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Costs and Benefits of a Bicycle Helmet Law for Germany

By Gernot Sieg*

This study presents a cost-benefit analysis of a law requiring cyclists to wear a helmet when riding a bicycle in Germany. The cost benefit-analysis takes into account the benefit of increased security when cyclists wear a helmet or use a transport mode that is less risky than cycling. The analysis also considers the cost of purchasing helmets, reduced fitness when cycling is replaced by a motorized transport mode, the discomfort of wearing helmets and environmental externalities. The benefits of a helmet law are estimated at about 0.714 *of the costs. A bicycle helmet law for Germany is found to be a waste of resources.*
JEL: K32; L91; R41

I. Introduction

Many studies show that bicycle helmets effectively reduce head injuries among cyclists. On the other hand, about 9 out of 10 cyclists in Germany do not wear a helmet. For this reason, the German federal government is aiming to ensure that significantly more cyclists wear a helmet, and some politicians are calling for a law requiring cyclists to wear a helmet.

A helmet law would affect cyclists who previously (in the Status Quo of no helmet law) only occasionally or never wear a helmet when cycling (see Figure 1). A helmet reduces the severity of injury in the event of an accident (Protection effect), but may reduce the pleasure of cycling and be a nuisance (Comfort effect). Furthermore, cyclists who do not have a helmet have to buy one (Purchase effect). Some will therefore opt for another mode of transport, for example bus or car, rather than wearing and/or buying a helmet. These cyclists increase their safety by changing the nature of exposure to risk related to the traffic mode used (Exposure effect), but sacrifice the positive impact of cycling on the cardiovascular system (Health effect). Furthermore, motorized transport is noisy, pollutes the environment and fosters global warming (Environment effect).

Human beings are usually capable of behaving successfully even in complex and risky situations like traffic. However, from a social point of view, the decision to buy and use safety equipment can be distorted by externalities. Due to a comprehensive social security system in Germany, most of the expected medical costs and losses of earnings are external to a rational cyclist's decision to buy or use a helmet. Furthermore, due to sales taxes, the private purchasing costs of helmets exceed the social costs of production. Because of such externalities, even homogenous, rational individuals would not install some safety equipment even if it were efficient from a social point of view. Furthermore, many individuals regulary have problems estimating the probability of rare events occurring, such as bicycle accidents. A cost-benefit analysis can be uses to identify such market failure.

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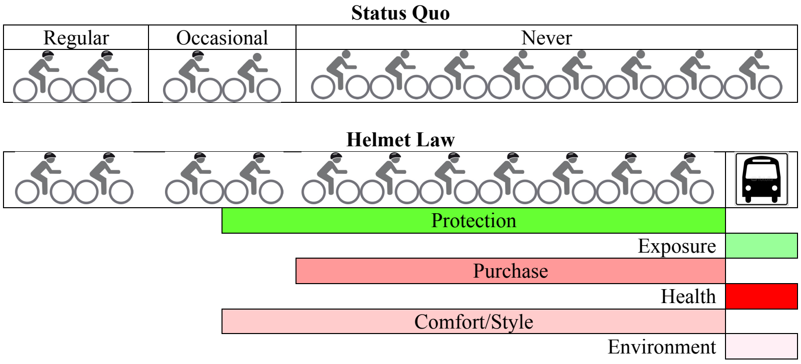

Figure 1. Negative (red) and positive (green) effects of a helmet law

Note: The size of the effect bars is not proportional to the monetary value but indicates which cyclists are the source of the effect in question. For the monetary value see Figure 2.

From a utilitarian perspective,[1] the benefits of a helmet law should at least exceed the costs. If this is not the case, resources are wasted. Empirical evidence on the costs and benefits of helmet laws is rather scarce (Taylor and Scuffham, 2002; de Jong, 2012) and there is no consensus as to whether or not helmet laws increase welfare (Robinson, 2007).

