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EVALUATING THE TRADEOFFS BETWEEN DOLLARS SPENT AND LIVES SAVED IN MILITARY SETTINGS

Thomas J. Kniesner, John D. Leeth, and Ryan S. Sullivan¹

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1 INTRODUCTION

A fundamental tenant of economics is that actions should be evaluated in terms of benefits and costs, including actions aimed at reducing military or civilian casualties. Safety improvements only expand individual or social welfare if the benefits of the improvements exceed their costs. Monetary costs of safety programs are generally determined through engineering or accounting studies and are fairly non-controversial. Against their costs, must be weighed the value of fewer fatalities and injuries, which requires both an accurate assessment of the fatalities and injuries eliminated and a monetary value of the lives saved and injuries avoided. Some argue that no monetary value can be placed on human life so any effort that improves safety is worthwhile. Clearly, the military cannot operate as if human life had infinite value. The focal message of our chapter is that choices must be made because complete safety is impossible and approving every advancement in armament, technology, or training that would reduce casualties or injuries would soon exhaust the military budget and leave no resources available for the core activities of defending the country.

Even in civilian life people do not act as if their life has infinite value. People drive small cars, although small cars are more dangerous than large cars, because small cars are cheaper to

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purchase and operate. People ski, bike, and roller-blade, although walking is far safer, because the excitement of the activities compensates for the added risk. People smoke, drink alcoholic beverages, and eat unhealthy food, although the health hazards are well known, because the current pleasure from smoking, drinking, and eating outweighs the possible long-run consequences. In short, people make decisions daily regarding their own safety, and in their decisions they do not act as if their own safety is infinitely precious.

In the following chapter we examine how economists evaluate safety improvements and then provide a case study of the approach by examining the cost-effectiveness of adding armor protection to tactical wheeled vehicles (TWVs) in the U.S. military. We begin by describing the economic approach to evaluating the monetary benefits of saving lives and reducing non-fatal injuries and illnesses. In a nutshell, economists value the benefits of greater safety by observing the trade-offs people actually make between safety and other job or product characteristics.

For instance, suppose we see that two otherwise identical jobs differ in terms of safety: one is completely safe, but in the other there is a 1 in 100,000 chance of a workplace injury resulting in death. The completely safe job pays \$80 less per year than the job with a chance of a workplace fatality. Workers here are sacrificing \$80 annually in the form of a lower wage to eliminate a 1 in 100,000 chance of injury on the job that results in death during the next year. With 100,000 workers each contributing \$80, one life would be saved on average, meaning collectively the value workers are placing on that one life, and implicitly their own life, is \$8 million. Because the actual life saved is not known, but in a sense is drawn randomly from the 100,000 workers, economists refer to the resulting figure as the value of a statistical life (VSL). By dividing the wage gain by the change in the chance of death ($\$80/0.00001$), the dollar figure has been standardized to one life saved. Although the monetary value is expressed as the amount

per life, it is derived by observing the amount of money workers sacrifice to avoid a slightly higher chance of death, and so might be better thought of as the value of mortality risk reduction (US EPA 2010b).

Rarely do you see two jobs that are otherwise identical except for the chance of a workplace fatality. Economists derive VSL estimates econometrically using large data sets that allow us to control for other factors affecting wages or product prices to generate the *ceteris paribus* impact of risk. After describing the theory behind VSLs, we summarize the major econometric approaches of generating VSL estimates and provide a broad overview of the empirical results. VSLs vary by income and demographic characteristics such as age, gender, or race so no single estimate is appropriate in all situations. Across the multitude of empirical studies, the range of VSL estimates is quite large, from \$0 to \$40 million. As we will explain, better empirical modeling and improved risk information reduces the likely range of VSLs to \$4 million to \$10 million. Government agencies such as the Environmental Protection Agency (EPA) and the U.S. Department of Transportation evaluate safety improvements using a VSL of about \$8 million.

We conclude the chapter with a case study examining the cost effectiveness of two large scale vehicle replacement programs that were implemented in the U.S. military to increase vehicle armor protection for troops in day-to-day operations. The principal aim of the replacement programs was to reduce fatality and injury risk for U.S. military personnel. The case study illustrates a common problem when evaluating safety efforts. Frequently, estimates of risk reduction are based on engineering studies that do not consider changes in behavior that might mitigate or completely counteract the direct improvement in safety. For example, requiring drivers to wear seatbelts might reduce deaths or injuries given an accident, but might also

encourage drivers to drive faster or more recklessly increasing the number of accidents, which puts the driver at greater risk as well as other drivers, passengers, and pedestrians (Peltzman 1975). Simply estimating the lower chance of death or injury from using a seatbelt will overestimate the benefits of requiring seatbelt usage if behavioral responses are large.

The case study we present shows that the move from a lightly armored TWV to a moderately armored TWV reduced infantry fatalities at a cost of \$1 million to \$2 million per life saved. With a VSL somewhere in the \$4 million to \$10 million range, the move passes any reasonable criterion for cost-effectiveness. The change had no impact on fatalities in armored and cavalry, and administrative and support units. Switching to the even more costly, and highly armored third alternative did not appreciably reduce fatalities in any of the different unit types examined, despite engineering studies showing it to be a safer vehicle. The offsetting behavior of our own troops or actions by the enemy in response to the change counteracted the direct improvement in safety from adding armor making the move cost-ineffective.

2 THE ECONOMIC APPROACH TO VALUING SAFETY

The economic theory behind valuing safety is built on the assumption that people do not like to take gambles with their lives or their health. There may be some thrill seekers who seek out risk for its own sake, but such individuals are relatively rare. The vast majority of people dislike risk and are only willing to accept risk if they get something in return. All else equal, a worker might choose to work in a more hazardous workplace if he or she receives a higher wage or consumer might be willing to purchase a more hazardous product if its price were lower. On the other side of the market, improving workplace and product safety is expensive and firms may be willing to pay higher wages to their workers or reduce prices to their customers to avoid paying the added costs.

To see how the opposing forces play out in the market assume for the moment a labor market where there are only two types of jobs: a job with zero risk of a workplace injury ($\pi = 0$) and a job with a high risk of a workplace injury ($\pi = \pi_{\text{high}}$). The jobs are identical in every other respect. In such a situation, no worker would willingly choose the dangerous job over a safe job. At best, the worker is uninjured and earns the same as in the perfectly safe job and at worst, the worker is injured and bears the pain of injury and the loss of income. To use an analogy, it is as if the worker is being given the choice between a dollar with certainty or a gamble where there is a $1-\pi$ chance of a dollar payoff and a π chance of a 0 payoff. Regardless of risk preferences rational workers would always choose the dollar payoff with certainty. For workers to accept the gamble the payoff if uninjured must be high enough to outweigh the utility loss if injured. In the real world the payoff may include a higher wage, better fringe benefits, or a more pleasant work environment, but in the context we are developing, where everything else about the job is the same and workers dislike risk, the only possible reward for accepting a riskier job is a higher wage. Differences in economic circumstances, family situations, and general tastes and preferences among workers will cause some workers to demand a very large wage premium to be willing to accept a dangerous job while others will accept a fairly small wage premium.

