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Implications for traffic safety from car drivers' secondary task engagement – An economist's view

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A B S T R A C T

This paper develops an economic model of driver behaviour and discusses the traffic safety implications when the driver listens to the radio, uses a mobile phone, and has passengers in the car. The main findings are that, even though engaging in the three distractions reduce the driver's concentration and his driving performance, they can improve the traffic safety situation for both himself and the passengers. By reasoning a little beyond the pure results of the model the paper also suggests that having access to the radio and a mobile phone can improve safety due to the driver being able to receive information about driving conditions and inform people about lateness. The safety implications of having passengers in the car will also depend on how much the driver is attached to the passengers; the more concerned he is about their safety, the more careful he becomes.

1. Introduction

Annually, more than 1.2 million people die, and more than 50 million incur non-fatal injuries, in accidents on the world's roads (World Health Organization, 2015). Therefore, identifying the factors contributing to road traffic accidents is of great importance. Several studies suggest that driver distraction is one of the major causes (see e.g. Huemer et al., 2018; McEvoy et al., 2006).

Therefore, it is disturbing that a systematic literature review by Huemer et al. (2018) finds that more than 20% of drivers engage in secondary tasks, such as using mobile phones and other electronic devices, while driving. The most common secondary task engagements while driving are, according to an observational study conducted by Kidd et al. (2016) in Northern Virginia, USA, holding a mobile phone (5.1% of observed drivers), talking on a hand-held mobile phone (4.2%), either eating or drinking (3.1%), either talking or singing with a passenger present (2.7%), manipulating a mobile phone (2.3%), and either talking or singing without a passenger present (2.1%). A somewhat lower total secondary task engagement (16.8% of drivers) was observed in St. Albans, UK (Sullman et al., 2015), where the most common secondary tasks were talking to passengers (8.8%), smoking (1.9%) and talking on a hands-free cell phone (1.7%).

By using data from 905 crash events, Dingus et al. (2016) analysed the accident risks associated with a range of observable distractions while driving, such as in-vehicle radio use, mobile phone use, and interaction with passengers. These three prevalent activities increased accident risks by 1.9 times, 3.6 times, and 1.4 times, respectively. However, it is worth noting that the effect on accident risk from having passengers in a vehicle is influenced by the age of the driver (see e.g. Doherty et al., 1998; Engström et al., 2008; Rueda-Domingo et al., 2004). Moreover, a meta-analysis that assessed changes in accident risk associated with mobile phone use (Elvik, 2011) concluded much the same as Dingus et al. (2016); using a mobile phone while driving led to a threefold increase in accident risk.

Therefore, it is well-established in the literature that secondary task engagements are widespread among drivers and that driver distraction is a frequent contributor to driving errors (Young and Salmon, 2012) and, consequently, increasing the accident rate. Nevertheless, the problem of driver distraction and its contribution to road traffic accidents is still not very well known (World Health Organization, 2011).

Therefore, the aim of this paper is to analyse the safety impacts of engaging in secondary tasks while driving by introducing an economic model of drivers' behaviour. We will focus on the most prevalent distractions, such as radio listening, mobile phone use, and interaction with passengers (Dingus et al., 2016). The model presented here assumes that the drivers are subjective, risk-neutral utility maximisers. Thus, we make a clear distinction between drivers' accident perception, i.e. the perceived level of accident risk and accident loss, on the one hand and their respective objective values on the other hand. For similar models analysing traffic safety issues and taking economic models as starting

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points, we refer to O'Neill (1977), Blomquist (1986), Janssen and Tenkink (1988), Jørgensen (1993), Jørgensen and Polak (1993) Jørgensen and Wentzel-Larsen (1999), Levy and Miller (2000), Jørgensen and Pedersen (2002), Elvik et al. (2004) and Elvik (2009, 2014). However, none of these studies have analysed traffic safety issues in the same manner as it is done in this one.

The rest of this paper is organised as follows. In Section 2, we describe briefly the model of a driver's behaviour and the interpretation of its parameters. Further, in Section 3, we discuss the influence on the model's parameters when the car driver starts either using the radio, using a mobile phone, or interacting with the passengers. A special focus is placed on discussing the conditions that must be met for the driver wishing to engage in these activities. The latter is an important issue, because devices like radios and mobile phones in the cars do not affect safety if the driver does not use them while driving. Finally, the main conclusions and the most relevant weaknesses of the analysis are summarised in Section 4.

2. A model of driver behaviour

2.1. General model

When assuming that the driver's perceived pecuniary costs per km are independent of speed (X), a subjective, rational, risk-neutral car driver will select a speed that minimises the sum (TC^S) of time costs and subjective expected private loss per km driven; that is:

$$Min_X TC^S(X) = T^S(X) + P^s(X)\cdot L^S(X), \quad T_X^S < 0,\ T_{XX}^S > 0, \quad P_X^S > 0,\ P_{XX}^S > 0, \ldots\ldots L_X^S > 0, L_{XX}^S > 0 \tag{1}$$