Whereas cost-benefit analysis is used regularly to determine the impact of road investment projects in Germany and many other countries, they are not used regularly to asses the impact of measures designed to improve traffic safety, arguably because some important impacts are difficult to include. However, following the seminal paper of Sælensminde (2004), many studies now include health and external cost changes when people change from travel by car to cycling or walking or vice versa. However, there has been considerable variation in how the health effects of cycling and walking are included in cost-benefit analyses (Cavill et al., 2008). The interpretation and comparison of cost benefit ratios becomes problematic and variable when some impacts, such as on the environment, climate, and health, are not valued in markets or in choice situations similar to market transactions. In order to consider the impact of cycling and walking on health this study uses the "Health economic assessment tool for cycling and walking" (HEAT) provided by the WHO Regional Office for Europe (Kahlmeier et al., 2013), enabling a sound interpretation of the results. Whereas wearing a helmet and carrying it around is obviously a nuisance, there are no market prices for this discomfort. The comprehensiveness dilemma (Sager, 2013) for the current study is that we must choose between a narrow CBA excluding the Comfort/Style aspect, and a comprehensive cost-benefit analysis, including Comfort/Style even without market-based evaluations. However, because the Comfort/Style argument is important for most cyclists who do not wear helmets, this study includes the utility losses when calculating the benefit cost ratio. Because a sensitivity analysis shows that opting for a narrow CBA, excluding the Comfort/Style aspect, does not change the policy implications, comprehensiveness is not a dilemma for this study.

[1] van Wee and Rietveld (2013) discuss ethical aspects of using the value of statistical life (VSL) for the ex ante evaluation of transport policy options.

The following analysis calculates the social benefits and social costs of a mandatory helmet law for Germany. The approach is similar to that of de Jong (2012) in using a simple mathematical model of individual decisions to cycle with and without a helmet law and by using parameter estimates from previous studies (see Table 2), as done by Elvik et al. (2009). However, the present study develops a more detailed model and uses more current data for Germany.

II. Helmet law and modal split

In 2008, all cyclists in Germany cycled a total distance of $W = 3.296942 \times 10^{10}$ km (Bundesministerium für Verkehr, 2012), which is a annual distance of 401 km per head. A fraction of $q_h = 0.13$ of this distance is cycled wearing a helmet (Bundesanstalt für Straßenwesen, 2013). The number of cyclist accident victims in 2012 in Germany was 74,776, including $F_g = 406$ fatalities, $F_s = 13,854$ seriously injured and $F_l = 60,516$ slightly injured (DeStatis, 2013).

An unintended but inevitable effect of requiring a helmet when cycling is the substitution of the bicycle by other modes of transport. In principle, all non-helmet wearer could choose not to ride a bicycle. In a survey by Rissel and Wen (2011), 22.6 per cent of the respondents answered that they would cycle more if they did not have to wear a helmet, as is required by Australian law. Of occasional cyclists, who used a bicycle in the last week, but do not cycle daily, 40.4 percent reported that they would cycle more if there were no helmet law. Robinson (1996) reports that the Australian helmet law discouraged children to the extend of 42 percent reduction in the first year, whereas the figure for adults was only 29 percent. Carpenter and Stehr (2011) analyze laws in the U.S.A. requiring youths to wear a helmet when riding a bicycle and show that the laws significantly reduced youth bicycling by 4-5 percent. Using the results of the most current and econometrically sophisticated study from Carpenter and Stehr (2011), this present study assumes a reduction $r = 0.045$ of bicycling if a helmet law is passed and this reduction is accomplished entirely by previously non-helmeted cyclists. Then, after the helmet law has been passed, the totaol distance $[q_h + (1 - q_h)(1 - r)]\ W$ is cycled (helmeted) and only the distance $W_{ind} = (1 - q_h) \cdot (1 - r)\ W$ is cycled with a helmet because of the law.

People substitute a distance $W^S = (1 - q_h)r\ W$ of cycling by other transport modes. To identify the distances travelled by these other modes, this study assumes that the travel time budget does not change.[2] At a cycle speed of $v_f = 12.3$ km/h, the annual distance of 401 km takes 32.6 hours to cycle. The second assumption is that the former cyclist spends his/her time budget according to the current modal split of $ms_c = 0.31$ on cars, $ms_b = 0.26$ on public transport and $ms_p = 0.3$ as pedestrians (Jahn and Krey, 2010). Because these values are calculated for distances travelled (and not for time spent), we use the speeds of walking $v_p = 4.9$ km/h, of going by car $v_c = 24.9$km/h and of public transport $v_b = 17.0$ km/h to calculate how much time t is spent traveling 1 km of distance using the different transport modes according to the observed modal split:

$$t = \frac{ms_c/v_c + ms_b/v_b + ms_p/v_p}{ms_c + ms_b + ms_p}.$$

[2]See Mokhtarian and Chen (2004) for a discussion of travel time budgets.

