,000 to $600,000 (1980 dollars). This comparatively low value is consistent with smokers being more willing to bear risk.

All the articles we have considered thus far use market data in order to estimate the risk-dollar tradeoff. Another way to estimate these tradeoffs is by using a survey in which the respondents are asked their values for different changes in risk. The survey approach has the advantage of obtaining estimates for the structural willingness to pay for non-marginal changes in risk, as illustrated in Figure 1. However, the main shortcoming of surveys is that, unlike the market approach, they rely on hypothetical questions, which are subject to strategizing and biases. Nonetheless, we include in Volume I the article by Jones-Lee, Hammerton and Philips (Volume I, Chapter 19), which is an early survey approach to estimate the value of a statistical life. Interestingly, policy analyses in the United Kingdom have relied primarily on values of statistical life from surveys rather than market studies because the market estimates for the UK have often been quite high and unstable.

**Volume I, Part IV**

Individuals who are at risk differ in terms of the length of life that is being exposed to risk. There are also important lifecycle effects that may affect people's attitudes toward risk. Estimation of a single value of life for the population assumes that an elderly person values a risk reduction the same as a young person, even though the latter is likely to forego more life years should the risk materialize. The articles in Part IV seek to address this concern by computing the tradeoff between dollars and the discounted lost life years due to the health risk. That is, the appropriate independent variable in the hedonic model is the expected years of life lost, and this value must be discounted to reflect the greater utility placed on life lived now
relative to life years later. The easiest way to account for years of life lost is to interact the risk variable with the age of the individual. Thaler and Rosen (Volume I, Chapter 10) and others have used this approach and found that the price-risk gradient decreases with age. However, this formulation doesn’t account for the role of discounting.

The appropriate measure for the discounted loss of life expectancy should take the following form:

\[ p(1 - e^{-rT})/r, \]

where \( p \) is the fatality risk, \( r \) is the rate of discount, and \( T \) is the remaining period of life. Moore and Viscusi (Volume I, Chapter 25) include this expected loss in life expectancy in the hedonic equation instead of the job risk variable and find an estimated rate of time preference of 10–12 per cent with respect to expected life years. They find an estimate of the implicit value per life year that ranges between $171,000 and $195,000 (1986 dollars).

Viscusi and Moore (Volume I, Chapter 27) develop a model of lifetime job choice and derive a functional form for the worker’s decision to engage in potentially hazardous work. They use a Markov decision model of lifetime choice of job risks in order to estimate the discount rate people place on future life years and find that workers discount future life years by 11 per cent.

Part IV also includes other studies of the role of discounting with respect to years of life. These estimates often vary across studies, but they tend to be in a much more reasonable range than similar estimates of implicit rates of time preference, such as those that have been estimated for differences in energy efficiency of appliances. Using such differences in the quantity adjusted value of a statistical life for policy purposes remains much more controversial than the use of average values of statistical life. Moreover, the various studies included in Part IV address these discounting issues for adults, but do not examine the role of discounting for people at the tails of the population, such as young children and the elderly. These groups are often those most vulnerable to environmental risks.

**Volume II, Part I**

The articles in Volume I establish how economists would value risk reductions from regulatory policies. Using these values as a guide, one can set the stringency of regulations in a way that balances the competing effects. By comparing the benefits to the costs of the regulations, one can arrive at the efficient outcome in which net benefits are maximized.

By contrast, the articles in Volume II start out by assuming an imperfect world in which efficient regulation is not attainable. There are many impediments to efficient regulation; most notably, many environmental and health regulations in the United States are based on legislation that seemingly forbids the use of benefit-cost analysis in establishing standards. For example, the Clean Air Act states that ambient standards for common air pollutants cannot be set in a manner that considers compliance costs and should be set at levels that provide an ‘adequate margin of safety’. Standards for hazardous air pollutants should be set at levels that provide an ‘ample margin of safety’. The Federal Water Pollution Control Act of 1972 established that all of the nation’s water bodies should be ‘fishable and swimmable’. The Occupational Safety and Health Act (OSHA) of 1970 set a goal ‘to assure so far as possible every man and woman
in the Nation safe and healthful working conditions’. At face value, the legislative terminology gives very little leeway for agencies to use benefit-cost analysis in promulgating its standards. Indeed, the legislation also makes no mention of cost considerations.