Programs that improve workplace safety have costs. Firms may need to purchase additional equipment or protective devices, install machine guards, slow down the pace of production or stop production entirely to service equipment, hire consultants to advise management or train workers in safe procedures, and devote valuable management time to monitor safety. For some employers safety-enhancing efforts may be quite expensive, but for other employers the costs may be slight. Because of the inherent dangers in production, firms in mining, logging, fishing, and construction will need to spend more than firms in manufacturing,

retail trade, or financial services to achieve the same level of safety for their workers. To be willing to bear the costs of safety programs employers must anticipate corresponding economic benefits, such as greater output, lower pay for workers, smaller insurance premiums, or lower fines for violating government standards.

If wages were the same in both safe and risky jobs, all workers would choose to work in establishments with complete safety and all firms with at least some inherent dangers would choose to offer risky employment. Workers would gain nothing from accepting any job risk and firms would earn no economic returns from investing in safety. The excess demand for labor in risky jobs will cause their wages to rise and the excess supply of labor in safe jobs will cause their wages to fall. The wage gap between the two types of jobs will cause some workers to realize that they can improve their welfare by accepting a risky job and some firms to realize they can expand profits by making the necessary investments to eliminate job hazards. The movement of workers and firms between the two types of jobs will continue until no firm can expand its profits by adjusting its expenditures on safety and no worker can expand his or her expected utility by changing jobs.

The wage gap sorts firms and workers into the two submarkets. The firm on the margin is indifferent between offering safe or hazardous employment. For the so-called marginal firm, the costs of the safety programs necessary to eliminate job hazards just equal the benefits of greater safety, the drop in wage. Likewise, the worker on the margin is indifferent between the two types of jobs: the utility gain from the higher wage just offsets the utility loss from the greater likelihood of a drop in income, medical expense, and pain and suffering from an injury or illness. Because the wage difference ($w_{\text{high}} - w_0$) seen in Figure 1 reflects both sides of the market, it measures both the marginal cost (the added cost of safety programs) and the marginal benefit (as

measured by worker preferences) of improving safety. Notice that if job risk represents the chance of a fatal workplace injury, then the implied VSL in this market is $(w_{\text{high}} - w_0)/(\pi_{\text{high}} - 0)$.

[Insert Figure 1 here.]

The process that sorts workers and firms among the various levels of risk is the same when there are three or more discrete levels of risk. Wages rise as risk expands and the higher wage encourages the less risk averse workers to accept higher risk jobs and firms with lower costs of providing safety to eliminate hazards. In the limit, risk becomes continuous and the resulting equilibrium relationship between wages and risk is described by a function described by a curve such as the one in Figure 2.² As is well known in economics, firms maximize profits by using inputs to the point where marginal benefit equals marginal cost. In the case of safety inputs, the additional costs include the added expense of buying additional equipment, slowing down the pace of production, or paying for safety training, while the additional benefits include the drop in wage firms must pay to attract workers as the risk of injury falls and they move down the wage function in Figure 2. Because the costs of providing a given level of safety vary among workplaces, the optimum level of safety will also vary. In the end, all firms provide their workers the level of safety where marginal benefits equal marginal costs, but firms with lower inherent costs of reducing hazards provide a safer workplace and locate to the left along the wage relationship shown in Figure 2, and firms with higher costs provide less safety and locate to the right.

[Insert Figure 2 here.]

Similar to firms, people maximize their welfare by pursuing actions to the point where the marginal benefit of an action equals its marginal cost. In terms of safety, the added benefit of

² See Kniesner and Leeth 1995, Chapter 3 for a formal derivation.

accepting a lower risk job (moving to the left along the wage function) is the lower chance of injury and the added cost is the drop in the wage. All workers maximize their welfare levels by comparing the marginal benefit of safety against the marginal cost of safety, but the more risk averse workers will value the potential benefits more highly and locate to the left along the wage relationship in Figure 2 and the less risk averse will value the potential benefits less highly and locate to the right.

Firms supply a given type of workplace based on the market wage function and their ability to produce a safe work environment. Workers sort into a given job risk based on the market wage function and their preferences regarding safety. In the end, wages must adjust along the entire risk spectrum to equilibrate the supply of and demand for labor at all points. If there is a shortage of workers at any level of risk, wages will rise at that risk level causing some firms to alter their expenditures on safety and some workers to relocate to the now better paying jobs. The movement of firms and workers will create labor shortages elsewhere and cause wages to rise at these other levels of risk. A surplus of labor at any level of risk will cause wages to fall at that risk level, which will cascade throughout the entire risk spectrum as firms and workers adjust to the new lower wage. For equilibrium to be established in the market there cannot be an excess demand for labor or an excess supply of labor at any level of risk.

The slope of the wage function shown in Figure 2 measures the income a worker must sacrifice to lower his or her chance of injury by a small amount. Because a worker maximizes welfare by equating marginal cost with marginal benefit, the slope of the wage function also equals the value workers place on small improvements in safety. When safety is measured as the probability of a fatal injury the resulting slope can be transformed into a VSL by dividing the wage gain by the associated rise in the probability of death. An implicit value of injury can be

found in a similar manner by dividing an estimated market wage change for a small reduction in the probability of a workplace nonfatal injury or illness by the change in the probability. The resulting calculation is known as the value of a statistical injury (VSI).

The thought process of market equilibrium is the same in product markets as in labor markets, except the end result is a negative relationship between price and risk. The added cost of producing safer products implies that the price of the product must rise as the probability of injury falls to compensate producers for the costs. At the same time, consumers value both more safety and more goods and services, meaning everything else the same they are only willing to purchase a riskier product if it is cheaper than a safer product. The interaction of firms and consumers generates a price function where firms sort along the function based on their abilities to produce safe products and consumers sort along the function based on their valuations of safety. In equilibrium, the slope of the market price function provides an estimate of consumers' willingness to pay for added safety, which can be used to generate a VSL or a VSI, depending on how risk is measured.

3 VSL ESTIMATES

The majority of VSL estimates are derived from estimates of a market wage equation such as

$$\ln(w) = c + \sum_{i=1}^m \alpha_i \pi_i + \sum_{j=1}^n \beta_j X_j + \varepsilon, \quad (1)$$

where $\ln(w)$ is the natural logarithm of wage, π 's are measures of workplace risk, the X_i 's are demographic variables (such as education, race, marital status, and union membership) and job characteristics (such as the non-fatal injury risk, wage replacement under workers' compensation insurance, and industry, occupation, or geographic location indicators), ε is an error term, and c , α_i , and β_j are parameters to be estimated. Many studies also include interaction terms between workplace risk and various X 's to determine variation in risk compensation by type of worker

(union/nonunion, white/black, native/immigrant, young/old) or by level of income replacement from workers' compensation insurance.