The average annual distance $w = 401$ km of cycling is substituted by

$$w_s = \frac{w}{v_f}\frac{1}{t} = 319 \text{ km},$$

and of that, 113 km by car, 95 km by public transport and 110 km by walking. To summarize, people substitute a distance $W^s = (1 - q_h)rW$ of cycling by

$$W_i^s = \frac{ms_i}{ms_c + ms_b + ms_p} \frac{(1 - q_h)r\ W}{v_f} \frac{ms_c + ms_b + ms_p}{ms_c/v_c + ms_b/v_b + ms_p/v_p}$$

with $i \in \{c, b, p\}$.

III. Monetary evaluation of the effects of a helmet law

Except for the costs of new helmets (Section 3.4) and the health effect, this study uses statistical averages that are proportional to the annual distance W cycled in Germany to calculate all costs and benefits. Therefore, it is irrelevant whether effects occur because of a change in helmeted cycling or a change in the number of helmeted cyclists. Only in order to estimate the number of helmets cyclists have to buy because of the law, do we need to calculate the number of cyclists and helmet owners in Germany.[3]

A. Protection effect

Bicycle helmets are a passive safety measure and cannot prevent, but only reduce the consequences of accidents. In the case of an accident, head injuries are usually also associated with those of the extremities as well, the extent of which a helmet can not reduce. Richter (2005) analyzed 22,794 cyclists hospitalized as victims of traffic accidents at the "Abteilung fr Unfallforschung der Unfallchirurgischen Klinik der Medizinischen Hochschule Hannover", Germany, and found a proportion of 48 percent head injuries, of which 68 percent were located in the protection area of a helmet. Therefore, in this study it is assumed that a bicycle helmet is able to reduce substantially a fraction of $q_{head} = 0,3264$ of all injuries.[4]

A meta-study by Attewell, Glase and McFadden (2001) notes that the risk of head injury is reduced by 60 percent by wearing a bicycle helmet, and in particular, the risk of brain injury by 58 percent and of facial injuries by 47 percent. The most comprehensive meta-study is by Elvik (2013), who concludes that bicycle helmets effectively reduce head injuries. In contrast, no (or a negative) neck-injury effect is observed. For the following calculations, the odds ratio calculated in a publication bias-adjusted meta-analysis (random effects model) of 23 studies by Elvik (2013) is used. He calculates an odds ratio of 0.5, with a 95 percent confidence interval of 0.39 to 0.65. In this study, the concept of risk reduction is used and the assumed risk reduction value of $rr = 0.5$ means that wearing a bicycle helmet reduces the severity of an injury in 50 percent of the accidents.[5]

[3]Furthermore, in the HEAT algorithm, output depends also but only slightly on the number of cyclists.

[4]Hagel and Yanchar (2013) calculate a value of 20 percent to 40 percent of head injuries in bicycle injuries for Canada and Dinh et al. (2010) report that 25 percent of trauma admission registered in the Royal Prince Alfred Hospital, Sydney, Australia, had head injuries.

[5]The odds ratio is different from the relative risk and the odds ratio will always exaggerate the size

The value of a statistical life is set to $VSL = 1.574$ Million € (Kahlmeier et al., 2013). The statistical cost of a severe injury (at least one day at the hospital) is set to $S_s = 0.13 \cdot VSL$ and a minor injury to $S_l = 0.01 \cdot VSL$ (European Conference of Ministers of Transport , ECMT).[6] It is assumed that the positive effect of wearing a bicycle helmet is that there will be only a serious injury instead of a fatality, a minor injury instead of a serious injury and no injury instead of a minor injury. This assumption is used here because only head injuries are considered and because a bicycle helmet is a passive safety measure that does not prevent accidents but only reduces the severity of an injury.

When calculating the effect of helmet-wearing, using actual numbers of fatalities and injuries, we have to consider that the observed numbers are fatalities and injuries in the current (2012) population of helmet wearers and non-wearers. That means, for example, that some of the seriously injured helmeted cyclists of 2012 would have been fatalities if they had been unhelmeted. To calculate the hypothetical numbers F_g^h, F_s^h and F_l^h of victims in a completely helmet-free environment, we use the fact that risk reduction rr only works for the fraction of head injuries q_{head} of the proportion of q_h helmeted cyclists and therefore only for a proportion $f = q_h \cdot q_{head} \cdot rr = 0.0212$, the accident severity is reduced from fatality to severe, severe to slight or slight to none.

$$F_g = (1 - f)F_g^h \tag{1}$$

$$F_s = fF_g^h + (1 - f)F_s^h \tag{2}$$

$$F_l = fF_s^h + (1 - f)F_l^h \tag{3}$$

The system of equations are solved by

$$F_g^h = \frac{F_g}{1 - f} \tag{4}$$

$$F_s^h = \frac{F_s - f(F_g + F_s)}{(1 - f)^2} \tag{5}$$

$$F_l^h = \frac{F_l(1 - f)^2 + f(f(F_g + F_s) - F_s)}{(1 - f)^3} \tag{6}$$

getting numbers of $F_g^h = 414.8$, $F_s^h = 14,145.3$ und $F_l^h = 61,521.1$.