where $Y_z = \frac{\partial Y}{\partial z}$. $T^S(X)$ are the car driver's perceived time costs per km driven, $P^s(X)$ is the perceived probability that an accident will occur per km, and, finally, $L^s(X)$ is the perceived private accident loss if an accident does occur. The $T^S(X)$ relationship is, among other things, influenced by the driver's income, the purpose of the journey, the comfort of the car used (see e.g. Gunn, 2008; Wardman et al., 2016), and, finally, his knowledge about the time–speed relationship. The $P^S(X)$ relationship is influenced by the driving characteristics of the car, the quality of the roads, and the levels of the driver's accident perception and vehicle-handling skills. Finally, the $L^S(X)$ relationship is influenced by how safe the car he is driving is, his conditions of insurance (Hsu et al., 2015), and by the number of passengers. The latter influences L^S, because the car driver is concerned about the safety of the passengers, see the breakthrough works by Jones-Lee (1989, 1991). The stated signs of the derivatives are in line with ordinary assumptions in moral-hazard models; an increase in safety effort (a reduction in X) reduces the probability of an accident and accident loss at diminishing rates and increases the cost of care (time cost) at an increasing rate.

With the restrictions placed on the signs of the derivatives in Eq. (1), it is straightforward to prove that $TC_{XX}^S > 0$, which implies that the value of X (X^*) that leads to $TC_X^S = 0$ is a global optimal value. It is worth noting that we have disregarded speed limits in the above model and, thereby, the influence on speed selection of the driver's perceived probability of being caught speeding and his perception of the magnitudes of penalties for speeding. These factors could be incorporated in the model, but they would lead to unnecessary complications of later formulae without providing the analysis with much new insight.

2.2. Specification of the actual functions

For later use, we will specify more precisely the functions above. The choice of functional forms is made under three main considerations. First, they must be intuitively reasonable, and the signs of their derivatives should be in accordance with those that are imposed in Eq. (1). Second, they must lead to mathematically tractable solutions. Finally, it must be possible to conclude in which directions the model's parameters will change when the car driver becomes involved in the three distractions mentioned earlier. From the above considerations, it follows that we employ the following objective relationships over the relevant range of speed:

$$T^O(X) = k\cdot\frac{1}{X}, \quad P^O = a_0 X^{a_1}, L^O = b_0 X^{b_1},\ a_0,\ b_0 > 0, \quad a_1,\ b_1 > 1 \tag{2}$$

and the following subjective ones

$$T^S(X) = \mu\cdot T^O(X)\ , \quad P^S = \alpha\cdot P^O(X)\ , \quad L^S = \beta\cdot L^O(X) \quad \mu,\ \alpha,\ \beta > 0 \tag{3}$$

where k is the driver's time costs per unit of travel time, $\frac{1}{X}$ is driving time per km, and P^O and L^O are objective values of the probability of an accident per km driven and private accident loss if an accident does occur, respectively. Hence, $\left(k\cdot\frac{1}{X}\right)$ are time costs per km driven. The power functions between P^O and X and between L^O and X are used commonly in driver speed selection models, see, for example Elvik et al. (2004), Elvik (2009, 2014) and Elvik et al. (2019) for a thorough review and discussion of the validity of power and exponential functions in traffic safety models. The specifications in (2) have the useful properties that the parameters a_1 and b_1 and the sum $(a_1 + b_1)$, in particular, display considerable stability throughout the driving population and the total stock of cars and under different driving conditions (Jørgensen and Polak, 1993). Increasing (decreasing) values of a_0 and b_0 in equation (2) indicate that the objective probability of being involved in an accident and its objective private loss increase (decrease), respectively. When the driver, for example, improves his vehicle handling skills, the value of a_0 will decrease, whereas a safer car will decrease b_0.

Finally, in (3), we assume proportional relationships between perceived values of time costs, accident risk, and accident loss on the one hand and their respective objective values on the other hand; that is the percentage differences between objective and subjective values are the same at any speed. If, for example, $\alpha > 1$ the driver overestimates the probability of an accident, if $\alpha = 1$ he correctly estimates it, and, finally, if $\alpha < 1$, he underestimates it. Thus, the values of α and β signal the driver's accident perception, that is his or her ability to judge the driving risk and the consequences of an accident; when their values tend to one, the better are their accident perception. From equation (3), it follows that the $P^O(X)$ and $P^s(X)$ relationships and the $L^0(X)$ and $L^s(X)$ relationships will never intersect each other when $X > 0$. This means that, if the driver overestimates the probability of an accident and accident loss ($\alpha,\ \beta > 1$) at low speed he will do the same at higher speed.

Empirical studies show that drivers' perceived relationship between driving time and speed decreases convexly (Elvik, 2009) and are, hence, in line with the signs of the derivatives of the $T^S(X)$ function employed above. The slope of the curve is, however, flatter for low speeds and steeper for high speeds than is the objective curve.[1] This means that drivers underestimate (overestimate) the time savings of increasing speed when it is initially low (high). In the following, to reduce the number of symbols, and without much loss of generality, we will assume that the driver has correct perception of the real time-speed relationship; that is, $\mu = 1$ in (3).