Viscusi (2004) provides a good example of how one can use labor market data to estimate a VSL. For his measure of risk Viscusi relies on data drawn from the Census of Fatal Occupational Injuries (CFOI), which are discussed in more detail in Viscusi (2013). Since 1992, the Bureau of Labor Statistics (BLS) has compiled yearly data on all workplace fatalities in the U.S. by examining death certificates, medical examiner reports, OSHA reports, and workers' compensation records. Viscusi uses the CFOI data to determine mortality risk by first grouping fatalities by 2-digit industry (72 industries) and then by 1-digit occupation (10 occupations) to generate a total of 720 industry-occupation cells. He then calculates the frequency of a workplace death by dividing the average number of fatalities by the average number of employees within each industry-occupation cell from 1992 to 1997. By averaging over six years, Viscusi minimizes possible errors in characterizing risk resulting from the random fluctuation of workplace fatalities over time. In the sample data the average fatality risk is 4/100,000 with the lowest risk level 0.6/100,000 and the highest about 25/100,000.

Viscusi then combines the fatal risk data with individual worker data from the 1997 merged outgoing rotation groups of the Current Population Survey (CPS). As is fairly typical, he excludes from his sample agricultural workers, part-time workers, workers younger than 18, and workers older than 65. His estimate of equation (1) includes no interactions between fatal injury risk and other control variables and assumes a linear relationship between log hourly wage and fatal injury risk. Consequently, with a fatality risk measure of deaths per 100,000 workers and a work year of 2000 hours, the value of a statistical life is $VSL = \alpha \times \exp(\ln(w)) \times 100,000 \times$

2000.³ Although the VSL function depends on the values of the right-hand side in (1), most commonly considered is the mean VSL. The VSL from his baseline regression of equation (1) for all workers is \$12.1 million.⁴

House prices provide another avenue for determining implied VSLs. All else equal, houses located in less desirable areas should sell for less than houses located in more desirable areas. If desirability reflects the absence of pollution or some other hazard then the smaller chance of pre-mature death, injury, or illness and the resulting higher price can be used to estimate a VSL. As with labor market studies, the underlying framework for generating the VSL values is a market price equation that relates house price to environmental hazards, holding other factors constant. Specifically,

$$\ln(p) = c + \sum_{i=1}^m \alpha_i E_i + \sum_{j=1}^n \beta_j C_j + \varepsilon, \quad (2)$$

where $\ln(p)$ is the natural logarithm of price, the E 's are environmental hazards, and the C 's are structural, neighborhood, and other control variables that affect price (for instance, number of rooms, number of bathrooms, lot size, neighborhood median income, and distance to central city).

Gayer, Hamilton, and Viscusi (2000) use the approach of estimating a market price equation to determine the implicit value of avoiding cancer. As part of a Remedial Investigation of a Superfund site the Environmental Protection Agency (EPA) releases an assessment of the site's risks across the various affected areas, including the elevated risk of contracting cancer. The authors use the risk information and individual housing data drawn from an area surrounding a Superfund site in the greater Grand Rapids region of Michigan to estimate equation (2). They

³ If α is small then $\alpha \times \exp(\ln(w)) \approx \alpha w$.

⁴ All dollar figures we present and discuss have been adjusted for inflation to 2010 using the CPI-U.

find that in the period following the EPA's release of its report, a 1.81 per 1,000,000 reduction in cancer risk (the mean level in the sample) raises the price of the average house by about \$25. The estimates imply that the household valuation of reducing one cancer is about \$13.9 million, and with the average number of household members at 2.573 the individual value of reducing one cancer is about \$5.4 million.

Economists have examined a variety of products and actions to determine reasonable values for VSLs. When consumers purchase products that directly decrease risk such as the decision to buy a bike helmet or a smoke detector, the approach is quite straightforward: simply divide the cost of the product by the lower likelihood of death. In some cases, actions to expand safety may not require a monetary outlay, such as using a seat belt or driving more slowly, but even here it is oftentimes possible to generate a VSL by combining the safety effects of the action with dollar estimates of the opportunity cost of time.

In a particularly interesting and relevant example of the indirect approach, Rohlfs (2012) develops VSL estimates by examining two tactics used by young men during the Vietnam War era to avoid the draft: enrolling in college and voluntarily enlisting. Although one might not necessarily view voluntarily enlisting as a strategy to avoid the draft, by enlisting men could avoid the possibility of having their careers interrupted through required military service and they could choose their branch of service, obtain specialty training, and in some cases enter as officers. Enlisting also improved one's chance of survival. From 1966 to the end of U.S. involvement in the war, the death rates of volunteers and officers were lower than the death rates for draftees.

To see how Rohlfs determines the value of avoiding the draft by voluntarily enlisting in the military consider Figure 3, which shows two supply curves. The first is the supply of men to

the military if there were no draft. The second is the supply of men volunteering to serve in the military given a draft. At every wage more men are willing to enlist in the military with a draft than without a draft to avoid the costs of having their careers interrupted, to be able to choose their branch of service and type of training, and to expand their odds of survival. The supply of men with the draft is everywhere to the right of the supply curve without a draft. Given the level of pay in the military the number of men who would enlist without a draft is E_{nd} and the number of men who would enlist with a draft is E_d . Rohlfs estimates the increase in the number of enlistees during the Vietnam War era, all else equal, and then uses the estimates with outside estimates of the supply elasticity of men willing to enlist in the military to determine the vertical distance between the two supply curves in Figure 3. The vertical distance represents the increase in military pay just necessary to generate the same increase in enlistments as generated from the draft. It represents the dollar value of avoiding the draft for the marginal enlistee during the period (the one just indifferent between enlisting or taking his chance with the draft). Rohlfs uses a similar procedure for determining the dollar value of enrolling in college for the marginal student (the one just indifferent between attending college or taking his chance with the draft), except in the college alternative situation he is examining two demand curves instead of two supply curves.

[Insert Figure 3 here.]

Based on college enrollments the cost of avoiding the draft for the marginal student was about \$30,000, and based on enlistments the cost of avoiding the draft for the marginal volunteer was about \$117,000. Rohlfs generates the implied VSLs by assuming the only cost of being drafted is the higher likelihood of death. He refers to the resulting values as upper bounds on true VSLs. Specifically, he divides his estimates of the value of avoiding the draft by the associated

differences in mortality risk and finds VSLs for young men in the \$1.6 million to \$5.2 million range using information from college enrollments and in the \$7.4 million to \$12.1 million range using information from military enlistments. The range of values arises from differences in empirical specifications underlying the estimates of costs and risk. Rohlfs argues credit constraints prevented many young men from attending college during the period causing the enrollment data to understate the cost of the draft and the VSL of draft-age men. He believes the higher range derived from information on enlistments more accurately reflects the true VSL of young men at the time.