The statistical monetary value of reduced injury severity or fatalities resulting from the wearing of bicycle helmets can now be calculated. The value N^h is hypothetical, because it compares a situation that all cyclists wearing a helmet to that of no cyclists at all wearing a helmet:

$$N^h = (1 - rr)q_{head}[(VSL - S_s)F_g^h + (S_s - S_l)F_s^h + S_l F_l^h]$$

which is $N^h = 686,766,000$ €. Using the fact that in Germany the annual distance cycled is $W = 3.296942 \times 10^{10}$ (Bundesministerium für Verkehr, 2012), we can estimate a statistical value for the protection provided by a helmet to $V_{km}^h = N^h/W = 2.083$ Cent per km cycled. Remembering that the law induces

of the effect, compared to a relative risk. Using the estimate of an odds ratio as risk reduction, as in this study, slightly overestimates the actual risk reduction of bicycle helmets.

[6]If there are only data about injuries, a weighted average of $S_m = 0.027 \cdot VSL$ per injury is used.

$W_{ind} = (1 - q_h) \cdot (1 - r) \cdot W$ of helmeted cycling the benefit derived from this induced helmet use is

$$N_f = V_{km}^h \cdot W_{ind} = N^h(1 - q_h)(1 - r) = 570,600,000 \text{ €}$$

per year.

B. *The substitution of cycling: Impacts on health, exposure to risk and environment*

Cycling has a positive effect on health and increases life expectancy (de Hartog et al., 2010). Substituting the bicycle by other transport modes is thus expected to have negative health consequences. Following Kahlmeier et al. (2013) and using the algorithm HEAT provided on the webpage www.heatwalkingcycling.org by the WHO Regional Office for Europe, the statistical value of the health gains can be estimated to $h_f = 6.676443 \times 10^{-7} \cdot VSL = 1.05$ € per additional km cycled and $h_p = 1.586171 \times 10^{-6} \cdot VSL = 2.50$ € per additional km walked by a pedestrian.[7] Using a bus or a car is not conducive to good health. The distance W^s of cycling that is substituted therefore induces monetary costs of $h_f \cdot W^s$ and only the distance W_p^s that is walked improves health by $h_p \cdot W_p^s$. The monetary losses due to deteriorating health are

$$K_h = h_f \cdot W^s - h_p \cdot W_p^s$$

i.e. $K_h = 472,974,000$ €.

The former cyclists are also at some degree of risk when walking, driving or using public transport. The number of accidents (fatalities) per 1 Million (100 Million) passenger-km in 2011 (DeStatis, 2013) are $r_B^u = 0,14$ ($r_B^g = 0,02$) if using public transport, $r_C^u = 0,26$ ($r_C^g = 0,23$) if driving a car, $r_P^u = 0,92$ ($r_P^g = 1,76$) if walking and $r_F^u = 2,35$ ($r_F^g = 1,22$) if bicycling. (Not) using transport mode i (reduces) induces costs of

$$rc_i = r_i^g \cdot 10^{-11} \cdot VSL + r_i^u \cdot 10^{-8} \cdot S_m$$

per kilometer. Because the distance W^s of cycling is substituted by W_p^s of walking, W_c^s of traveling by car and W_b^s of public transport, the benefit is

$$N_n = rc_F \cdot W^s - rc_p W_p^s - rc_c W_c^s - rc_b W_b^s$$

i.e. $N_n = 122,629,000$ €.

From an environmental point of view, the substitution of cycling is undesirable. Traveling by car induces external costs $c_c = 0.0314$ € per kilometer (Umweltbundesamt, 2007). Therefore, additional costs are $K_e = c_c \cdot W_c^s = 11,481,400$ € annually.

[7] Input data for the algorithm are that 63,510,000 million cyclists, that is, the unhelmeted 87 percent of B_f =73,000,000 cyclists in Germany, reduce cycling by 0.18840 km at 124 days and additional walk a distance of 8.0534 km annually, resulting in an annual reduction of cycling W^s additional walking of W_p^s.

