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The vehicle value externality

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ABSTRACT

This paper introduces the vehicle value externality as a previously unacknowledged cost of car traffic. Unlike established externalities such as emissions or congestion, the vehicle value externality arises from the impact of vehicle value on accident damages. By developing a model linking insurance premiums to this externality and applying it to German car traffic data, we estimate the annual aggregate cost at 10 billion euros in 2021.

1. Introduction

Beyond the costs individually borne by drivers, automobile use imposes a wide range of external costs on other road users and society as a whole. Economic research has identified and analyzed various such externalities, including greenhouse gas emissions, pollution, road damage, traffic congestion, land use (Parry et al., 2007; Santosa et al., 2010), accident risk (Edlin and Karaca-Mandic, 2005), and vehicle weight (Anderson and Auffhammer, 2014). This paper introduces a further, hitherto unexplored externality, the vehicle value externality.

The vehicle value externality arises from the fact that drivers are generally liable for damages they cause to other vehicles. If someone drives a more expensive car, they increase the expected damage that other road users can cause to their vehicle. The costs to others of a more expensive vehicle, however, is not something drivers need to consider when purchasing a vehicle; in other words, these costs are outside of their individual decision-making calculus. By utilizing data from German car traffic, we demonstrate that these costs are significant.

In Section 2 we identify the externality in a theoretical model. As expected, the externality is determined by the value of a driver's vehicle involved in an accident and the likelihood that other drivers, rather than the involved driver, caused the accident. In Section 3 we quantify the vehicle value externality for Germany. To do this, we utilize data on premiums for motor vehicle liability and comprehensive insurance, as these aggregate information on anticipated vehicle damage. Section 4 briefly concludes.

2. The model

Consider $i = 1, \ldots, N$ ex ante identical drivers. A representative driver's vehicle has a value of v. If the driver is involved in an accident, the expected damage to his vehicle is α times 100% of the previous vehicle value. In addition, the driver can suffer personal injury. The expected value of the monetary-valued personal injury is h. Thus, the total expected damage from an accident suffered by the driver is $d = \alpha v + h$.

A driver can have an accident with or without the involvement of other drivers. Let p_k be the probability of an accident with $k = 1, \ldots, K \leq N$ involved drivers. Ex ante, a driver is responsible for the kth part of the total accident damage if k drivers are involved in the accident. Driver i therefore faces the following expected loss when participating in car traffic

$$l_i = \sum_{k=1}^{K} \frac{1}{k} p_k d_i + \sum_{k=1}^{K} \frac{k-1}{k} p_k d_{-i}, \tag{1}$$

where d_i denotes the expected damage suffered by driver i in an accident, and d_{-i} denotes the expected damage suffered by each of the other drivers involved in the accident. The first sum on the right-hand side of (1) measures the expected damage that driver i causes to himself in traffic and the second sum measures the expected damage that driver i causes to other drivers.

The expected accident losses of all drivers in total are given by

$$L = \sum_{i=1}^{N} l_i = N \sum_{k=1}^{K} p_k d,$$

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which can be decomposed into

$$L = \sum_{k=1}^{K} p_k d_i + (N-1)\sum_{k=1}^{K} p_k d_{-i}.$$

Now consider a marginal increase in the value of driver i's vehicle. This increases the expected damage that driver i can inflict on himself in car traffic, as well as the expected damage that other drivers can inflict on driver i and for which they are liable to driver i. The marginal increase in the expected loss associated with an increase in the value of driver i's vehicle accruing to himself reads

$$\frac{\partial l_i}{\partial v_i} = \alpha \sum_{k=1}^{K} \frac{1}{k} p_k,$$

whereas the total expected loss of all drivers increases by

$$\frac{\partial L}{\partial v_i} = \alpha \sum_{k=1}^{K} p_k.$$

When driver i decides on the value of his vehicle, v_i, he takes into account that a higher vehicle value increases the damage he suffers in the event of an accident. However, driver i has no incentive to take into account the higher expected damage that other drivers cause to his vehicle if the value of his vehicle increases, since the other drivers are liable for this higher expected damage. Therefore, driver i triggers a negative externality on the other road users when he decides on the value of his vehicle.

The marginal externality that driver i triggers on other drivers through a more expensive vehicle, mx_i, is determined by

$$mx_i = \frac{\partial L}{\partial v_i} - \frac{\partial l_i}{\partial v_i} = \alpha \sum_{k=1}^{K} \frac{k-1}{k} p_k.$$

The total vehicle value externality that driver i triggers on the other drivers, x_i, is obtained by integrating mx_i

$$x_i = \sum_{k=1}^{K} \frac{k-1}{k} p_k \alpha v_i. \tag{2}$$

The vehicle value externality that driver i imposes on others is the expected damage to driver i's vehicle, αv_i, weighted by the probability that other drivers, not driver i, cause the accident. Information about expected accident damage is typically embedded in the premiums drivers pay for motor vehicle liability and comprehensive insurance. In the following section, we use this information to quantify the vehicle value externality.