4 CONTINGENT VALUATION ESTIMATES

Besides using market data, VSLs can also be estimated using data from surveys where individuals are questioned about their willingness to pay for small changes in risk. Generally, the surveys used in contingent valuation (also known as stated preference) studies describe a base risk level that can be reduced by engaging in some activity, purchasing some product or service, or purchasing a different, safer product than the product originally described.

In the simplest form, survey data provide direct values of people's willingness to pay (WTP) for improvements in safety. Unlike studies using market wage or price data, contingent valuation studies attempt to uncover preferences directly. In terms of Figure 2, market studies estimate the market wage equation $W(\pi)$, whereas contingent valuation studies estimate the preferences underlying the wage equation. In equilibrium, the slope of the market wage function equals the marginal benefit to the worker from a slightly safer job. The equality of the two values means it is unnecessary to estimate underlying preferences to determine appropriate VSLs, but for more substantial improvements in safety market determined values will overstate people's willingness to pay for greater safety. The marginal benefit of further gains in safety declines as

safety improves. Attempting to estimate the value functions of workers or consumers that underlie the market wage or price functions is quite difficult. Because the price of safety is implicit, identifying the parameters of the structural equations underling equilibrium is more difficult than estimating a standard simultaneous equation system such as the supply and demand for a homogenous product such as milk (Brown and Rosen, 1982; Epple, 1987; Kahn and Lang, 1988).

As with all surveys, one must ensure that respondents carefully consider the alternatives that are presented. Specifically, researchers should prioritize the creation of unbiased surveys. For example, respondents tend to place a higher value on a safety device or policy when it is the only option available on a survey. Also, the order of the survey questions should be considered. Respondents often place higher values on safety devices or policies when they appear first in a set of questions. These are just a couple of examples regarding the complications that can result from incorrect survey designs so that the subsequent VSL estimates gathered from the survey may be biased.

Contingent valuation surveys are also more challenging to construct than other surveys because many people have difficulty properly understanding complex probability concepts and are unaccustomed to the notion of trading income for expanded safety. For example, people generally understand the simple difference in payoffs between betting on a race horse with 4:1 winning odds versus betting on a horse with 2:1 winning odds. They might have a harder time, however, understanding whether or not they would support a government policy that reduces mercury levels in the local water supply and thus decreases the risk of death for each constituent by 0.00001 at a cost of \$50 per taxpayer. If respondents do not fully understand the probability concepts in surveys, then the VSL estimates from the survey may be inaccurate. Due to the

problems we have just listed, we prefer to rely on VSLs generated from market data that reflect workers or consumers actual willingness to pay for added safety than on survey data that reflect how one might react to a hypothetical event.⁵

5 VSL HETEROGENEITY

VSL estimates vary depending on both the set of control variables included in the estimating wage or price equation and the underlying population examined (Viscusi 2013). In the United States, VSL estimates are higher for union workers than for non-union workers, higher for whites than blacks, and higher for women than men (Viscusi and Aldy 2003, Viscusi 2003, Leeth and Ruser 2003). VSLs for native workers are roughly the same size as for immigrant workers, except for non-English speaking immigrants from Mexico who appear to earn little compensation for bearing very high levels of workplace risk (Hersch and Viscusi 2010). VSLs rise as people age, at least until the mid-40s, and then gradually decline (Kniesner, Viscusi, and Ziliak 2006 and Aldy and Viscusi 2008). Not surprising given that safety is generally considered to be a normal good, VSLs are larger for higher income groups within a country at a point in time, within a country over time as the country's income increases, and within developed countries than within less developed countries (Mrozek and Taylor 2002, Viscusi and Aldy 2003, Costa and Kahn 2004, Bella Vance, Dionne, and Lebeau 2009, Kniesner, Viscusi, and Ziliak 2010).

VSLs can vary across populations because of differences in risk preferences. Groups more willing to take risks will locate further to the right along the market wage function, and if the wage function is concave from below as shown in Figure 2, more risk tolerant groups will have a smaller reduction in wage for a given increase in safety and a lower VSL. Alternatively, some populations may have a lower VSL because they are less careful than others and their

⁵ For further discussion see Carson, Flores, and Meade (2001) and Hausman (2012).

lower safety productivity causes the wage function they face to lie below and to be flatter (resulting in a lower VSL) than the wage function faced by others. The lower ability of some workers to produce safety makes it desirable for employers to offer them smaller wage premiums for accepting risk. Discrimination may also result in two separate market wage functions with the disadvantage group facing not only lower wages at every level of risk but also smaller increases in wages for given changes in risk than for the advantaged group.

The range of VSL estimates across studies is quite large, in the order of \$0–\$40 million (Mrozek and Taylor 2002, Viscusi and Aldy 2003, Bellavance, Dionne, and Lebeau 2009). The inter-study variation can create a dilemma for policy makers. A proper evaluation of any program designed to improve safety and health requires an estimate of the benefits generated by the program. A too low VSL will underestimate the benefits of a mortality risk reduction, resulting in a rejection of desirable programs, while too high of a VSL will overestimate the benefits of mortality risk reduction, resulting in accepting undesirable (in a cost/benefit sense) programs.

One approach to solving the dilemma of the wide range of VSL estimates is to use some sort of meta-analysis to combine the various estimates into a single value that corresponds roughly to the mean of the estimates. For instance, the U.S. Environmental Protection Agency (EPA) recommends using \$8.0 million to value the lives saved from eliminating environmental hazards based on fitting a Weibull distribution to 26 separate VSL estimates (U.S. EPA 2010a). The \$8.0 million is the central estimate (mean) of the fitted distribution. The U.S. Department of Transportation (DOT) uses an \$8.6 million VSL to evaluate the benefits of improving transportation safety based on the mean value of nine fairly recent labor market VSL studies (US DOT 2008).

The difficulty with meta analyses is that they include results from studies with known problems, which “imparts biases of unknown magnitude and direction,” (Viscusi, 2009, p. 118). Kniesner et al. (2012) take another approach and demonstrate how using the best available data and econometric practices affects the estimated VSL so as to narrow the range of estimates. They devote particular attention to measurement errors, which have been noted in Black and Kniesner (2003), Ashenfelter and Greenstone (2004), and Ashenfelter (2006). Although they do not have information on subjective risk beliefs, they use very detailed data on objective risk measures and consider the possibility that workers are driven by risk expectations. Published industry risk beliefs are strongly correlated with subjective risk values,⁶ and they follow the standard practice of matching to workers in the sample an objective risk measure. Where Kniesner et al. (2012) differ from most previous studies is the pertinence of the risk data to the worker’s particular job, and theirs is the first study to account for the variation of the more pertinent risk level within the context of a panel data study. Their work also distinguishes job movers from job stayers. They find that most of the variation in risk and most of the evidence of positive VSLs stems from people changing jobs across occupations or industries possibly endogenously rather than from variation in risk levels over time in a given job setting. They demonstrate how systematic econometric modeling narrows the estimated value of a statistical life from about \$0–\$40 million to about \$4 million–\$10 million, which Kniesner et al. (2012) then show clarifies the choice of the proper labor market based VSL for policy evaluations.