C. Comfort losses

Additional costs arise through the utility losses caused by helmet wear. Youths do not like wearing helmets, primarily because they are regarded as uncool (Stiftung Warentest, 2012). Helmets are also incompatible with "big hair" such as that of Marge Simpson. In addition, a helmet generally reduces air circulation. As the benefit components of a good helmet, Stiftung Warentest, the leading German consumer watchdog, rates accident prevention at 50 percent, handling and comfort (including effective air circulation to prevent increasing temperatures under the helmet) at 35 percent, heat resistance at 10 percent and pollutants at 5 percent. According to Ritter and Vance (2011), a share of $q_g = 0.094$ of all cyclists uses a helmet occasionally. Assuming that these cyclists already own a helmet, they do not incur marginal acquisition costs, so that the only marginal costs are the comfort reduction when using, and the inconvenience of carrying around a helmet when not actually cycling. These cost vary, so that wearing the helmet is sometimes optimal and sometimes not. Assuming rational behavior[8], the utility losses must exceed the gains derived from helmet protection. However, some of the protection effect of a helmet, for example hospital costs and part of productivity losses, are external to cyclists because they are covered by social insurance. Therefore, it is assumed that only a fraction $c_i = 0.60$ of the benefits V_{km}^h are internalized (Elvik, 1994). If occasionally helmeted cyclists wear a helmet for a fraction $q_m = 0.50$ of rides, utility losses due to helmet wear are at least

$$ul = c_i \cdot q_m \cdot V_{km}^h = 0.00625 \text{ €/km} .$$

Furthermore, cyclists who never wear helmets in the status quo suffer a loss of comfort when forced to cycle helmeted. Arguably, they wear no helmet because their losses would be rather high and not because their travel distance or income is rather small. However, in this study, it is assumed that ul are the utility losses imposed by helmet use and a helmet law induces utility losses

$$K_g = ul \cdot W_{ind} = 171,118,000 \text{ €}$$

per year.

D. Costs of helmets

Costs for helmets have to be taken into account.[9] Costs arise from the fact that helmets must be produced and purchased. Retail prices range between 10 and 140 €. The cheapest good adult helmet costs 18 € and the cheapest good kids helmet 20 € (Stiftung Warentest, 2012). Cyclists are advised to buy from specialized dealers. 47.75 € is the average recommended retail price charged by specialized dealers for the twelve best-selling helmets sold by amazon.de at December 12th, 2013. It is assumed for the present study that helmets can be purchased for 32.875 €, which is the average of the cheapest (18 €) and the average recommended retail price (47.75 €). In Germany, prices include a 19 percent sales tax, which is not a social cost, such that the opportunity costs of a

[8]Börjesson and Eliasson (2012) find that cyclists generally take the health effects into account when making their choices.

[9]Broadstock and Collins (2010) show that prices influence the demand for cycling to a greater extent than the income effects.

helmet are $C_H = 27.62$ €. All manufacturers recommend replacing helmets after $l_H = 5$ years.

Up to now we calculated average values per kilometer cycled using data about the distance travelled by bicycle of all cyclist in Germany during a year. The average distance travelled, 401 km, was used only to illustrate some results. However, to calculate the number of helmets cyclist have to buy to comply with a helmet law, we have to estimate the number of cyclist who do currently not own a helmet. In Germany there are about $B_f = 73,000,000$ bicycles (DeStatis, 2013) which is used as number of cyclist, ignoring cyclists who own more than one bike and shared used of a bicycle (but not of a helmet). According to Ritter and Vance (2011), a fraction $q_i = 0.124$ of German cyclists wear a helmet regularly and $q_g = 0.094$ sometimes. Regular and occasional helmet users already own a helmet but all of those, who have never used a helmet, have to buy a new one. Therefore, costs of

$$K_m = B_f \cdot (1 - q_i - q_g) \cdot \frac{C_H}{l_H}$$

i.e. $315,412,000$ €, arise.

E. Benefit cost ratio

As Figure 2 shows, most important is the protection effect N_f. This effect is about 25 percent higher than the (negative) health effect and therefore, a fully enforced bicycle helmet law is effective from a health perspective. However, the production costs of helmets K_m amount to about half of the monetary value of the protection effect. There is a safety (Exposure) gain, due to the substitution of bicycle riding by less risky modes, which amounts to about a third of the helmet costs. However, from an environmental point of view, the substitution is not desirable. The welfare losses due to reduced comfort when cycling are calculated at about two thirds of the helmet costs. To summarize, we can calculate a benefit-cost ratio of

$$BCR = \frac{N_f + N_n}{K_m + K_e + K_g + K_h} = 0.714.$$

A law that make the wearing of bicycle helmets in Germany mandatory is thus a waste of resources.

