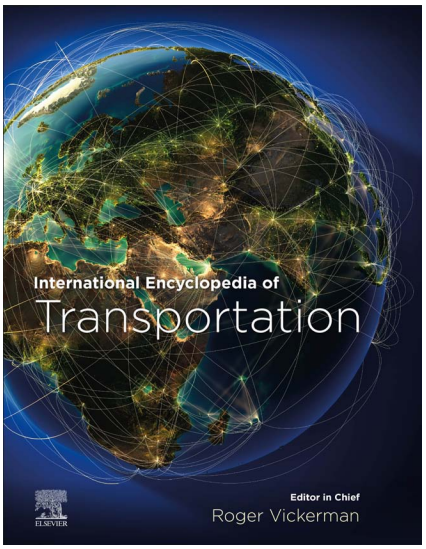

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Economics of Transportation Safety

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Transportation has always been risky. Our ancestors faced risks from being thrown from horses or drowning in rivers. The mechanization of transportation increased the forces exerted on the human body when something goes wrong. Mass transportation increased the number of possible casualties in any incident. Private grief becomes a public spectacle.

Highway transportation is particularly risky. The World Health Organization reports that highway crashes are the eighth leading cause of death with 1.4 million annual fatalities. (Note that safety professionals prefer the word "crash" to "accident" because the latter suggests that occurrence is due to pure fate and cannot be influenced by human decisions.) The per capita risks in low- and middle-income countries are 3 times higher than in the safest countries in northern Europe despite relatively low levels of motorization. In contrast, the risks on railways, waterways, and airways are much lower. But incidents in these modes attract considerable public attention relative to highway crashes.

Economics and Engineering

The proximate cause of crashes is an interaction between vehicle operators (riders, drivers, pilots, etc.), their vehicles, and the infrastructure (highways, railway track, waterway, airway, etc.). For highways, the matrix by Haddon (1972) categorized the factors that explain crash causation and consequences. This three-by-three matrix has the driver, the vehicle, and the highway on one axis, and factors that occur prior to a crash, during a crash, and after a crash on the other axis. This matrix along with illustrative factors is shown in **Table 1**. While this matrix is specific to highway crashes, clear analogies can be made to other modes.

Economics is a complement to, and not a substitute for, the work of human factors and engineering professionals. Economics is important because, long before a crash occurs, drivers have made decisions on how aggressively they drive and how well they maintain their vehicles. Bus and trucking companies have decided on employee training. Highway engineers have decided on design characteristics of the road. The legislature and police authorities have set traffic laws and decided on how aggressively to enforce these laws. Public bodies have decided on budgets for the provision of first responders and trauma centers.

Each of these actors has made decisions by comparing the benefits and costs of their actions. To an economist, the "safety problem" emerges because their decisions do not accord with the best interests of society as a whole. There are "too many" crashes. Economists describe this as a market failure. By understanding why actors do not act in a socially optimal way, interventions can be designed to persuade actors to modify their behavior and ameliorate the market failures.

Table 1 Haddon's matrix

	Before the crash	*During the crash*	*After the crash*
The driver	• Conduct (speed, etc.) • Skills • Vehicle maintenance	• Use of active safety devices (fastening of seat belt prior to the trip, use of child safety seat)	• Skills and equipment of first responders
The vehicle	• Design • Safety equipment • Collision detection • Collision avoidance	• Energy absorption • Cabin design • Passive safety devices (air bags)	• Ease of extraction from vehicle • Integrity of fuel and battery systems
The highway	• Design • Materials • Maintenance	• Guardrails • Breakaway sign posts	• Ease of access by first responders • Location of first responders and trauma centers

How Safe is Safe Enough?

Crashes are undesirable, yet costly to prevent. While society cannot afford to eliminate all crashes, it certainly would prefer that there are fewer crashes than there are today. Determining exactly how many crashes are acceptable to society is difficult. However, understanding the process that actors go through in determining safety provides insights that are useful when designing interventions in the market.

Socially Desirable Decisions by Private Users

Models of safety determination fall into two broad categories. The first category is models of private users operating their own vehicles. This category includes:

- automobile drivers;
- motorcyclists;
- pedal cyclists, pedestrians, and other nonmotorized road users;
- pilots flying their private planes; and
- recreational boaters.