6 SUMMARY

We have been emphasizing that complete safety, even if technologically feasible, will not be possible in practice due to economic reasons. Decision-making units from families to government agencies must make choices on how to spend resources to make their component

⁶ See Viscusi and Aldy (2003) for a review.

members optimally safer when that personal safety enhancement is the objective under consideration. Economists regularly employ the money metric known as the value of a statistical life, which is the benefit portion of the cost-effectiveness calculation for a safety enhancement revealed by individuals' implicit willingness to pay for reduced harm via wages received or prices paid for products that involve personal risks. We have noted that how a death might occur or the personal characteristics affecting willingness to accept danger such as age (both of which are important for military applications) can play important roles in how one evaluates the cost-effectiveness of increased personal safety. We now turn our attention to a specific case study of the efficiency considerations or cost-effectiveness of military decisions to improve the safety features of armored tactical wheeled vehicles. We emphasize that the same principles useful in evaluating government enhancing safety policy in private labor and product markets are also of equivalent relevance to military considerations, where they may have been underutilized as efficiency inducing decision criteria up to now.

7 CASE STUDY: ARMORING TACTICAL WHEELED VEHICLES

The following case study provides a summary of the methods and results presented in a recently published article by Rohlfs and Sullivan (2013a), "The Cost-Effectiveness of Armored Tactical Wheeled Vehicles for Overseas U.S. Army Operations." In their study, Rohlfs and Sullivan use a VSL cutoff of \$7.5 million to determine the cost-effectiveness of three separate armored tactical wheeled vehicles. In addition to summarizing the methods and findings in Rohlfs and Sullivan (2013a), we discuss the policy implications of their results and the limitations of using VSL cutoffs in evaluating the tradeoffs between dollars spent and lives saved for this and other military programs.

Due to the sensitive nature of the data used in Rohlf's and Sullivan (2013a) and security restrictions put in place by the Office of Security Review (OSR), all vehicle systems in the case study to follow are labeled with the generic titles of Types 1–3, the months of data are denoted as 1 through 71, and the theater of operations is labeled Theater A.

7.1 Background and Data

As discussed in Rohlf's and Sullivan (2013a), over the course of the Global War on Terror the U.S. Army engaged in two large scale vehicle replacement programs intended to reduce the fatality and injury risks of U.S. troops. Both programs affected wheeled ground vehicles that U.S. forces used for day-to-day operations. The first replacement program involved replacing a large number of lightly armored Type 1 tactical wheeled vehicles (TWVs), which cost roughly \$50,000 per vehicle in 2010 dollars⁷, with \$170,000 medium armored Type 2 TWVs. The second replacement program began at the time the first program was ending, and it involved replacing about 9,000 Type 2 TWVs with \$600,000 heavily armored Type 3 TWVs. The total cost of the Type 3 TWV procurement program was approximately \$50 billion.⁸

Due to security restrictions by OSR, we are not permitted to disclose specific information about the attributes and history of each vehicle. We can however state that, in general, the U.S. Army maintains each vehicle type primarily for troop transport and vehicles vary somewhat in terms of maneuverability, weight, and speed. The central difference between vehicle types is variability in their armor protection.

⁷ All prices presented in the replacement vehicle case study are in 2010 dollars.

⁸ This is most likely an underestimate of the actual value of the program because it does not include many costs such as maintenance and fuel. It should also be noted that the \$50 billion figure is for all service types, not just the Army, which was the focus of the study by Rohlf's and Sullivan (2013a).

Rohlf and Sullivan (2013a) used a variety of publicly available data sets from the Department of Defense (DoD) in their statistical analysis.⁹ They obtained vehicle data from the Theater A portion of U.S. Army Materiel Systems Analysis Activity's Sample Data Collection (U.S. AMSAA, SDC, 2010) and cost information from cost experts within the Army Material Command (AMC) and Cost Analysis and Program Evaluation (OSD-CAPE) departments in DoD.

Type 2 and 3 TWVs typically have higher maintenance and fuel costs in comparison to Type 1 TWVs. Specifically, Rohlf and Sullivan (2013a) estimated that in-theater fuel and maintenance costs are \$5.50 per mile for Type 1 TWVs and \$10.50 per mile for Type 2 and Type 3 TWVs. Type 3 TWVs are also more expensive to transport overseas in comparison to the other types due to their heavy weight. Notably, the deterioration of the vehicle types is higher during war than peacetime and thus, normal expected lifetime costs must be adjusted while in-theater. For purposes of their study, Rohlf and Sullivan (2013a) assume a one-way trip and three-year lifespan for all vehicle types and that the U.S. Army uses each vehicle in combat for all three years. The estimated costs of an average three-year deployment (including procurement and transportation costs) then are \$143,000 for a Type 1 TWV, \$345,000 for a Type 2 TWV, and \$780,000 for a Type 3 TWV. The three cost estimates use 484 miles per month as a constant rate of usage, which is the rate observed for the average vehicle in the SDC data.

Rohlf and Sullivan (2013a) used casualty and unit level characteristics from the Defense Manpower Data Center (DMDC) for all Army units over a 71 month time period in Theater A. They group the data at the battalion level to match up closely with how the Army assigned

⁹ Some of the data used in Rohlf and Sullivan (2013a) are considered For Official Use Only (FOUO). For another author to use the data requires that person to have an official defense-related government purpose. Rohlf and Sullivan have made arrangements with the U.S. Naval Postgraduate School (NPS) to officially sponsor potential replicators of their project, so that replicators could obtain access to the data.

vehicles and tasks. They also group the data into four distinct unit types: infantry, armored and cavalry, administrative and support, and “other.”

As for casualties, the Army incurred 34 deaths and 266 combat-related injuries in Theater A in the average month. The standard deviation in deaths across months is 23, the standard deviation in combat-related injuries is 166, and total Army casualties in Theater A often changed by more than 100 from one month to the next. Unit level controls include detailed information on the number of troops, the fraction that are officers, Private or Private First Class (PFC), high school graduates, male, black, Hispanic, average days of deployment experience, and age by unit and month, the unit’s name, and its home state within the United States.

7.2 Econometric Methods

To evaluate the cost-effectiveness of Types 1-3, Rohlf and Sullivan (2013a) first examine the relationship among the three vehicle types and overall unit fatalities. Specifically, they use standard econometric methods including regression analysis to estimate changes in unit-level casualty rates as a function of each unit’s complement of vehicle types while controlling for other factors. Their modeling approach appears below. From Rohlf and Sullivan (2013a):

“For a given unit i in month t , suppose that fatalities are determined according to the following linear equation:

$$fatalities_{it} = \sum_{j=1}^3 \alpha_{cj}^f * q_{jit} + \beta_c^{f'} \mathbf{x}_{it} + \varepsilon_{it}^f, \quad (1)$$

where q_{1it} , q_{2it} , and q_{3it} represent the quantities of each of three types of vehicles possessed by unit i in month t , \mathbf{x}_{it} is a vector of control variables that might include other vehicle quantities, troop characteristics, or fixed effects for month, province, month by province, or unit, ε_{it}^f is random error, and the coefficients are allowed to vary by the unit’s classification c as infantry, armored or cavalry, administrative and support, or other. Let vehicle types one, two, and three be defined as Type 1, Type 2, and Type 3 TWVs.