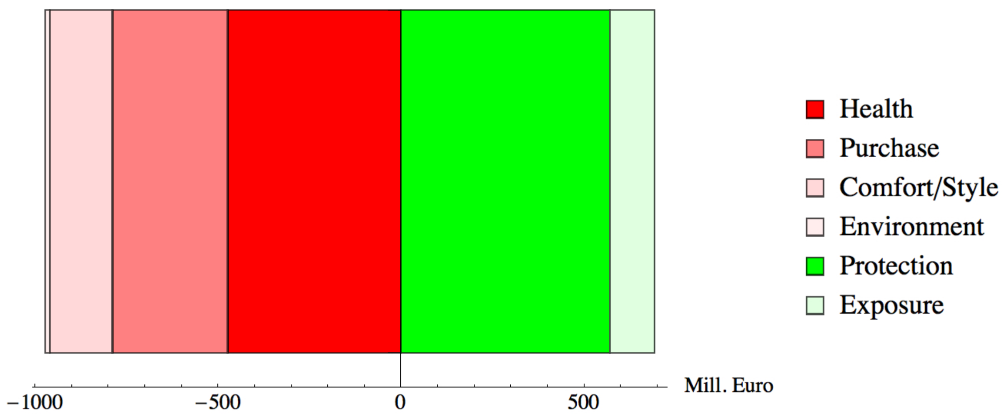

FIGURE 2. ANNUAL COSTS (RED) AND BENEFITS (GREEN) OF A HELMET LAW

In reality, there are generally not only winners, but also losers from policies. The larger the benefit cost ratio, the easier it is to compensate the losers. Usually, resources are scarce and only the most efficient policy measures are funded. Following a cost-benefit approach, the projects with the highest benefit cost ratio should be the first to be implemented. Cavill et al. (2008) find, in their review on the studies of economic valuation of transport infrastructure or policy, that included data on walking and/or cycling and health effects, a median benefit cost ratio of 5. Compared to safety belts or bicycle brakes and lights, a helmet becomes part of a person's outfit and is therefore is very important for social communication. Governmental regulation of such a personal matter is justified, if at all, only if the benefit cost ratios are relatively large compared to those of other available policies .

F. Sensitivity Analysis

There is a range of plausible assumptions about the parameters used in this study that may change the benefit cost ratio. Therefore, additional calculations are made using, when possible, the boundaries of a 95 percent confidence interval of the used parameters.[10] In Table 1, each cell includes a parameter value in the first row that leads. in combination with the other normal parameters, to the benefit cost ratio (BCR) displayed in the second row of the cell. In none of the scenarios is a benefit cost ratio larger than one calculated. Isolated estimation errors of the risk-reduction effect of bicycle helmets, the proportion of head injuries of bicycle accidents, the value of a statistical life, social costs of producing a helmet, the reduction of cycling due to a helmet law or the utility losses from using a helmet, do not alter the conclusion that a bicycle helmet law for Germany would waste resources.

TABLE 1—COMPARISON OF DIFFERENT SCENARIOS

Parameter	low	normal	high	Description
rr	0.39	0.50	0.65	Risk reduction by a helmet
BCR	0.809	0.714	0.570	
q_{head}	0.2	0.3264	0.4	Proportion of head injuries
BCR	0.519	0.714	0.816	
VSL	944,400 €	1,574,000 €	3,148,000 €	Value of Statistical Life
BCR	0.583	0.714	0.858	
C_H	15.13 €	27.63 €	40.13 €	Social costs of a helmet
BCR	0.837	0.714	0.622	
r	0.018	0,045	0,072	Reduction of cycling
BCR	0.928	0.714	0.597	
ul	0 €	0.00625 €	0.0125 €	Utility loss of a helmet
BCR	0.867	0.714	0.607	

IV. Omitted effects

There are further effects of a helmet law that are omitted in this study because there is only weak evidence that the effects are statistically significant different to zero and/or because the monetary values are small.