Given the stringent nature of the legislative goals, the question of whether benefit-cost analysis is allowed has frequently been the object of judicial challenges. For example, the Supreme Court ruled in 1981 that the legislative mandate for OSHA is to achieve a regulatory goal that is ‘capable of being done’, rather than one that passes a benefit-cost test. In its 1999 ruling on the setting of national ambient air quality standards (NAAQS), the D.C. Court of Appeals ruled that the Environmental Protection Agency (EPA) ‘is not permitted to consider the cost of implementing standards’, thus forbidding the use of benefit-cost analysis.

In contrast to the legislation and judicial review that frequently precludes benefit-cost analysis, all presidential administrations since Ronald Reagan have required an analysis of regulatory costs within the decision-making process. President Reagan’s Executive Order 12291, issued in 1981, required that agencies explicitly consider the costs involved in a ‘major rule’ (i.e., one with an annual effect on the economy of $100 million or more). The order stated, ‘Regulatory action shall not be undertaken unless the potential benefits to society for the regulation outweigh the potential costs to society.’ To oversee this process, the order transferred regulatory oversight to the U.S. Office of Management and Budget’s Office of Information and Regulatory Affairs (OIRA). President Clinton’s Executive Order 12866, issued in 1993, stated, ‘Each agency shall…propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs.’ Thus, the current regulatory framework is inconsistent in that the executive branch requires the use of benefit-cost analyses in the promulgation of regulations, yet the legislation frequently prohibits it.

Even when legislation does not forbid the use of benefit-cost analysis, its use is sometimes restricted due to the distrust many regulatory officials have in the process. Also, while benefit-cost analysis leads to efficient regulation, it does not in itself address the equity concerns of different regulations. Thus, where compensation from the ‘winners’ to the ‘losers’ of a given regulation is impossible, the efficiency criterion may be a lesser concern in the regulatory framework, and the need for monetizing the health benefits is lessened.

Given that the regulatory policy cannot be subjected to a requirement that benefits exceed costs, is there some weaker test that might be applied to eliminate the most inefficient regulations? Surely regulations for risk and the environment should on balance be safety-enhancing for them to be considered warranted. Assessing these net risk effects has come to be known as risk-risk analysis.

Volume II, Part I, features this type of analysis. Whereas the efficiency criterion establishes the goal of maximizing net benefits, risk-risk analysis uses the less restrictive criterion that a health regulation should only be promulgated if it reduces the overall risks to society.

There are many ways in which a risk regulation could lead to a net increase in risk to society, and there are different levels of complexity involved in risk-risk analyses. A rudimentary risk-risk analysis would compare the risk reductions that would result from the regulation to the competing risk increases that result from the regulation. For example, a regulatory decision to ban the sale of the artificial sweetener saccharin might reduce cancer risk; however, if people then substitute sugar in place of saccharin, the resultant increases in obesity would pose an increase in health risk. The risk-risk regulatory criterion holds that the ban should only take place if the health improvements from reducing the cancer risk are greater than the diminishment
in health due to the increased incidence of obesity. Another example of multiple, competing risks resulting from a regulation would be the increase in occupational risks resulting from the transportation and installation of control technologies to reduce risks from emissions. In the risk-risk framework, any regulatory decision on whether to institute these control technologies would need to consider these competing risk increases.

A slightly more complex risk-risk analysis considers the offsetting behavior that would result from a proposed regulation. Some researchers refer to these consequences as moral hazard effects. The classic example of such compensatory behavior is presented in Peitzman’s (Volume II, Chapter 14) article on automobile safety. He found that the increased safety provided to drivers by vehicle regulations leads them to drive more recklessly, largely offsetting the risk reductions of the regulation and posing a net increase in risk to pedestrians. Thus, a risk-risk analysis of vehicle regulations would need to examine whether the net effect of the regulations is an increase or decrease in risk. These behavioral responses also influence the overall effect of the regulation on safety, which is the subject of Volume II, Part IV.