Because the focus of this study is the effects of replacing one vehicle type with another, it is convenient to rearrange the terms in Equation (1) to obtain the following specification:

$$fatalities_{it} = (\alpha_{c2}^f - \alpha_{c1}^f) * q_{2it} + (\alpha_{c3}^f - \alpha_{c1}^f) * q_{3it} + \alpha_{c1}^f * \sum_{j=1}^3 q_{jit} + \beta_c^f \mathbf{x}_{it} + \varepsilon_{it}^f. \quad (2)$$

Equation (2) serves as our main regression specification, with $\sum_{j=1}^3 q_{jit}$, q_{2it} , q_{3it} , and varying formulations of \mathbf{x}_{it} as the regressors. The differences $(\alpha_{c2}^f - \alpha_{c1}^f)$ and $(\alpha_{c3}^f - \alpha_{c1}^f)$ measure the effects of replacing Type 1 TWV with a Type 2 or Type 3 TWV.”

Rohlf and Sullivan (2013a) next focus on the costs related to the vehicles by estimating changes in expenditures by unit as a function of the different vehicle types and their usage rates.

Their expenditure modeling technique follows.

“To relate these effects on fatalities to dollar costs, let p_{0j} denote the purchase price (including shipping cost), and let p_{1j} denote the additional cost per mile driven for a type j vehicle. Let $mileage_{jit}$ denote the miles driven of type j vehicles by unit i in month t , and define $expenditure_{it}$ as unit i 's month t expense for all three vehicle types:

$$expenditure_{it} = \sum_{j=1}^3 \left(\frac{1}{36} p_{0j} * q_{jit} + p_{1j} * mileage_{jit} \right). \quad (3)$$

Expenditures can be written as a linear function symmetrically to the fatalities equations:

$$expenditure_{it} = (\alpha_{c2}^e - \alpha_{c1}^e) * q_{2it} + (\alpha_{c3}^e - \alpha_{c1}^e) * q_{3it} + \alpha_{c1}^e * \sum_{j=1}^3 q_{jit} + \beta_c^e \mathbf{x}_{it} + \varepsilon_{it}^e, \quad (4)$$

where $(\alpha_{c2}^e - \alpha_{c1}^e)$ and $(\alpha_{c3}^e - \alpha_{c1}^e)$ represent the monthly costs of replacing a Type 1 TWV with a Type 2 or Type 3 TWV. Expressing the costs of changing vehicle type through Equation (4) helps to ensure that the same factors are held constant and the same sets of observations are compared to one another for the cost as for the fatalities estimation. The mileage and expenditure data are constructed from the SDC sample and use the same sampling weights as the vehicle counts; consequently, the measurement error in vehicle quantities that affects the fatalities regressions does not affect the coefficients in Equation (4).

The cost per life saved from replacing a Type 1 with a Type 2 TWV is $-(\alpha_{c2}^e - \alpha_{c1}^e)/(\alpha_{c2}^f - \alpha_{c1}^f)$, negative one times the ratio of the difference between the coefficient for Type 2 TWVs and the coefficient for Type 1 TWVs from Equation (4), the expenditures equation, divided by the corresponding difference in coefficients from Equation (2), the fatalities equation. The cost per life saved from replacing a Type 2 TWV with a Type 3 TWV is $-(\alpha_{c3}^e - \alpha_{c2}^e)/(\alpha_{c3}^f - \alpha_{c2}^f)$, which is computed as negative one times the difference between the coefficient for Type 3 TWVs and the coefficient for Type 2 TWVs from Equation (4), all divided by the corresponding difference in coefficients from Equation (2). We calculate standard errors for the ratios by estimating Equations (2) and (4) together using seemingly unrelated regression and applying the delta method.

Other dependent variables considered in our analysis are combat-related injuries and miles driven of different vehicles. Measuring effects on injuries helps to identify a

benefit of changing vehicle type not included in the cost per life saved calculations. In order to better interpret the effects on injuries, we compute ratios $(\alpha_{c2}^i - \alpha_{c1}^i)/(\alpha_{c2}^f - \alpha_{c1}^f)$ and $(\alpha_{c3}^i - \alpha_{c2}^i)/(\alpha_{c3}^f - \alpha_{c2}^f)$ of injuries reduced per life saved, where the i superscript denotes coefficients from the injury equation. Measuring effects on the mileage variables help to determine the extent to which the replacement policies led units to alter their behavior.”

7.3 Armored Vehicle Case Study Findings and Discussion

We point readers to Tables I-IV in Rohlfs and Sullivan (2013a) for details on their findings. The three bullet points below summarize their results:

- The preferred estimates indicate that the medium armor provided by Type 2 TWVs over the lightly protected Type 1 TWVs reduced fatalities at a cost of \$1 million to \$2 million per life saved for infantry units.
- For armored and cavalry units and administrative and support units, the estimates indicate that the switch from Type 1 to Type 2 TWVs did not reduce fatalities.
- The switch from Type 2 to Type 3 TWVs did not appreciably reduce fatalities for any of the four unit types, despite the higher cost and heavier armor of the Type 3 TWVs.

In their original article, Rohlfs and Sullivan (2013a) did not discuss in detail the policy implications of their results. However, in terms of evaluating the tradeoffs between dollars spent and lives saved, the policy implications are relatively straightforward. It does not appear that the extra armor protection provided by Types 2 or 3 TWVs over Type 1 TWVs provide enough benefit (in terms of saving lives) to warrant the additional costs for armored and cavalry or administration and support units. Thus, the results from Rohlfs and Sullivan (2013a) suggest that it would be more cost-effective to use Type 1 TWVs in the day-to-day operations for armored and cavalry or administration and support units..

For infantry units, the results suggest that Type 2 TWVs are much more cost-effective in comparison to Type 1 TWVs. Fatalities are reduced at a relatively low cost of \$1million to \$2 million per life saved when adding on the medium armor. The additional armor protection

provided by Type 3 over Type 2 TWVs does not appreciably reduce casualties. The findings, therefore, advocate a policy geared toward everyday infantry units using Type 2 TWVs over Types 1 and 3 TWVs given their combat requirements.

Type 3s do not appear to reduce fatalities or injuries appreciably for any of the unit types, despite their higher cost and greater armor protection. The results in Rohlf and Sullivan (2013a), therefore, suggest that Type 3s should not be used in operations for any of the unit types. Of course, other benefits may exist that go beyond vehicle-provided force protection, so this is a simplification of the policy recommendations from the basic empirical results (that we discuss in further detail below).