Private users invest money, time, and effort to reduce risks. They invest in their skills, purchase vehicles with more safety features, and pay for maintenance. They can conduct themselves cautiously, perhaps at a cost of taking longer for their trip. This can be referred to as preventive effort. Users trade off these costs against a reduced probability of a crash or increased survivability in the event that a crash occurs. In making their decisions, they adjust for the state of the infrastructure and their assumptions about the effectiveness of emergency response.

While all users prefer more safety to less safety, they may vary in their prevention costs (thrill-seeking users find it more costly to act cautiously) and the magnitude of the losses in the event of a crash (e.g., the losses incurred by a head of household vs. a single person). Consequently, users may rationally exercise different levels of prevention and hence have different safety outcomes.

The variation in safety outcomes is not necessarily a market failure. However, choices are only socially desirable if actors are (1) fully informed about the cost of preventive actions, (2) are aware of the consequences of their actions on crash occurrence and survivability, and (3) are responsible for the full consequences of any crashes that they cause, including damages to other users and bystanders.

Socially Desirable Decisions for Commercial Carriers

The second category of models describes markets where passengers and freight shippers contract with a commercial carrier. Examples include:

- taxis, buses, and other forms of public highway transportation;
- trucking;
- rail passenger and freight services;
- passenger and freight airlines;
- maritime companies; and
- pipelines.

There is a principal-agent problem in that while passengers and shippers have preferences for the level of safety they are willing to purchase, it is the carriers' conduct that produces safety outcomes (Maurino et al., 1995). Passengers and shippers have to select a carrier whose safety matches their own preferences.

Commercial Passenger Transportation

Carriers expend preventive costs to lower the safety risks. While at low safety levels, expenditures on prevention may result in a reduction in total costs due to fewer crashes; in general, carriers that offer higher safety have to charge higher fares to break even. Passengers with a high valuation of safety, and the ability to pay the higher fares, gravitate to carriers offering higher safety. A vertically differentiated market may exist with high safety—high price carriers coexisting with low safety—low price carriers. Often, a variety of safety levels in the market are seen as an indication of market failure. But this is not the case if passengers vary in their tastes for safety, and are able to recognize the safety level offered by different carriers.

Commercial Freight Transportation

Shippers of freight look to minimize the cost of transporting their goods. But in doing so, they have to trade off the costs of more safety with the consequences of any crashes that occur. Because different commodities have different costs of handling and cause different levels of harm in the event of a crash, it is likely that safety varies by type of commodity. Delicate cargoes and those that present high hazards in a crash are handled with considerable care, and more robust and benign cargoes move at lower levels of safety. As with passenger transportation, the variety of safety outcomes does not necessarily indicate a market failure. But socially desirable decisions depend on shippers being knowledgeable about the level of safety on offer, and on carriers, and hence shippers, bearing the full consequences of crashes. The latter is particularly important for hazardous materials, where releases can harm bystanders.

Socially Desirable Decisions by the Infrastructure Providers

In vertically integrated modes such as pipelines and railways, carriers also control safety of the infrastructure. In aviation and maritime, commercial and private users depend on decisions made by ports and airports, and traffic control services. But the distinction is most stark on roads. Design and maintenance of the highway is crucial to system safety, yet there is a separation between the highway authority and the users.

How should the highway authority decide on appropriate design? Economies of density and scale mean that there are a limited number of roads between two places, and a common highway authority presides over the entire network. Consequently, a "one-size-fits-all" level of safety is offered to all users irrespective of their safety preferences. In an ideal world, the authority would select a level of safety that provides the greatest amount of social benefit. This level may not sit well with users who desire a higher level of safety, and those users who would prefer the lower user fees associated with a lower level of safety. There is already a market failure inherent in road provision associated with imperfect competition or monopoly.

Socially Desirable Decisions by Emergency Responders

An often-underestimated way to improve safety is better emergency response. Prompt medical attention during what is called by emergency physicians the golden period (often about 60 minutes) after trauma occurs can be crucial in preventing fatalities. Prompt response to crashes involving hazardous materials can be crucial in mitigating harms to people and property. As with highway infrastructure provision, a "one-size-fits-all" approach is necessary recognizing that emergency services and trauma centers serve other hazards in addition to transportation crashes.