2.3. Model results

Plugging Eq. (3) into Eq. (1) result in the driver wanting to minimise the following expression:

[1] From Elvik (2009), the perceived relationship between travel time per km (T) and speed measured in km per hour can be derived as $T(X) = 0.129\cdot e^{-0.025X}$.

$$Min_X TC^s = \frac{k}{X} + \gamma b X^c, \quad \gamma = \alpha\beta, \; b = a_0 b_0, \; c = a_1 + b_1 \tag{4}$$

in which $\gamma bX^c = Q^S$ is expected subjective accident private loss per km driven. The first-order conditions for minimum value of TC^s imply that the driver's perceived optimal value of speed (X^*) is[2]:

$$X^* = \left[\frac{k}{\gamma bc}\right]^d \text{ where } d = \frac{1}{1+c} \tag{5}$$

Because $c > 0$, it follows from Eq. (5) that $0 < d < 1$. Eq. (5), in combination with the functions in (2), gives the following expressions for the values of the driver's objective probability of an accident (P^{O^*}) per km, objective private accident loss (L^{O^*}), and expected objective private accident loss per km (Q^{O^*}):

$$P^{O^*} = a_0 \cdot \left[\frac{k}{\gamma bc}\right]^{da_1}, \; L^{O^*} = b_0 \cdot \left[\frac{k}{\gamma bc}\right]^{db_1}, \; Q^{O^*} = P^{O^*} \cdot L^{O^*} = b \cdot \left[\frac{k}{\gamma bc}\right]^{1-d} \tag{6}$$

Further, from Eqs. (4) and (5), it follows that driver's expected perceived optimal costs (TC^{s^*}) and expected objective optimal costs (TC^{O^*}) per km driven are:

$$TC^{S^*} = k \cdot \left[\frac{k}{\gamma bc}\right]^{-d} + \gamma b \cdot \left[\frac{k}{\gamma bc}\right]^{1-d} \text{ and } TC^{O^*} = k \cdot \left[\frac{k}{\gamma bc}\right]^{-d} + b \cdot \left[\frac{k}{\gamma bc}\right]^{1-d} \Rightarrow \tag{7}$$

$$TC^{S^*} = k^{1-d} \cdot b^d \left[(\gamma c)^d + \gamma^d \cdot c^{d-1} \right) \Big] \text{ and } TC^{O^*} = k^{1-d} \cdot b^d \left[(\gamma c)^d + c^{d-1} \right) \Big]$$

3. The effect on traffic safety – model discussions

Commonly, in terms of driver behaviour, radio listening, mobile phone use, and passenger conversation will, broadly speaking, influence the driver's time costs per unit of time *(k)*, his objective and perceived probabilities of being involved in an accident (the a_0 and α parameters), and his objective and perceived private accident loss (the b_0 and β parameters). However, the three activities above will influence the model's parameters and, thereby, traffic safety in different ways (Dingus et al., 2016). Consequently, we will analyse them separately. In line with our earlier statement, we assume that the values of a_1 and b_1 are unaffected by the above engagements and also apply at any speed.

3.1. The effect of radio/stereo listening

In the following, we assume that the car driver controls the use of the radio. Thus, a subjective and rational car driver will use the radio if:

$$TC_R^{s*} < TC_W^{s*} \tag{8}$$

where TC_R^{s*} and TC_W^{s*} denote total perceived optimal costs per km driven when the car driver uses the radio and when the radio is switched off, respectively. A sensible assumption is that, when the radio is switched off, it has no impact on any of the relationships above and, thereby, also has no impact on the safety measures.

Moreover, the $L^0(x)$ and $L^s(x)$ functions and, thereby, the b_0 and β parameters will not be influenced by radio listening either; if an accident does occur, its perceived and objective consequences are independent of whether the radio is switched on. If we recognise that the driver becomes less aware when he starts listening to the radio, the $P^O(X)$ relationship shifts upwards.[3] This will increase a_0 and b, whereas a_1 and, thereby, the c and d parameters in Eqs. (4) and (5) will remain constant. This means that radio listening will alter the objective probability of an accident by the same percentage at any speed. Furthermore, another essential, but sensible, assumption is that the driver's time costs per unit of time (k) are lower when the radio is switched on than otherwise. The more he enjoys and gets involved in the radio programme, the more significant are the changes in a_0 and k likely to be.

When evaluating the behavioural and safety consequences of radio listening, it is essential to discuss the extent to which the driver's accident perception (the value of α) change. In the following, we will focus on two instances.

3.1.1. Accident perception is changed

This means that α is constant and that the percentage changes in the $P^O(x)$ and the $P^S(x)$ relationships will be the same. Broadly speaking, the car driver is aware that he becomes less attentive when he starts listening to the radio. Thus, in summary, radio listening will reduce k, increase a_0, and, thereby, b, while the other parameters will remain constant.

By inspecting Eqs. (5) and (6), it is easy to verify that radio listening will reduce both speed (X^*) and the private loss of an accident (L^{O^*}). To deduce the influence on the probability of an accident (P^{O^*}) and expected private loss ($Q^{O^*} = P^{O^*} \cdot L^{O^*}$) it is useful to infer when the car driver wishes to listen to the radio. From the TC^{S^*} - function in (7), it follows, after some mathematical computation, that

$$EL_k TC^{S^*} = 1 - d, \; EL_{a_0} TC^{S^*} = d, \tag{9}$$

where $EL_k TC^{S^*}$ and $EL_{a_0} TC^{S^*}$ denote the elasticities of TC^{S^*} with respect to k and a_0, respectively. Hence, from Eq (9) and inequality (8), it follows that the driver will listen to the radio if

$$r_k \cdot (1-d) > r_{a_0} \cdot d \Rightarrow \frac{r_k}{r_{a_0}} > \frac{d}{1-d} \tag{10}$$