One key distinction between the study by Rohlf and Sullivan (2013a) and others (citations withheld due to security concerns) is that other studies tend to focus exclusively on the differences in improvised explosive device (IED) casualty rates between the various vehicle types (with a specific focus on Type 3 TWV IED casualty rates), while the Rohlf and Sullivan estimates “measure the full reduced-form effects of changing vehicle type, taking into account the intrinsic properties of the vehicles and any behavioral responses by the units.” For instance, other studies highlight the findings which show that the fraction of IED attacks resulting in death is higher for Type 1 and 2 vehicles than for Type 3 vehicles. The other studies use the IED results to suggest Type 3 TWVs save “thousands of lives” in comparison to Type 1 or 2 TWVs. It should be noted, however, that the other studies (incorrectly) assume that soldiers in Type 3 TWVs are attacked by IEDs at the same rate as soldiers in other vehicles. Others’ research also implicitly assumes that the extra protection on Type 3 TWVs has no effect on the exposure of soldiers to attacks that do not involve IEDs or that occur outside of the vehicles.

As discussed in Rohlf and Sullivan (2013b), it appears that the assumptions used in previous studies are not valid. When soldiers adopted the heavily armored Type 3 vehicles, for instance, insurgents may have directed their efforts away from IED attacks on vehicles and toward attacks on less armored soldiers outside of their vehicles. Providing troops with safer vehicles may have increased their willingness to take on risks. In the SDC data, there was strong evidence of a substitution effect among armored and cavalry units. When the Army replaced their Type 1 and 2 vehicles with the heavier Type 3 vehicles, soldiers made greater use of their TWVs and less use of vehicles with more firepower, such as tanks. Anecdotal evidence also suggests that soldiers avoided certain dirt roads and bridges when driving Type 3 TWVs due to their weight. If the behavioral responses just described could have occurred – and could have changed the rate at which units were exposed to different types of attacks – then the appropriate way to measure the vehicles’ full effect is to use the approach in Rohlf and Sullivan (2013a) of examining the impact of the vehicles on a unit’s overall fatalities.

One limitation of the Rohlf and Sullivan (2013a) study is that they do not monetize all the different capabilities each of the three vehicles provides. The only benefits from the vehicles that their study monetizes are the vehicles’ impacts on fatalities and injuries. It might be the case that some of the non-traditional benefits or costs, which are not accounted for in the study, may slightly adjust their estimates. For example, some of the vehicles may have greater maneuverability or less weight and the like in comparison to the others, which may or may not enhance offensive capabilities. Such offensive capability attributes may cause the vehicles to be more or less cost-effective than indicated in Rohlf and Sullivan (2013a). Indeed, Rohlf and Sullivan (2013a) discuss this limitation of their study and state that their estimates “should be interpreted with the caveat that they do not capture other potential benefits, such as increasing

mission success.” A complete cost-benefit analysis would require monetizing non-traditional benefits and costs as outlined in OMB (1992). For the reasons listed above, then, the policy recommendations discussed earlier may not be as straightforward as they first appear.

The non-traditional costs and benefits of the vehicle types make it somewhat difficult to provide exact recommendations on optimal vehicle matters to policy makers. An extension of the original Rohlf's and Sullivan (2013a) study could fruitfully examine the other vehicle attributes which may or may not impact “mission success.” However, given that force protection (saving lives) was the Army's principle aim of the vehicle procurement programs, advocating the provision of light armored Type 1 TWVs to administrative and support units and medium armored Type 2 TWVs to infantry units would appear to be a reasonable recommendation from analysts to policy makers. The increase in armor protection provided by Type 3 TWVs over Type 2 TWVs does not appear to justify their cost (for their life-saving capabilities). Exceptions, however, could be made for particularly combat intensive units to receive the heavily armored Type 3 TWVs depending on their capability requirements.

8 FINAL THOUGHTS: APPLICATIONS TO OTHER MILITARY SETTINGS

We conclude by noting a few possible applications of the decision criteria we have examined with respect to armoring vehicles as they might apply in other military areas and constitute topics worthy of further empirical research.

One possibility relates to the general issue of military hardware and force protection. Obvious examples are defensive weapons systems to protect the civilian population from terrorist attacks or purchases of body armor, which can be evaluated similarly to how we have examined the decisions to enhance the armor protection of tactical vehicles.

Another issue would be to examine the optimal number of medics for different military unit types with the focus on whether the number pass a cost-effectiveness test. For example, it is typical for infantry platoons (40 or so persons) to have one medic with them in the field. Unfortunately, this means that some squads (usually around nine people) frequently must go on patrols without medics. Would it be desirable in a big picture sense to hire additional medics to save lives versus spending resources on alternative life-saving means? This is currently an unanswered question. Moreover, few medics are assigned to support type units even though some support units see significant action given the non-traditional front lines that exist in Afghanistan and Iraq. It may or may not make sense from an improved potential safety outcome objective to increase the number of medics in support units. Further investigation using the VSL cutoff for improved resource allocation would be a productive way to begin to consider further allocation of medics to units currently operating without them.

The final possible application we will mention concerns one of the costliest areas related to military affairs – the substantial amount of resources spent to help care for wounded soldiers through the VA medical system. We have been emphasizing that the concept of VSL captures the benefit side of efficiency calculations of health and safety enhancing interventions and that VSL varies by both personal characteristics and source of injury. A list of VSL values by patient situation could potentially help evaluate better the tradeoffs among resources and lives saved across numerous medical procedures and get greater total health benefits for the military from allocating limited funds as efficiently as reason tempered by ethical considerations would allow.

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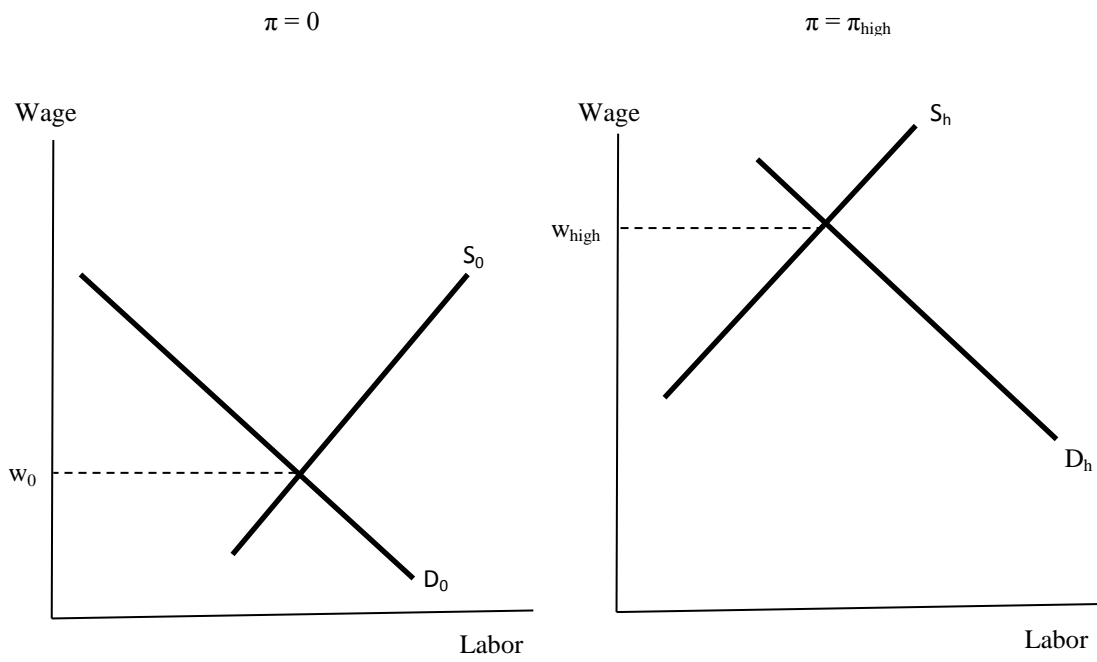