Summary of Desirable Decisions

To summarize the discussion thus far, if transportation users (1) are fully aware of the risks, (2) are fully aware of the costs and benefits of mitigating the risks, and (3) voluntarily accept the risks to gain the benefits of mobility and economic opportunity, then there is not a "safety problem." Moreover, safety outcomes can vary between individual private users and various commercial carriers. This results from variations in willingness to pay for safety by private users and passengers, and variation in the safety prevention costs and harms caused for freight commodities. High safety may optimally coexist with lower levels of safety in vertically differentiated markets. To an economist, this is an indication that the market works and does not necessarily indicate a market failure.

Why the Market Fails

The underlying relationships that describe the socially desirable outcomes are difficult to measure. Calculating the optimal levels of safety in a particular mode is not trivial, and may be practically impossible. However, there are extensive failures in the market for safety. These lead to many actors exerting less preventive efforts than is socially optimal. Consequently, a productive role for public policy is to identify the extensive market failures and devising interventions to ameliorate or correct them. This may be more productive than agonizing over estimating what the level of safety "should be."

The failures derive from the following three underlying characteristics of safety:

- For most actors, the beneficiaries of their preventive efforts include other actors. Unless they are altruistic, this leads the actor to underinvest in prevention because they reap only part of the benefit. Economists call this an uncompensated externality.

- The costs of prevention are incurred in the present and are incurred on every trip. The benefits of reduced crashes do not occur on every trip and only happen at randomly determined points in the future. Actors may discount these future benefits and underinvest in prevention in the present.
- Unlike characteristics such as price that are readily observable, actors may be poorly informed and may purchase a product and service that does not match their tastes in safety. This is because safety is a probabilistic attribute and may not be observable on every trip. Moreover, other actors might avariciously take advantage of poorly informed purchasers by selling a low safety product at a price that is consistent with higher levels of safety.

Externalities

Safety externalities are abundant. Injuries are sustained by innocent vulnerable road users struck by motorized vehicles. Bystanders are affected by hazardous materials releases. Legal structures have developed to assign fault and recover damages. But, they are not a panacea. There may be limitations on the harms that can be legally recovered, and victims may find that the responsible party does not have the financial resources to pay compensation.

Bilateral Crashes

While a surprisingly large number of crashes involve a single vehicle (e.g., a motor vehicle running off the roadway), collisions with other users predominate. The actions of both parties determine the probability of a crash. A complex legal literature describes how fault should be assigned to ensure that the actor who can reduce the risk at the lowest possible cost should be given incentives to take action (Shavell, 2004). Market failures abound in the adjudication of fault in multi-vehicle crashes.

Cognitive Failures by Individuals

Private users make decisions to expend effort to mitigate risk in the present, but the consequences of their actions or inactions occur in the future. Passengers have to choose between the level of fares and future crash risks. Some individuals may be myopic in ignoring or downplaying the future consequences. Others may lack self-control when trading off effort in the present with future negative consequences. More broadly, humans tend to be very poor in evaluating the probability of low-probability crashes, and thinking about the consequences of deadly events. There is considerable overconfidence, with the majority of drivers believing that they are safer than the average driver, which cannot be true statistically. Individuals also suffer from cognitive dissonance in that nearly all trips are completed safely reinforcing beliefs that a crash "will not happen to me." As a result of this range of cognitive failures, users downplay the future probable benefits from investing in safety in the present. They take less care than they should.

Imperfect Information

While fully informed actors can have cognitive problems in processing information, the problem is compounded when actors are poorly informed. Private users may be poorly informed about the safety characteristics of their vehicles and the magnitude of the potential safety benefits from modifying their conduct. The situation is even worse for commercial transportation. Passengers and shippers have to form an opinion about the levels of safety that carriers are offering. Unlike other attributes of service such as price and speed, information on safety is difficult to observe, obtain, or understand. Crashes are rare events and tend to be a poor indicator of the safety of individual carriers.