where r_k and r_{a_0} denote percentage decrease in k and percentage increase in a_0, respectively. From physical rules, it can be deduced that approximate values of the elasticities of accident rate and accident loss with respect to speed are 1.7 and 2.3, respectively (Jørgensen, 1991).[4] This implies that $a_1 \approx 1.7$ and $b_1 \approx 2.3$ in our model which subsequently result in $c \approx 4$ and $d \approx 0.2$ in the formulas above. Thus, inequality (10) shows that the driver will listen to the radio if the percentage reduction in his time costs (k) is at least $1/4 \left(= \frac{0.2}{1-0.2}\right)$ of the percentage increase in a_0. If, for example, radio listening increases the probability of an accident by 10% (a_0 increases by 10%), he must experience at least a 2.5% decrease in time costs (k) if he wishes to use the radio. In other words, a radio in the car has no influence on any traffic safety measure if $(r_k / r_{a_0}) < 0.25$, because then the drivers will not use it.

It can be verified from the equations in (6) that

$$EL_k P^{O^*} = da_1 \,, \; EL_{a_0} P^{O^*} = 1 - da_1 \tag{11}$$

[2] It is easy to verify that the second-order conditions for a global minimum value of TC^s are met; that is $T_{XX}^S > 0$ for all X.

[3] Dingus et al. (2016) have estimated that crash risk almost doubles when drivers are adjusting the radios. When they are only listening, the increase in crash risk is probably much lower.

[4] Quite a few of the works mentioned above using power functions in speed selection models suggest that $c = a_1 + b_1 \approx 4$. From physical rules follow that the stopping length (ST) of a car is:$ST = R \cdot X + \frac{1}{2 \cdot S} \cdot X^2$ in which R is the driver's reaction time, X is speed in meter/second and S the deceleration factor in meter/second^2. It then follows $EL_X ST = \frac{R \cdot X + \frac{1}{S} \cdot X^s}{R \cdot X + \frac{1}{2 \cdot S} X^2}$ where $EL_X ST$is the elasticity of ST with respect to X. For reasonable values of X between 14 and *28* m/second, R between 1.0 and 1.5 s and S between 3.0 (winter driving) and 7.0 (summer driving) (Jørgensen, 1991) it follows that $EL_X ST$ varies between 1.3 and 1.9 and with an average around 1.7. If we take ST as an indicator of accident occurrence (Elvik et al. (2004) it follows that $EL_X P^S = a_1 \approx 1.7$. When $c = 4$ follows $b_1 \approx 4 - 1.7 \approx 2.3$.

where $EL_k P^{O^*}$ and $EL_{a_0} P^{O^*}$ denote the elasticities of P^{O^*} with respect to k and a_0, respectively. Consequently, radio use will reduce ($r_k \cdot da_1 > r_{a_0}$), not alter ($r_k \cdot da_1 = r_{a_0}$), and increase ($r_k \cdot da_1 < r_{a_0}$), the objective probability of an accident if:

$$r_k \cdot da_1 \geq (<)\, r_{a_0} \cdot (1 - da_1) \Rightarrow \frac{r_k}{r_{a_0}} \geq (<) \frac{1 - da_1}{da_1} \tag{12}$$

From the stated parameter values above, radio listening will decrease the accident rate if the ratio to the percentage reduction in time cost to the percentage increase in objective risk of an accident is greater than 1.9 $\left(= \frac{1-0.2 \cdot 1.7}{0.2 \cdot 1.7} \right)$. When combining inequalities (10) and (12), it follows that, when $\frac{1}{4} < \left(\frac{r_k}{r_{a_0}} \right) \Big\langle 1.9$, the driver wishes to listen to the radio even though he realises that it will increase the probability of an accident. If radio listening increases the probability of an accident by, say, 10%, having a radio in the car will increase the accident rate if the reduction in time cost is greater than 2.5% but less than 19%.

Finally, it can be deduced from equation (6) that

$$EL_k Q^{O^*} = 1 - d \text{ and } EL_{a_0} Q^{O^*} = d \tag{13}$$

where $EL_k Q^{O^*}$ and $EL_{a_0} Q^{O^*}$ are the elasticities of Q^{O^*} with respect to k and a_0, respectively. Hence, radio listening will reduce, and not alter or increase, the driver's expected accident loss if

$$r_k \cdot (1 - d) \geq (<) r_{a_0} \cdot d \Rightarrow \frac{r_k}{r_{a_0}} \geq (<) \frac{d}{1 - d} \tag{14}$$

Inequality (10) and (14) in combination imply that the condition for increasing total driving costs is identical to the condition for turning the radio on. Hence, having a radio in the car can never increase the expected objective private accident loss when the driver's perceptual skills (α) are constant. Consequently, the most relevant measure of the driver's overall safety situation indicates that his safety will be improved by having access to a radio in the car.

3.1.2. Accident perception is unchanged

This means that the driver thinks that his driving performance and, thereby, his $P^S(X)$ function is the same whether he is listening to the radio or not. Hence, since a_0 increases, α will be reduced such that (αa_0) and thereby (γb) are constant; see equation (2) and equation (3).