The most thorough and complex type of risk-risk analysis considers the health effects that result from the opportunity costs of a regulation. The promulgation of each regulation requires the allocation of scarce resources to the regulation, and diverting such resources results in a decrease in national wealth. Squandering resources on policies that have little beneficial effect has a real opportunity cost in that it takes funds that consumers otherwise could have spent in a more health-enhancing manner. Given the long-observed link between wealth and individual risk (see Viscusi, Volume I, Chapter 11), such a diversion of resources would result in an increase in health risks. That is, the empirical evidence suggests that risk reduction is a normal good; so as one’s wealth increases, one will spend more on healthful practices such as better nutrition and preventive care. Any decrease in wealth resulting from a regulation would therefore result in an increase in health risks. Thus, a risk-risk analysis of a government regulation must compare the health improvement to the indirect increase in health risk due to decreases in economic resources and the resulting reduction in the disposable income of individuals.

The articles featured in Part I all explore the link between wealth and risk in order to assess whether risk reductions meet the risk-risk standard. Their goal is to estimate the risk increase per dollar reduction in national wealth due to a regulation. Keeney (Volume II, Chapter 1) was the first to estimate the negative effects of regulations on fatality risks due to the opportunity costs of the regulations. Using estimates from other studies of the relationship between mortality rates and income, he considers both the cost of a regulation and the distribution of the burden of the cost as a function of income. He finds that a $12.3 million loss of income (1992 dollars) results in one statistical death. Lutter and Morrall (Volume II, Chapter 3) use international data on gross domestic product and mortality to estimate the wealth-mortality relationship, and they find that a loss of income between $8.0 million and $9.6 million will result in an additional statistical death.

The correlation between wealth and health is commonly accepted. What is subject to more debate is the direction of the causality: does wealth lead people to invest in and improve their health, or do healthier people tend to make more money? Chapman and Hariharan (Volume II, Chapter 2) attempt to disentangle these effects by controlling for initial measures of health, thus isolating the effect from wealth to health. They find that a $12.2 million loss of income results in one statistical death.
Risk-risk analyses seek to identify the dollar regulatory expenditure that leads to the loss of one statistical life. In contrast, the literature that was the focus of Volume I addressed how much people were willing to pay to save a statistical life. These magnitudes must be related, as the risk-risk amount must be below the willingness to pay amount or else all lifesaving expenditures on balance will be counterproductive.

To address this issue and to avoid the problems associated with estimating wealth-health linkages, Viscusi (Volume II, Chapter 4) develops a theoretical model that links the value of a statistical life with the health-wealth relationship. He shows that the regulatory expenditure that leads to a loss of a statistical life is equal to the marginal value of life divided by the marginal propensity spent on health, which is always below 1.0. For example, given an estimate for the value of a statistical life of $5 million and an estimated marginal propensity to spend on health of 0.1, any regulation that results in an income loss of more than $50 million will lead to a net increase in risk.

Lutter, Morral and Viscusi (Volume II, Chapter 5) generalize this model to include expenditures on harmful behavior, such as drinking and smoking, that result from income gains. Doing so reduces the estimate of the cost at which regulations become risk increasing to a level of approximately $20 million. Finally, Gertham and Johannesson (Volume II, Chapter 6) examine data from Sweden to estimate the cost at which regulations become risk increasing. They find that the income loss that induces an expected fatality is approximately $6.8 million when the costs are borne equally among all adults, $8.4 million when the costs are borne proportionally to income, and $9.8 million when the costs are borne progressively to income.

**Volume II, Part II**

The articles in Parts II–V examine the regulatory performance of health and safety regulations. To assess the overall benefits of a regulation, the analyst must couple the benefit of a risk reduction with the expected risk reduction that will result from the regulation. This yields a benefit estimate of the regulation that can then be compared to the regulatory costs, arriving at an efficient regulation in which net benefits are maximized. Typically, this assessment takes place before a regulation is promulgated. The case studies in Volume II address both such ex ante assessments as well as ex post assessments of performance.

Unfortunately, the regulatory record suggests that regulations seldom pass an efficiency test. As alluded to earlier, one reason for the regulatory shortcoming is that costs are often left out of the regulatory decision. Regulators often aim to eliminate lifetime fatality risks such as those that are as low as one in a million, no matter what the costs involved.