Vertically differentiated markets require customers to sort themselves among the safety offerings, and this is difficult when information is poor. If customers are totally uninformed, all carriers offer a low level of safety. Carriers would be unable to convince customers that they are offering a high level of safety with a commensurate higher price. Therefore, differences in safety offerings indicate that customers are at least partially informed. Albeit, poor information is endemic in safety markets.

Carriers also suffer from imperfect information. Carriers rely heavily on the skills of their employees to produce safety. Yet, they are imperfectly informed about their skills at the point of hiring, and frontline employees tend to perform their duties without direct supervision. Especially in commercial road transportation, drivers with poor safety records can successfully masquerade as having higher skills in order to work at carriers who pay higher wages and wish to provide a high-quality product.

Carrier Myopia

As with private users, some carriers may be myopic in that they downplay the future consequences of their current actions. They may be very well aware of the costs of employee training but do not appreciate the beneficial effect on future crashes. This failure is particularly associated with inexperienced new entrants to the market.

The problem also extends to incumbent carriers. If passengers and freight shippers are imperfectly informed, then conditions are ripe for some carriers to cheat. Carriers that previously offered a higher level of safety could cut their safety investments (and hence their costs) while still masquerading as a higher-safety carrier and charging a high price. Such carriers can earn profits, at least until the customers find out and either shun the carrier or demand a lower price. Why might a carrier do this? Carriers close to bankruptcy

may be particularly susceptible. The carrier may hope that the cost savings provide a buffer until favorable trading conditions return. Other financially stressed carriers may discount the future consequences of crashes because they know that they do not have the finances to meet any judgments.

Economists tend to be skeptical about such arguments, because a carrier has invested to obtain a reputation for high quality. Why would such a carrier want to squander its reputation? Nevertheless, cheating tends to be very prevalent, and has severe consequences. Customers end up purchasing a service that differs from their tastes, and, in the event of a crash, the carrier may not have the financial resources to pay compensation.

Imperfect Competition

The market failures due to lack of choice in modes with economies of density and scale have already been discussed. Even in inherently competitive modes such as highways, a "one-size-fits-all" level of infrastructure safety results in a market failure. When there are few competitors, a small number of safety choices are available in the marketplace, and most passengers and shippers cannot obtain the exact level of safety that they desire. In commercial modes indivisibilities in vehicle size (airplanes, trains, and less-than-truckload trucking) mean that customers with different tastes in safety share the same vehicles, and a limited number of safety options are on offer.

Relative Magnitude of the Market Failures

The applicability and magnitude of the market failures varies significantly between modes and between private users and commercial passenger and freight services. **Table 2** provides a summary using a star rating of the relevance of the six market failures to the various modes and market segments. The more stars indicate the more prevalent market failures.

Market Interventions

Recognizing how the market failures originate and which actor(s) they affect is the basis for intelligent public policy prescription. Policy responses need to be tailored to the root causes of the problem, and the actor who can most effectively change the market outcome. No intervention is a panacea by itself, and some interventions have their own weaknesses. Consequently, these interventions should be thought of as complements and not substitutes.

Liability

Externalities and bilateral crashes are directly addressed by making responsible parties legally liable for their actions (Shavell, 2004). Liability is a powerful solution to these problems but it is not without limitations. The law may limit some losses from being recovered (e.g., emotional harm or lost profits as opposed to physical damage). It is also an "after-the-fact" market intervention. Private users and commercial carriers who are myopic may still underinvest in safety, even if they ultimately have to pay compensation.

Insurance Requirement

Insurance goes hand in hand with liability because of the concern that a responsible party may not have the resources to satisfy claims (Dionne, 2014). Insurance also tackles the problem of myopia by transforming future consequences into premiums that have

Table 2 The magnitude of the six market failures by mode

	Externalities	*Bilateral crashes*	*Individual cognitive failures*	*Imperfect information*	*Carrier myopia*	*Imperfect competition*
Private driving	*	***	***	**	Not applicable	***[a]
Private aviation and boating	*	*	**	*	Not applicable	*
Commercial passenger	*	**	**	***	***	**
Road freight	***	**	Few	**	***	***[a]
Airfreight	*	*	Few	*	***	Few
Maritime freight	**	*	Few	*	***	Few
Rail freight	**	***	Few	*	**	***
Pipelines	***	Not applicable	Few	*	**	***

Notes: *, limited failures; **, some failures; ***, substantial failures.
[a]Failure comes from the provision of highway infrastructure.

to be paid in the present. Private users and commercial carriers can trade off greater safety investments against reduced premiums in the present, and there is less chance of myopia. Insurance companies also have incentives to monitor the activities of their clients, and this gives incentives to insured parties not to shirk on preventive efforts.