[10]The value $ul = 0$ € indicates that there are no losses due to Comfort or Style, the value of $ul = 0.0125$ € indicates that helmet owners who never wear the helmet in the status quo are rational in the sense that utility losses due to wear are at least as high as the expected (internal) benefits due to protection.

Since Peltzman (1976), it is evident that individuals compensate for risk reduction. For example, cyclists who are forced to wear a helmet may cycle faster (Adams and Hillman, 2001; Elvik, 2013), a change in driving behavior which reduces the positive effects of a helmet law. However, Fyhri, Bjørnskau and Backer-Grøndahl (2012) do not support a risk-compensation effect of helmets, in particular because the speeding behavior of the most affected "speed-happy" group is associated more with other types of equipment than bicycle helmets. It is not because of the helmet that these cyclists ride fast, they use all available equipment (including helmets), because they want to ride fast. Therefore, risk compensation that may decrease the positive effects of a helmet law is ignored in this study.

Bikers are heterogenous. The helmet-wearing rate is positively affected by household income, the number of children in the household and by having an urban place of residence, and the helmet-wearing rate of women is lower than that of men (Ritter and Vance, 2011). The present study does not account for cyclist heterogeneity beyond helmet use and ownership. In reality, however, cyclists also differ in terms of distance cycled (and many other factors). A helmet law may shift the cyclist population in favor of more risky cyclists by crowding out traditional cyclists (Li et al., 2013; Fyhri, Bjørnskau and Backer-Grøndahl, 2012). However, it is not easy to formulate a group-specific helmet law only for risky groups, because cyclists are often members of different groups. There is no reliable data on whether or not a km cycled by an experienced (thus probably low risk) mountain biker (high risk) is riskier than a km of a person who infrequently (high risk) cycles traditionally (low risk). Furthermore, the fewer cyclists on the road, the less car drivers will be aware of them. A helmet law then decreases the safety in numbers effect (Jacobsen, 2003). To address cyclist heterogeneity, traffic infrastructure, environment and other risk influencing factors a local group-specific cost-benefit analysis is appropriate, but due to a lack of reliable data, has rarely been conducted.

Helmet efficiency depends on several factors that differ in accidents. According to Richter (2005), the mean speed of collision for fatal accidents is 52.3 km/h, whereas the mean speed of collisions for non fatal is 20.8 km/h. In the event of an accident, a bicycle helmet works like "a crumple zone" by absorbing energy through the compression or fracture of the inner shell, which reduces brain acceleration.[11] In Germany and in the European Union, helmets have to pass the norm EN 1078, which requires that at impact speeds of nearly 20 km/h, acceleration of the head be less than 250 times the gravity of earth g. Arguably, the ability of bicycle helmets to prevent fatalities is lower that of preventing injuries. Meehan et al. (2013) show that in accidents between bicycles and motor vehicles, the odds ratio of a helmet law for children younger than 16 for fatalities is 0.84, with a 95 percent confidence interval of 0.70 to 0.98. Therefore, the risk reduction rate in the current study may overestimate the impact of bicycle helmets on serious injuries and fatalities.

The effectiveness of a helmet is also influenced by how well it fits the head and the correct wearing position. However, Brian Walker (2005) of Head Protection Evaluation, Britain's principal helmet test lab, states: "Apart from racing cyclists, I rarely see a helmet that is worn properly." This study assumes that the helmet

[11] Curnow (2003) points out that the design of helmets is based on the theory that linear acceleration is the main cause of brain injury. Rotation of the head, which can even be increased by a helmet (Corner et al., 1987), is ignored.

wearers forced to do so by law fit their helmet as well as (current) voluntary users. However, cyclists obliged to wear a helmet may wear them improperly and fail to replace them after 5 years as recommended. If this is true, the positive effect on safety of a helmet law is overestimated in the present study. At the same time, the annual purchase costs are lower than estimated.

Also not included in this study is the small negative effect of a bicycle helmet law on car congestion and the albeit modest costs of law enforcement which occur when the police spends time on helmet law enforcement that could be spend differently. Furthermore, it is assumed that the helmet law induces all cyclists to wear a helmet, which in reality will not be the case. However, when law breakers are only average cyclists who ignore the law, then only the costs and benefits of the law are reduced, but the cost benefit-ratio of the helmet law does not change.