The left-hand equation in (7) and inequality (8), in combination, imply that the driver will always listen to the radio if the time costs (k) are less when the radio is turned on than otherwise; that is, when $r_k > 0$. Then, it is easy to confirm from Eq. (5) and the equations in (6) that radio listening in this case also will reduce speed (X^*) and private accident loss (L^{O^*}).

Moreover, it follows from the P^{O^*} and Q^{O^*} expressions in (6), that radio listening will reduce, and not either change or increase, the objective probability of an accident (P^{O^*}) if

$$r_k \cdot da_1 \geq (<) r_{a_0} \Rightarrow \frac{r_k}{r_{a_0}} \geq (\leq) \frac{1}{da_1} \tag{15}$$

From the previously stated parameter values, this means that radio listening will reduce the objective probability of an accident if the percentage reduction in time cost (k), is greater than 2.9 $\left(= \frac{1}{0.2 \cdot 1.7} \right)$ of the percentage increase in a_0; if, for example, a_0 increases by 10%, k must be reduced by at least 29%. Second, radio listening will reduce, not change or increase expected objective private accident loss (Q^{O^*}) if:

$$r_k \cdot (1 - d) \geq (<) r_{a_0} \Rightarrow \frac{r_k}{r_{a_0}} \geq (\leq) \frac{1}{1 - d} \tag{16}$$

This means, using our stated parameter values, that radio listening will reduce Q^{O^*} if the relative reduction in time costs (k) is more than 1.25 of the relative increase in a_0. Thus, contrary to the case when the driver's perceptual skills are independent of whether he listens to the radio (α is constant), access to a radio in the car may increase expected objective private accident loss. However, it is interesting to note that, even though the driver is not aware that his driving skills are being reduced by radio listening, his safety situation can improve, providing that the reduction in his time costs is sufficiently large.

3.1.3. Additional comments to radio/stereo in the cars

There are two important circumstances pointing in opposite directions that are not considered above. Radio listening can inform the driver about future driving problems, like closed roads, slippery roads, and traffic jams leading to the model above underestimating both the safety benefits as well as the overall benefits of having radio in the car. On the other hand, our results hinge upon the assumption that the driver controls the use of the radio. This is, of course, true when he drives alone but may not be true when having, for example, his own children as passengers. He may then have to listen to music that he is very tired of and which he does not like at all. Then his time costs *(k)* will increase, causing less safe driving. However, one can argue against this again that without the radio/stereo, the driver must listen to more of the youngsters' quarrel, which can be even more disturbing than the music.

3.2. The effect of mobile phone use

In the following, we assume that the car driver controls the use of the mobile phone while driving and that it has no impact on safety when it is switched off. If mobile phone use has no lasting value to the driver beyond the time the call lasts, a subjective rational car driver will use the phone if

$$TC_M^{s*} < TC_W^{s*} \tag{17}$$

where TC_M^{s*} and TC_W^{s*} denote total expected perceived optimal costs per km driven when the car driver uses the phone and when he does not use it, respectively. When the driver starts talking on the phone, the model's parameters in equation (2) will change in the same directions as when he starts listening to the radio; that is, k will be reduced and a_0 will increase.[5] Even though the phone is hands-free, talking on it is likely a more demanding activity for the driver than is listening to radio; primarily because of poor sound quality and the driver having to make an active contribution to the conversation. Thus, in general, the percentage increase in a_0 will be far more significant when the driver uses the mobile phone than when he starts listening to the radio. Dingus et al. (2016) suggest that there is, on average, more than a fivefold increase in accident risk when using handheld mobile phones.[6]

The model analysis of the influence of mobile phone use on driver's risk will be the same as in the previous analysis of how the radio affects driver behaviour and traffic safety. In our opinion, a large proportion of drivers think that their driving skills are poorer when they talk on the phone because traffic safety campaigns in many countries have focused greatly on this issue. Thus, the assumption that the driver's perceived risk does not change, meaning that the $P^s(x)$ function is constant, is less relevant for phone use than for radio listening.

When assuming that the driver is aware that his technical driving skills are being deteriorated (a_0 increases) so that his perceptual skills (α) are constant, his desired speed (X^*), objective private accident loss

[5] It may be debatable whether k always decreases when the driver starts talking on the phone. It could be an unpleasant conversation, but, according to our model, a subjective rational driver will not use the phone if k increases, providing that the call has no lasting effect.

[6] In many countries, the use of handheld mobile phones while driving is prohibited. Dingus et al. (2016) have no estimates for hands-free use.

(L^{O^*}), and expected objective accident loss (Q^{O^*}) will be reduced, whereas the influence on the objective probability of an accident (P^{O^*}) is ambiguous. The fact that talking on the phone leads to a greater reduction in objective and perceived driving performance than does radio listening points in the direction that the driver wishes to spend less time on the first activity than on the latter. From inequalities (10) and (12), it follows that, if phone use, say, doubles the driver's objective accident risk (a_0 doubles), his reduction in time costs *(k)* must be at least 25% lower making him willing to use the phone and nearly 50% lower if his accident risk should be reduced.[7]

3.2.1. Additional comments to mobile phone use

The above analysis rests upon the assumption that the driver will only use the phone if his total subjective perceived driving costs (TC^{S^*}) are being reduced. Thus, a phone call has no lasting effect. However, when appraising the overall effects on safety from mobile phones, we must also consider the other effects on safety arising from being able to communicate while driving.