All insurance suffers from two main drawbacks. Moral hazard occurs when an actor covered by insurance acts in a riskier fashion than it would do otherwise because the insurance company is responsible for paying any claims. If insurance is optional, there are problems of adverse selection when low-risk clients opt not to purchase, and premiums increase as only higher-risk clients remain.

Information Provision

The obvious solution to imperfect information is making actors better informed. New private users and operating employees of commercial carriers are typically required to take classes and pass a test before receiving a license. The classes and tests focus on understanding the risks and rules of conduct. Subsequently, users are bombarded by public information campaigns warning of the consequences of fatigue, distraction, and alcohol.

Information can be provided to passengers and shippers to help them decide which carrier to select. Rating schemes can be put in place by the government or private providers. This is unambiguously a good thing, as customers become aware of which carriers offer poor service, and the customers provide a discipline on the market. However, such information cannot deal with the problem of cheating. Cheating carriers deviate from their past safety performance. Retrospective information on crashes may not be a reliable prediction of future performance. It is often argued that information should be provided on safety inputs, such as employee training, as opposed to safety outputs (crashes) as a predictor of future safety performance.

Safety Regulation

A familiar intervention is setting and enforcing minimum standards. These standards can be on user training and conduct, the safety features of vehicles, infrastructure design, emergency response, and management processes adopted within commercial carriers. These regulations only define a minimum. Users and carriers are free to adopt higher safety levels if they prefer. Therefore, safety regulation is not a good solution to the problems of imperfect information in passenger and freight transportation because it does not inform customers about the range of safety that is offered. For mode specific details, see Elvik et al. (2009), Evans (2004), Kristiansen (2005), Lamm et al. (1999), and Savage (1998).

A common regulatory concern is known as risk compensation (Blomquist, 1988). This is when a user or carrier compensates for regulatory action in one dimension by undertaking riskier actions in another dimension. For example, making a highway less risky by straightening curves may encourage road users to drive faster. This is not an argument that regulatory action should not be undertaken, but rather that the consequences of regulatory action may be overstated.

There is a tension between expressing the minimum as a specification standard or a performance standard. In many ways, a performance standard that specifies the required safety outcomes best addresses market failures and does so without the regulator micromanaging the production of safety. In practice, standards are often expressed as minimum technical specifications for user conduct and vehicles, as these form bright line rules for the determination of compliance and the assessment of penalties.

A regulatory approach requires a legislative framework to enact regulations, and then an enforcement strategy by the police, government inspectors, and the courts. In setting a minimum standard, there is a risk that the standard is either set too low or unreasonably high. Economists have long used a technique called benefit–cost analysis to help determine the level at which the standard should be set. This is combined with quantitative risk assessment techniques that attempt to estimate the effects of actions on the number and severity of crashes. The costs of the regulation are compared with the expected benefits. Purely financial costs and benefits are combined with monetarized equivalents of costs such as longer journey times and benefits such as reduced injuries (Jones-Lee and Spackman, 2013).

Regulations are meaningless unless they are enforced. Forming a strategy for regulatory enforcement is not trivial. For example, there is a trade-off between the probability of detecting a violation of the regulations and the size of the resulting penalty. There can either be a high probability of detection and a low penalty, or a low probability of detection and a high penalty. Users might also be rewarded for good conduct in addition to penalizing poor conduct. It is an empirical matter as to whether enforcement is effective in changing behavior and preventing recidivism.

Closing Comments

Safety is an important and contentious aspect of transportation. The annual number of fatalities and serious injuries is large. So is the amount of property damage and the potential harm to the environment. The provision of safety is riddled with cognitive and market imperfections. Corrective legal and regulatory interventions are longstanding and continue to evolve. Despite substantial improvements in the past half-century, society continues to demand that more should be done to further reduce the risks.

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