Morral (Volume II, Chapter 7) attempts to quantify this misuse of regulatory resources based on information generated in regulatory impact analyses. The heart of Morral’s paper is his analysis of 44 proposed, final, or rejected federal rules that were aimed at reducing mortality risks. Using information on the anticipated risks, benefits, and costs of the regulations provided by the agencies, he calculates the cost per life saved of each of the regulations. What is startling about his finding is the wide variation in cost per life saved across regulations. These values range from $100,000 cost per life saved for the National Highway Traffic Safety Administration’s (NHTSA) steering column protection regulation to $72 billion cost per life saved for the
Occupational Safety and Health Administration's (OSHA) formaldehyde regulation (costs in 1984 dollars). The exorbitant estimates of the cost per life saved for many regulations demonstrate the negative ramifications of failing to base regulatory standards on the efficiency criterion. Any reasonable benefit-cost analysis of the formaldehyde regulation would lead to the regulation not being adopted, since the cost per statistical life saved far exceeds the commonly accepted estimates of the benefit of a statistical life saved. Morrall's analysis makes clear the undesirable outcomes resulting from unsound regulatory policy. By shifting resources from the formaldehyde regulation to the steering column regulation, society can save many more lives for the same amount of money or, likewise, society can save the same number of lives for much less money.

There are a number of studies that question whether the risk assessment practices of regulatory agencies are misleading and lead to a misallocation of resources. For example, the multiplicative effect of using numerous conservative parameter assumptions significantly overstates the risk as discussed by Nichols and Zeckhauser (Volume II, Chapter 28). Another possible source of bias is the commonly used assumption that the relationship between the dose of the contaminant and the risk is linear. Also, some observers contend that regulatory agencies are more prone to regulate synthetic risks than natural risks, even though the former may pose a much smaller health threat.

In Part II, we offer the article by Ames, Magaw, and Gold (Volume II, Chapter 8) as representative of the considerable literature on cancer risks. They rank the risk from a variety of rodent carcinogens and find that many naturally occurring substances pose substantially greater risk than more frequently regulated pesticide residues and water pollution. For example, the main fumigant used for grain was banned even though the aflatoxin in the average peanut butter sandwich poses 75 times the risk of cancer. Such studies raise serious concerns about the performance of many health and safety regulations.

Volume II, Part III

According to economic theory, the government's role is not to aim to reduce all health risks to zero, but rather to regulate risks when a market failure leads to inefficient outcomes. Where health and safety risks are concerned, there are two prevalent market failures: (1) individuals are ill-informed about the risks they are exposed to, and (2) there exist externalities, in which economic activity is negatively affecting a third party not directly involved in any voluntary transaction involving the damage. In situations where people are fully informed of the risks and there are no externalities, then optimizing behavior will lead to an efficient outcome. Nonetheless, while efficiency implies that net benefits to society are maximized, it does not suggest the outcome is equitable. Distributional equity may be a legitimate component of a broadly defined efficiency test to the extent that society has a positive willingness to pay for such equity outcomes.

The early 1970s saw a wave of regulatory efforts aimed at addressing health and safety risks. The three biggest efforts by Congress to regulate risks were the establishment of the National Highway Traffic Safety Administration (NHTSA) in 1966, and the establishment of the Occupational Safety and Health Administration (OSHA) and the Environmental Protection Agency (EPA) in 1970. The underlying rationale for these regulations had little to do with any
explicit recognition of market failure. Instead, the regulatory approach adopted during this time was to seek technological solutions, such as capital investments in the workplace or changes in the safety design of automobiles, in order to reduce risks as much as possible with no regard to costs. In other words, the general approach was that risks are undesirable, and with the right technology they can and should be eliminated. This naïve approach led to unrealistic expectations, such as the claim by a co-sponsor of the Occupational Safety and Health Act, Representative William Steiger (R-Wis.), that by 1980 workplace injuries would be reduced by ‘fifty per cent or something like that’. Similarly, proponents of seatbelt standards promulgated by the National Highway Traffic Safety Administration (NHTSA) predicted that the occupant death rate due to car crashes would drop by 10 to 25 per cent within two years.