Let us first focus on one important positive one. Assume that the driver realises that he will arrive too late for work, an appointment or home for dinner. His time cost (k -value) for the rest of the journey will then increase significantly, since the time costs of late arrival are valued particularly highly (Abrantes and Wardman, 2011). The driver's stress due to lateness can also reduce his driving skills (Fuller, 2005); that is a_0 will increase. When both a_0 and k increase, while α and β are constant, it is easily seen from the equations in (6) and (7) that the values of P^{O^*}, Q^{O^*}, TC^{O^*} increase. The values of X^* and L^{O^*} will increase (decrease)[8] if the percentage increase in time costs is lower (higher) than is the percentage increase in accident risk (a_0). If the driver underestimates the fall in driving performance (α decreases), the increase in objective values of risk and total costs will be even higher.

A phone in the car will moderate the driver's stress in respect of lateness and, thereby, the increases in a_0 and k, because the mobile phone makes it possible for him to inform the relevant persons that he will be delayed. It is worth noting that this positive effect on traffic safety is present throughout the rest of the journey. This indicates that this positive effect on safety is greater the longer the distance to the destination.

To be reached by phone while driving can, however, in some cases cause more stress and time pressure and thus increase the value of time (*k)*; for example when learning that a client is waiting at work or that some close friends or family members have suddenly become ill. We do think, however, that the positive effect of being able to inform about own lateness outweighs the negative effect of learning about negative news because such news will occur quite rarely.

3.3. The influence from passengers

Because the driver is concerned about the safety of the passengers (Jones-Lee, 1989, 1991) and Jansson (1994) his objective accident loss (L^O) increases with the number of passengers. This can be interpreted such that the value of b_0 in the loss function in (2) increases. The more attached the driver is to the passengers (his wife, children, relatives, friends), the greater the "warm-blooded costs" (Jansson, 1994; Steimetz, 2008) and consequently the increase in b_0. Thus, the driver's relationship to the passengers and their number will influence his speed and safety measures, even though the passengers do not influence his time cost (k) and driving performance. Therefore, it is a sensible procedure to deduce the safety effects of having passengers in the car by discussing the "intrinsic" effects of the passengers and the effects of talking with them. Thus, it may be fruitful to distinguish between "considerate" passengers and "less considerate" passengers. We assume that taxi drivers are familiar with this problem.

3.3.1. Considerate passengers

Considerate passengers are afraid to disturb the driver and will neither talk to each other nor take the initiative to talk to the driver, but they will respond if he starts the conversation. Thus, the driver controls when he talks to the passengers, and he will not talk to them if his total perceived driving costs (TC^{S^*}) are being increased.

If the driver prefers not to interact with the passengers, it is reasonable to assume that they have minimal influence on his time cost (k) and driving skills (a_0) but that the value of b_0 increases because of his concern about the passengers' safety.[9] Hence, if we assume that the driver's ability to evaluate his accident loss is the same regardless of the number of passengers (β is constant), his perceived accident loss (L^S) changes with the same rate as L^0. Then, it is easy to verify from Eqs. (5), (6) and (7) that

$$EL_{b_0}X^* = -d\ ,\ EL_{b_0}P^{O^*} = -da_1\ ,\ EL_{b_0}L^{O^*} = 1 - db_1\ ,\ EL_{b_0}Q^{O^*} = d\ ,\ EL_{b_0}TC^{O^*} = d \tag{18}$$

Hence, speed (X^*) and the objective probability of an accident (P^{O^*}) will decrease, whereas the driver's objective private loss (L^{O^*}), objective expected private loss (Q^{O^*}), and total objective driving costs (TC^{O^*}) increase. Notably, the driver's perceived total driving costs will also increase under these circumstances ($EL_{b_0}TC^{S^*} = d > 0$) indicating that he would prefer to drive alone. However, the decision to either take on passengers or not is normally based on factors beyond their influence on the driver's total driving costs.

When the driver starts talking to the passengers, the model parameters will change in the same directions as for radio listening; k will be reduced and a_0 will increase, whereas the other parameters will remain constant compared to no interaction with the passengers.[10] It is reasonable to assume that interaction with passengers is a more demanding activity for the driver than is passive listening to the radio but less demanding than is talking on a mobile phone (Dingus et al., 2016). The former assumption stems from the fact that the driver must behave actively toward other persons, whereas the latter assumption stems from the fact that mobile phone use often implies poor sound quality and lack of possibilities for non-verbal communication.

Therefore, the implications for the driver when he starts talking with the passengers will, broadly speaking, be the same as when he starts listening to the radio; speed (X^*) and private accident loss (L^{O^*}) will be reduced, whereas the influence on the probability of an accident (P^{O^*}) is uncertain. When the driver is aware that his driving skills are being reduced (α is constant), expected accident loss (Q^{O^*}) will decrease. Because the percentage increase in a_0 (r_{a_0}) is probably greater at that point than when he listens to the radio, the threshold decrease in his time costs must then be greater making him willing to interact with the passengers. If he, for example, thinks that a_0 increases by 20%, his time costs must be reduced by 5% if he wishes to talk to the passengers. When he thinks his driving skills are unaffected, it is uncertain in what direction Q^{O^*} changes. The safety implications for the passengers will be the same as are those for the driver.