Figure 1 Labor Market Equilibrium with Discrete Risk

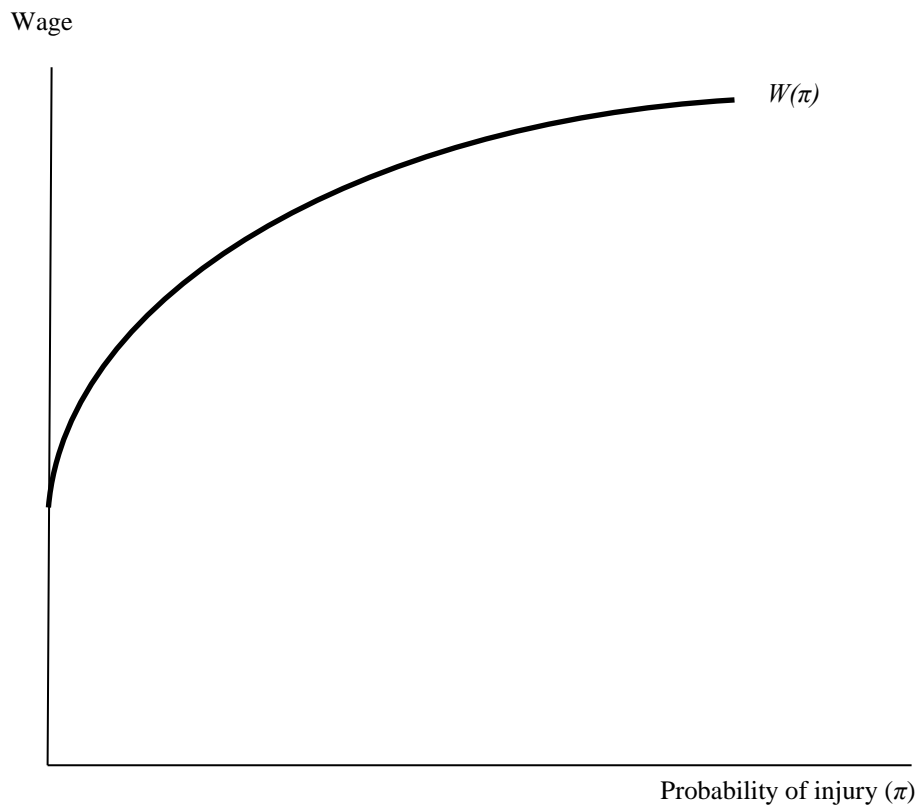


Figure 2 Labor Market Equilibrium with Continuous Risk

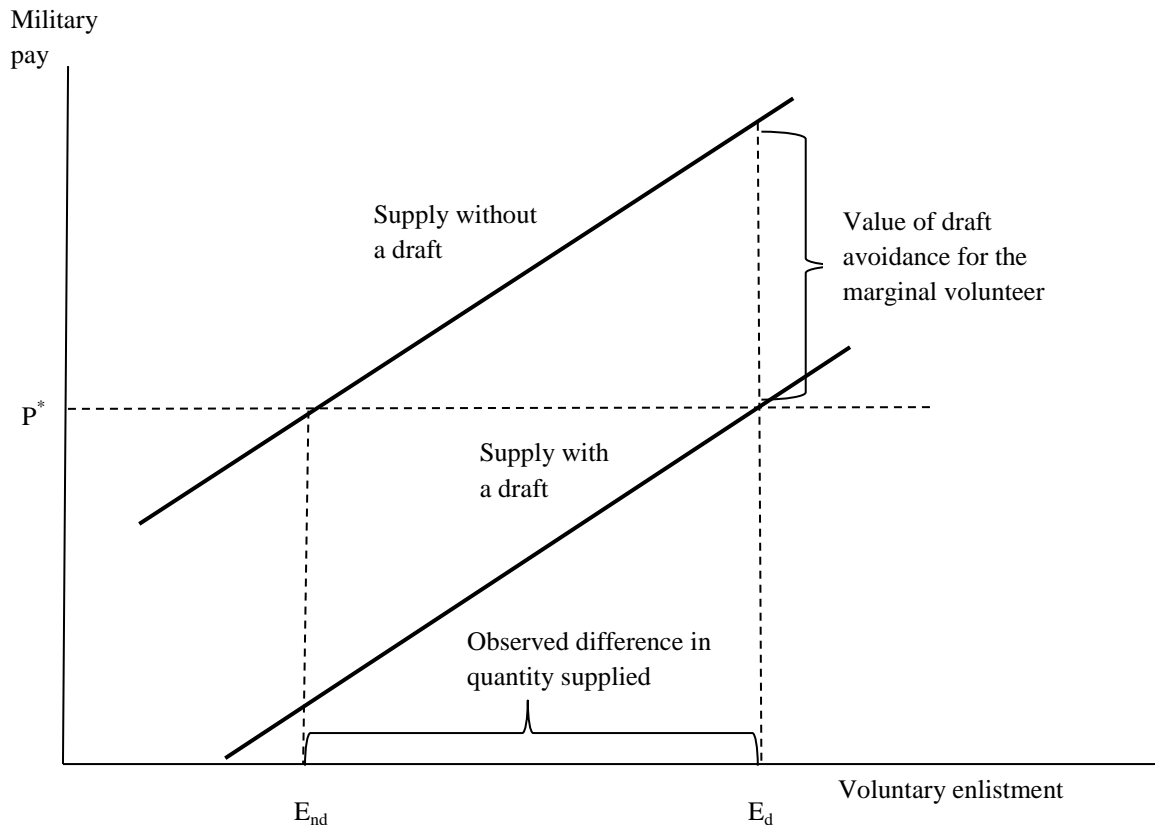


Figure 3 Supply of Voluntary Enlistments and the Vietnam Draft
(derived from Rohlfs 2012, Figure 1, Panel B)