In the three decades since the creation of OSHA, NHTSA, and EPA, many researchers have examined the performance of these agencies. These analyses typically use three criteria to judge success: (1) whether the agencies’ regulations have been effective in reducing risks, (2) whether the agencies reduced risks efficiently (rather than the costs not justifying the benefits of the health improvement), and (3) where efficiency has failed, have the regulations been adopted cost-effectively (i.e., whether the same gains could not have been achieved at lower cost to society). Parts III, IV, and V of Volume II examine the performance of these agencies in regulating job risks, product risks and environmental risks, respectively.

Much of the literature on regulatory performance has focused on the weak effects of these efforts on safety. Regulations will only have a potential for influence if they establish incentives for compliance. Thus, the cost of compliance must be below the expected cost of noncompliance, which is equal to the product of the probability of inspection, the number of violations per inspection, and the penalties per violation. These incentives are in fact quite small for job safety regulation, which accounts for the very small impact of such efforts.

Smith (Volume II, Chapter 10) conducted an early analysis of the effectiveness of OSHA at reducing workplace injury rates. He uses plant-level data on inspections and injuries, coupled with plant-specific information. In his research design, plants inspected later in the year are used as a control group, since forces at work prior to the inspection predominantly affect their injury rates. His treatment group consists of firms inspected early in the year. His results suggest that OSHA inspections in 1973 reduced injury rates by about 16 per cent, but that 1974 inspections had no statistically significant effect.

Viscusi (Volume II, Chapter 11) considers the behavioral response to safety regulations. In the case of OSHA, higher expected penalties would increase firms’ investment in safety. However, a rational behavioral response by workers to increased safety equipment would be to decrease the level of care and precaution they take in their work actions. Thus, the effectiveness of OSHA regulations would depend on the net effect. Using a pooled time series (1972–1975) and cross section of industry health and safety investments, he finds that OSHA penalties did not have a significant impact on injury rates. More recent studies have shown some beneficial effect of OSHA on safety, but far less than the framers of these policies predicted.

Volume II, Part IV

The early performance of product safety regulation was also disappointing. Peltzman’s (Volume II, Chapter 14) article evaluating efficiency of seatbelt regulations failed to find a
risk reducing effect. Peltzman uses a time-series analysis of annual death rates, controlling for income, the price of an accident, alcoholic intoxication among the population, average driving speed, and the ratio of young drivers to older drivers. His findings suggest that any reduction in fatalities due to the vehicle regulations of the late 1960s and early 1970s is offset by an increase in pedestrian fatalities, which is consistent with there being a behavioral response to seatbelt regulations. A more recent analysis of highway safety by Keeler (Volume II, Chapter 17) uses county-level data from 1970 to 1980 in a first-difference model, which allows for a much richer analysis than using annual nationwide data. As with the Peltzman analysis, Keeler also finds very weak evidence of a regulatory effect on reducing traffic fatalities.

The behavioral response in the Peltzman model presupposed a rational moral hazard response to regulation. The consumer product safety analysis by Viscusi (Volume II, Chapter 16) takes a different approach in that it hypothesizes that consumers may be victims of a 'lulling effect'. Safety devices may give consumers a false sense of security and lead them to overestimate the efficacy of safety devices. Government officials, for example, routinely referred to safety caps as being 'childproof' not 'child resistant'. The result is that there is no observed beneficial effect of the regulation. In addition, there is an adverse spillover effect. Diminished parental responsibility regarding access to drugs by children that occurred after the advent of safety caps has led to increases in poisonings for acetaminophen products such as Tylenol.

There are two other articles in our collection that examine motor vehicle regulations. Arnould and Grabowski (Volume II, Chapter 15) conducted an early benefit-cost analysis of passive restraint systems. They find that automatic seat belts yield high benefits relative to costs, but that air bags were less advantageous due largely to their high costs. Finally, we include a recent article by Levitt and Porter (Volume II, Chapter 18) that analyzes the effectiveness of seat belts and air bags in reducing fatalities. Most of the previous analyses of this issue rely on data collected only for fatal crashes. Their innovation is recognizing that this can lead to sample selection bias, since the use of the safety device influences the likelihood of fatalities, which in turn determines whether the crash is included in the data set. In other words, if seatbelts reduce the likelihood of a fatality, then many crashes in which people were wearing their belts and thus did not die won’t be included in the data set, and the effectiveness of the seat belts will be underestimated. They address this problem by limiting the sample to crashes in which someone in a different vehicle dies. They find that seat belts are more effective and air bags are less effective than previously found.