[7] Here, r_k and r_{a_0} in (10) and (12) denote percentage decrease in k and percentage increase in a_0, respectively when using a mobile phone.

[8] $EL_{a_0}L^{O^*} = -db_1$, $EL_kL^{O^*} = db_1$.

[9] It is debatable whether having quiet passengers in the car will reduce the driver's time costs; if he feels safer than when driving alone, k may reduce. On the other hand, if passengers cause him stress and limit his driving behaviour, k may well increase.

[10] If an accident happens, its objective and perceived consequences (L^{O^*} and L^{S^*}) are independent of whether the driver interacts with the passengers.

3.3.2. Less-considerate passengers

Less-considerate passengers will talk to the car driver and to each other as they feel. They may be adults as well as children; the driver's own children, for example, obviously belong to this group. In line with travelling with considerate passengers, if no one talks to each other, passengers in the car will probably not affect the driver's time cost and driving skills; they will increase the value of b_0 only with the consequences that X^* and P^{O^*} decrease and L^{O^*}, Q^{O^*}, TC^{O^*} increase.

When travelling with such passengers, the driver may have to talk to them even if he does not wish to; that is, his perceived total driving costs (TC^{S^*}) are being increased. This implies that the values of both k and a_0 increase. When both these parameters increase, while the driver's perceptual skills are unchanged (α constant), we have concluded in Section 3.2 that the values of P^{O^*}, Q^{O^*}, TC^{O^*} increase, whereas the value of X^* and L^{O^*} will increase (decrease) if the percentage increase in time costs *(k)* is higher (lower) than is the percentage increase in accident risk. When he thinks that his vehicle-handling skills are unchanged, meaning that (γb) in Eq. (5) is unchanged, his chosen speed (X^*) increases, which, subsequently, leads to an increase in all objective and subjective risk components and in his total objective and subjective total driving costs. Similar results can be deduced when the car driver, for example, must listen to noise and quarrel from his own children; all parents experience this situation as irritating and tiring. The traffic safety implications for the passengers will also in this case to the same extent as do those for the driver.

It is worth noting that travelling with such a group of passengers can also have the same impact on traffic safety as does travelling with "considerate passengers". It may well happen that the car driver feels safer and enjoys talking to them and listening to their conversation, thereby leading to a reduction in his time costs (k).

3.3.3. Additional comments of having passengers

The analysis above rests upon the assumption that the driver only cares about the passengers' safety or what Jones-Lee (1991) names "safety-focused altruism". The driver may, however, also care about the passengers' utility in general (pure altruism) implying that his time cost *(k)* also are influenced by the passengers' own values of time. If their values are higher (lower) than the driver's, k will increase (decrease). How much k changes depends on the driver's degree of pure altruism and the differences in the driver's value of time on one hand and his passengers' time values on the other hand. When k increases due to passengers are in a hurry, it is thus, not certain that the driver will slow down even though he still cares about the passengers' safety. When the passengers are the driver's young children it is reasonable to assume that his focus is their safety.

3.4. Other attitudes towards risk

In line with the economic models of drivers' behaviour referred to in Section 1 we have assumed that the driver is risk neutral. This implies that only subjective expected accident loss $(Q^S = P^S \cdot L^S)$ means something for his choice of speed (X^*) and his total subjective driving costs (TC^S). Thus, a certain percentage change in the subjective probability of an accident (P^S) has the same effects for his chosen speed and total subjective driving costs as the same percentage change in. (L^S).

A more realistic assumption may be that the driver is risk averse. It could then be derived using the results from Shavell (2004) that the elasticity of the driver's expected subjective utility with respect to L^S is more negative than that with respect to P^S. This implies that a certain relative change in the driver's subjective accident loss means more for his welfare than the same relative change in subjective probability of being involved in an accident. A reasonable interpretation of this is that risk averse drivers are less willing than their risk neutral counterparts to take on passengers (which increases L^S) than listening to the radio or using the mobile phone (which increase P^S).

A few works dealing with economic models of drivers' behaviour assume risk averse drivers, for example Steimetz (2008) and Fridstrøm (1999). Like this paper, Steimetz (2008) develops a model of how accident risk and safety effort are balanced but with emphasis on delays and external costs. The paper does not specify safety effort by speed as our paper and Fridstrøm (1999) do. By introducing a quadratic utility function, which implies risk averse behaviour, Fridstrøm (1999), concludes that accident reducing measures and severity reducing measures will influence speed in the same direction, no matter whether the driver is risk neutral or risk. Whether the effect on speed will be higher or lower when the driver is risk averse rather than risk neutral is, however, ambiguous. Transferred to our model these results suggest that reduced values of a_0 and b_0 also will increase speed when the driver is risk averse but is hard to say how the magnitude of the increase in speed is affected by the driver's attitude towards risk.