V. Conclusion

For Germany, the benefits of a law that obliges cyclists to wear helmets are smaller than the costs. From an aggregated welfare point of view, Germany would therefore lose from introducing such a law. However, wearing a helmet when bicycling, does indeed reduce the negative consequences of accidents. A cyclist "earns" a value of 2.08 Cents of reduced costs for society per km of cycling by using a helmet. This is an argument in favor of wearing a helmet when cycling, but not for supporting a mandatory bicycle helmet law for Germany. Furthermore, policies that aim at increasing helmet use may have unwanted side effects. By emphasizing that biking without a helmet is careless, potential cyclists may conclude that cycling is intrinsically rather dangerous and thus decide not to cycle. Because cycling is in fact a safe (per travel time), healthy and environmentally friendly transport mode, (over-)emphasizing the risk of cycling (per distance) is not a prudent policy.

Nonetheless, increasing road safety is an important policy goal. To increase cyclists safety, stricter speed limits for cars, better monitoring of traffic rules combined with increased law enforcement, improving the cycling infrastructure, and generally encouraging cycling are sound policy options. Cost-benefit analyses of these different options should reveal which are efficient.

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TABLE 2—INPUT PARAMETERS AND SOURCES

Symbol	Description	value	Source
rr	Risk reduction by a helmet	0.50	Elvik (2013)
q_{head}	Proportion of head injuries of all injuries	0.3264	Richter (2005)
VSL	Statistical value of life	1,574,000 €	Kahlmeier et al. (2013)
S_s	Statistical value of severe injury	$0.13 \cdot VSL$	ECMT (1998)
S_m	Statistical value of average injury	$0.027 \cdot VSL$	own calculation
S_l	Statistical value of minor injury	$0.01 \cdot VSL$	ECMT (1998)
c_i	Fraction of statistical cost that are internalized	0.6	Elvik (1994)
F_g	Fatalities among cyclist (annual)	406	DeStatis (2013)
F_s	Severe injuries among cyclist (annual)	13,854	DeStatis (2013)
F_l	Minor injuries among cyclist (annual)	60,516	DeStatis (2013)
q_h	Proportion of cyclists using helmets	0.13	Bundesanstalt für Straßenwesen (2013)
q_i	Proportion of cyclists reporting regular use	0.124	Ritter and Vance (2011)
q_g	Proportion of cyclists reporting occasional use	0.094	Ritter and Vance (2011)
q_n	Proportion of cyclists reporting no use of a helmet	0.782	Ritter and Vance (2011)
q_m	Proportion of cycling wearing a helmet of a occasional user	0.50	own estimation
C_H	Cost of a helmet	27.62 €	own estimation
l_H	Time to replacement	5 years	Recommendation Producer
B	Population of Germany	82,218,000	Bundesministerium für Verkehr (2012)
W	Distance cycled in Germany in 2008	$3.29694\ 10^{10}$ km	Bundesministerium für Verkehr (2012)
w	Average distance cycled (annual)	401 km	Bundesministerium für Verkehr (2012)
r	Reduction of cycling	0.045	Carpenter and Stehr (2011)
v_c	Average speed motorized using car	24.9 km/h	Jahn and Krey (2010)
v_b	Average speed public transport	17.0 km/h	Jahn and Krey (2010)
v_f	Average speed of cycling	12.30 km/h	Jahn and Krey (2010)
v_p	Average speed of walking	4.90 km/h	Jahn and Krey (2010)
h_p	Statistical value of health improvement through walking per km (annual)	1.586171×10^{-6} €	Kahlmeier et al. (2013)
h_f	Statistical value of health improvement through cycling per km (annual)	6.676443×10^{-7} €	Kahlmeier et al. (2013)
ms_c	Modal Split motorized using car	0.31	Jahn and Krey (2010)
ms_b	Modal Split motorized public transport	0.26	Jahn and Krey (2010)
ms_p	Modal Split walking	0.30	Jahn and Krey (2010)
c_c	External costs of a km driven by car	0.0314 Cent	Umweltbundesamt (2007)
r_b^u	accidents per 1 Million passenger-km public transport	0.14	DeStatis (2013)
r_c^u	accidents per 1 Million passenger-km car	0.26	DeStatis (2013)
r_p^u	accidents per 1 Million km walking	0.92	DeStatis (2013)
r_f^u	accidents per 1 Million km cycling	2.35	DeStatis (2013)
r_b^g	accidents per 100 Million passenger-km public transport	0.02	DeStatis (2013)
r_c^g	accidents per 100 Million passenger-km car	0.23	DeStatis (2013)
r_p^g	accidents per 100 Million km walking	1.76	DeStatis (2013)
r_f^g	accidents per 100 Million km cycling	1.22	DeStatis (2013)

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