**Volume II, Part V**

We include two articles that examine environmental regulation. Cropper et al. (Volume II, Chapter 19) examine whether the Environmental Protection Agency (EPA) balances the risks of pesticide use against the costs of banning pesticides in their regulatory decision making under the Federal Insecticide, Fungicide, and Rodenticide Act. They find that the EPA does indeed balance benefits against costs even though the regulations may not pass a formal benefit-cost test; that is, the likelihood that a pesticide is banned is positively correlated to the risks to human health and the environment and negatively correlated with the benefits associated with the pesticide. They also find that political factors such as lobbying by special-interest groups affect the regulatory decision making.
Hamilton (Volume II, Chapter 20) also analyzes the role of political factors in the regulatory decision-making process in his examination of the existence of environmental racism. He offers and tests three hypotheses for the existence of differential environmental risks by geographical concentration of ethnic groups. These hypotheses are as follows: (1) pure discrimination in which firms and politicians actively locate polluting plants in nonwhite areas; (2) differences in the willingness to pay for environmental amenities, which is a function of income and education; and (3) variation by income and race in the propensity to engage in collective action to oppose environmental disamneties. By examining the decision to expand hazardous waste sites as a function of race, income, education, and propensity to engage in collective action, he finds that it is collective action that offers the best explanation for capacity expansions. This fits the Coasian model in which polluters seek out locations in which expected compensatory payments will be the least.

**Volume II, Part VI**

Part VI explores a range of issues pertaining to the role of risk beliefs and the use of warnings to convey risk information. From an efficiency standpoint, a market failure occurs if individuals are not informed of the risks involved in their consumption decisions. Lichtenstein et al. (Volume II, Chapter 21) do indeed find that people tend to misperceive risks, systematically overestimating low-probability events and underestimating high-probability events. Therefore, such things as warning labels can presumably alleviate this source of inefficiency. The study by Viscusi and O’Connor (Volume II, Chapter 22) assesses the efficiency of warnings for job risks, which will affect worker risk perceptions, quit intentions, and reservations wage rates.

Information efforts do not, however, guarantee accurate risk beliefs. Warnings for cigarettes, for example, imply that smoking is dangerous, but do not indicate the level of the risk. The result is that there is overestimation of the risk, which is consistent with the patterns observed for highly publicized hazards. The other chapters in this section all examine whether (and to what extent) individuals misperceive certain risks.

**Volume II, Part VII**

Few risks are known with precision. Instead, risks are often ambiguous, leading to well-established anomalies such as the Ellsberg Paradox (Volume II, Chapter 26). Aversion to ambiguous risks has profound ramifications, particularly in that similar biases are also reflected in government policy (as discussed in Nichols and Zeckhauser, Volume II, Chapter 28). And, as discussed in Kunreuther, Hogarth and Meszaros (Volume II, Chapter 30), ambiguity bias may also impede the effective functioning of insurance markets.

An interesting phenomenon occurs in situations in which there are competing risk experts whose statements give rise to the risk ambiguity. The results reported in Viscusi (Volume II, Chapter 31) indicate that people are most prone to alarmist responses when there are divergent sources of risk information. Thus, disputes between experts from industry and government are more likely to lead to higher risk beliefs than are two divergent views from government scientists. People place the greatest weight on worst-case scenarios in that instance.
Conclusion

Risk management policy has raised a wide variety of issues of interest to economists, whose work in turn has informed regulatory policy. While the state of economic research now appears to be far ahead of the development of sound policies, many salient research questions have yet to be resolved. For example, risk-risk analysis in principle has a sound economic foundation, but a consensus on the empirical bases for such an analysis has yet to emerge. Similarly, behavioral responses to regulations are widely believed to be important, but we are less able to predict the contexts in which such efforts will prove to be important. Indeed, in the case of reduced tar cigarettes, there continues to be substantial debate over the extent of the behavioral response. As research on these and other risk-related issues continues, it will serve to provide policy makers with the tools needed to be more protective of individual health while at the same time recognizing the tradeoffs associated with particular interventions.