3. Quantifying the externality

Drivers are liable for the damage they cause to others. Thus, in most countries, including Germany, they are required to have motor vehicle liability insurance. The expected damage that driver i inflicts on others is represented by the second sum on the right-hand side of Eq. (1). In a competitive insurance market, the premium π_i^l that driver i pays for motor vehicle liability insurance equals this expected damage

$$\pi_i^l = \sum_{k=1}^{K} \frac{k-1}{k} p_k d_{-i}.$$

The motor vehicle liability insurance premium can generally be broken down into three parts: one for personal injury to others, one for property damage to other vehicles, and one for other types of damage, like damage to roads or other infrastructure. The part of the premium, that reflects the expected vehicle damage caused to others, π_i^v, is determined by

$$\pi_i^v = \sum_{k=1}^{K} \frac{k-1}{k} p_k \alpha v_{-i}. \tag{3}$$

Combining (2) and (3), the vehicle value externality becomes

$$x_i = \pi_i^v \frac{v_i}{v_{-i}}.$$

Since drivers are identical ex ante, each driver triggers a vehicle value externality on other drivers amounting to

$$x = \pi^v. \tag{4}$$

If information were available about how the motor vehicle liability premium is divided into a premium for personal injury, vehicle damage and other damages, the externality could be calculated directly using (4). Unfortunately, insurance companies do not provide any information on how the total motor vehicle liability insurance premium is divided between the three types of damage. We therefore take an indirect approach to calculate the externality. In addition to motor vehicle liability insurance most drivers purchase comprehensive insurance, which covers the expected damage that drivers cause to their own vehicles by participating in car traffic. This damage is represented by the first sum on the right-hand side of Eq. (1). Thus, in a competitive insurance market, the comprehensive insurance premium for driver i is

$$\pi_i^c = \sum_{k=1}^{K} \frac{1}{k} p_k \alpha v_i. \tag{5}$$

Taking into account ex ante identical drivers and combining Eqs. (3), (4) and (5), it follows that

$$x = \frac{\sum_{k=1}^{K} \frac{k-1}{k} p_k}{\sum_{k=1}^{K} \frac{1}{k} p_k} \pi^c. \tag{6}$$

Since information on the average premium of comprehensive insurance, π^c, and on accident probabilities are available for Germany, Eq. (6) allows a quantitative estimation of the vehicle value externality. In Germany, 258,987 car accidents occurred in 2021, including 63,684 single-vehicle accidents, 175,765 two-vehicle accidents, 16,745 three-vehicle accidents, 2850 four-vehicle accidents, 917 accidents involving five to nine vehicles, and 26 accidents involving 10 to 19 vehicles (Destatis, 2023a,b). This means that accidents with two cars occurred 2.76 times as often as with one car, 10.50 times as often as with three cars, 61.67 times as often as with four cars, 191.67 times as often as with five to nine cars and 6760.19 times as often as with 10 to 19 cars. As these figures suggest, accidents involving five or more cars only account for a negligible proportion of the total number of accidents. These are therefore not taken into account for further estimation of the vehicle value externality.

From the frequencies of car accidents, we can derive ratios between the conditional probabilities of a driver being involved in an accident with k cars within a year. Let β_k denote the conditional probability that k cars are involved, given that an accident has occurred. Based on the given data, we find that: $\beta_1 = .36\,\beta_2$, $\beta_3 = .095\,\beta_2$ and $\beta_4 = .016\,\beta_2$. By examining the ratios of these conditional probabilities, we can directly determine the ratios of the unconditional probabilities, that is, the probabilities that an accident involving k cars occurs. Let p denote the probability of an accident happening, then from the definition of conditional probability, we have: $p_k = p\,\beta_k$. Consequently, it follows that $p_k/p_l = \beta_k/\beta_l$ for all $k, l = 1, \dots, K$.

For $K = 4$ it can thus be derived from Eq. (6) that

$$x \approx .64\,\pi^c.$$

The average annual premium for comprehensive car insurance in Germany in 2021 was $\pi^c = 324$ euros (Statista, 2024). From this we conclude that the average annual vehicle value externality per car was 207 euros.

It is important to note that we quantified the externality under the specific assumption of identical drivers, who would pay the same insurance premiums. In reality, premiums vary significantly based on factors like driving experience, age, gender, occupation, and location. Our calculation, therefore, represents an average externality across all drivers.

Furthermore, our theoretical model assumes perfect competition in the insurance market, where premiums equal expected damages. However, real-world insurance premiums include profit margins, typically ranging from 2% to 20% of the premium. Edlin and Karaca-Mandic (2005), for example, consider a profit margin of 14%. While profit margins influence individual premiums, they do not significantly impact the overall externality calculation. This is because profit margins are part of the vehicle value externality. When a driver purchases a more expensive car, the liability premiums for other drivers increase, including the profit margins they pay. Thus, profit margins should be considered when quantifying the externality.

4. Conclusion

This paper has identified a vehicle value externality and estimated this externality for Germany. In 2021, the externality amounted to 207 euros per registered car. In the same period, the total stock of registered cars in Germany was around 48 million (Destatis, 2023a). The annual aggregate vehicle value externality thus adds up to around 10 billion euros, which corresponds to about .25 percent of German GDP. These figures suggest that, due to the vehicle value externality, a significant part of the costs of car traffic has been unpriced.

This paper has calculated the average vehicle value externality. However, more expensive vehicles generate a higher externality than cheaper ones. Therefore, to internalize the vehicle value externality through a Pigouvian tax, the levy could be based on the individual vehicle value, with the average levy corresponding to the average externality.

As a final remark, we would like to point out that the externality identified here is not limited to car traffic. Whenever individuals fail to account for the increased liability risk of others when acquiring valuable possessions, a value externality arises. However, this externality is particularly pronounced in car traffic, where individuals expose valuable assets to damage from a large number of anonymous road users. This distinguishes car traffic from other contexts with fewer potential liable parties. In the private sphere, the value externality can be remedied by strategies that resemble Coasesian internalization. For example, when a homeowner invites friends to his home filled with valuable items, he may ask that the friends leave their children at home. Alternatively, he may lock these items securely before the guests arrive. Another way to mitigate the value externality may be to only associate with people who have similarly valuable objects and comparable risk characteristics. In car traffic with a large number of anonymous participants, such strategies are practically impossible. Therefore, a Pigouvian-style levy, as proposed here, is a more suitable approach to internalizing the vehicle value externality.

Data availability

Data will be made available on request.

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