4. Concluding remarks

The main goal of this paper has been to show that economic models of a driver's behaviour may be useful tools to discuss the effects on traffic safety of common distractions while driving, such as listening to the radio, using a mobile phone, and interacting with passengers. The basic assumptions of the analysis are: 1) the driver is risk-neutral subjective rational, meaning that he chooses a speed (X^*) that minimises the sum (TC^S) of his time costs $(\frac{k}{X})$ and expected subjective private accident loss (Q^S); 2) the relationships between the objective probability of an accident (P^O) and objective private accident loss (L^O), on the one hand, and speed (X), on the other hand, are specified by power functions; 3) the relationships between subjective values of the probability of an accident (P^S) and private accident loss (L^S) and their respective objective values are proportional, implying that the percentage differences between objective and subjective values are independent of the driver's speed; 4) the three distractions mentioned above will in total influence the driver's time cost (k) and all the relationships mentioned above, but at different magnitudes; and 5) the driver wishes to use the radio and the mobile phone and interact with passengers if these activities reduce his subjective total driving costs (TC^{S^*}). Thus, the distinction between the driver's perceived values of accident risk and accident loss and their respective objective values is essential in our analysis.

Radio listening will reduce the driver's chosen speed (X^*) and the subjective and objective private consequences of an accident (L^{S*} and L^{O*}), and the reductions in these figures are more significant when the driver is aware that his driving performance is being deteriorated by the radio (α constant) than when he thinks that his driving skills are unchanged. The latter means that α reduces such that $(\alpha \cdot a_o)$ is constant. Expected objective private accident loss (Q^{O^*}) will be reduced in the former case, whereas the influence on it is inconclusive in the latter case; it depends on the relative magnitudes of the reduction in time costs compared to the reduction in driving performance. Independent of whether the driver is aware of poorer driving performance when listening to the radio, the influence on the probability of an accident (P^{O*}) is uncertain. However, if this figure should not increase, the reduction in time costs must be rather high compared to the reduction in driving performance, especially when the driver thinks that his driving performance remains constant. Thus, the overall conclusion on the safety effects of radio listening is that it likely leads to more but less serious traffic accidents. Another benefit of having access to the radio is the possibility of receiving information about driving conditions on the stretches of road being driven on.

When the driver uses a mobile phone for chatting with friends only, the traffic safety implications of the phone are broadly the same as are those for listening to the radio; the number of accidents may increase, but their consequences will be reduced. Since the reduction in both his real and perceived driving performance is greater when he starts using the mobile phone than when listening to the radio, the prevalence of radio use will be greater. The perceived safety implications of mobile phone use are more severe than are those when using the radio because the driver is aware that mobile phone use is dangerous. However, the possibility of sending messages about eventual lateness while driving can reduce the driver's stress and time cost and, thereby, improve his safety for the rest of the journey. The latter positive effect steaming from mobile phone use is seldom debated.

Even if the driver does not interact with the passengers, his chosen speed and the objective probability of an accident will decrease by the number of passengers, whereas both his objective accident loss and his expected objective accident loss will increase. This comes from the fact that the driver is concerned about the safety of the passengers. The more attached he is to his passengers, the greater the changes in the above figures. If the driver talks deliberately to passengers, his time costs are reduced, whereas his driving skills become poorer. The safety implications are, broadly speaking, like those for radio listening and mobile phone use. If the driver must interact with the passengers or listen to their quarrels against his will, all safety risk components will probably increase due to increasing time costs and poorer driving performance.

The most important message in this article is that, even though all three of these secondary engagements while driving are likely to reduce the driver's level of concentration and, thereby, his driving performance, they can improve the traffic safety situation both for the driver and for the passengers. The outcome depends critically on the relative changes in the driver's time costs compared to the relative changes in his actual and perceived driving performance. For example, although the driver may become deeply involved in a pleasant conversation with the passengers, implying that his driving skills deteriorate significantly, the negative influence on traffic safety may be outweighed by lower time costs and higher perceived probability of an accident. The above conclusions correspond to the results in Cheng (2015) which concludes that banning mobile phone use while driving reduces its prevalence by around 50 per cent but the ban has no significant impact on accidents and casualties.

Finally, we find it important to outline the most relevant objections to the model used. Firstly, the relationships between subjective and objective valves of accident risk and private accident loss on the one hand and speed on the other hand, are specified by common but rather simple power functions. Other assumptions regarding technology and drivers' perceptions may have given some other results. Additionally, our stated values of the parameters $a_1 = 1.7$ and $b_1 = 2.3$ used in some of our nummerical examples are uncertain. This implies that the threshold necessary percentage reductions in time costs making some risk components being reduced are uncertain. For example, when a_1 increases the threshold values estimated below Eqs. (12) and (15) will decrease meaning that the necessary percentage reductions in the driver's time costs leading to lower accident rate are being reduced. The sum of their values $(c = 4)$ and consequently $d = \frac{1}{1+4} = 0.2$ which we also use in numerical examples display, however, considerable stability across driving population and are often used in numerical examples (Jørgensen and Polak, 1993). It is also noteworthy that most of the model's general conclusions are based on that $a_1, b_1 > 1$, implying convexly relationships between accident occurrence and accident loss on one hand and speed on the other hand. These are common and reasonable assumptions. Finally, as emphasised in Section 3.4, assuming the driver being risk neutral is a common but debatable assumption in speed selection models of drivers' behaviour.

Statement of contribution

The main contribution of this study is that we reveal some counterintuitive effects of secondary task engagements when driving a car. For example, in conflict with traditional views we show that in some cases both radio listening, mobile phone use and talking to passenger may reduce both the probability of being involved in accidents and their severity. Consequently, when evaluating the final effects of safety measures, it is essential to infer their effects on drivers' behaviour. Our model assuming a subjective rational car driver is well designed to deal with such issues.

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