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Can a road safety measure be both effective and ineffective at the same time? A game-theoretic model of the effects of daytime running lights

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ABSTRACT

Studies that have evaluated the effects on accidents of daytime running lights for cars have consistently found that cars using daytime running lights are involved in fewer multi-party accidents in daylight than cars not using daytime running lights. However, studies evaluating the effects of mandatory use of daytime running lights have not always found an accident reduction. Although findings are mixed, there is a tendency for the aggregate effects of daytime running lights (i.e. the effects of an increasing share of traffic using daytime running lights) to be smaller than the intrinsic effects (i.e. the difference in accident involvement between cars using and not using daytime running lights). This paper presents a game-theoretic model to explain these apparently inconsistent findings. The game-theoretic model is based on so called Schelling-diagrams, originally introduced by Nobel laureate in economics Schelling. The effects of daytime running lights are modelled by means of Schelling-diagrams. It is shown that it is by no means impossible for cars using daytime running lights to always be safer than cars not using daytime running lights, while the total number of accidents remains constant even if the percentage of cars using daytime running lights increases from, say, 10% to 90%.

1. Introduction

Studies that have evaluated the effects on accidents of daytime running lights (DRL) for cars have been subject to several critical analyses and summaries, see, for example Theeuwes and Riemersma (1995), Elvik (1996), Koornstra et al. (1997) and Elvik et al. (2003). While the majority of researchers interpret studies as showing that the use of daytime running lights on cars is associated with an accident reduction, full consensus has not been reached and concern remains regarding the effects on motorcycle conspicuity of cars using daytime running lights (Cavallo and Pinto, 2012).

There are three anomalies in the results of studies that have evaluated the effects on accidents of daytime running lights for cars that have not been fully explained in previous reviews of these studies:

1. There is a clear time trend in the results of studies that have evaluated the intrinsic effects of daytime running lights for cars. Intrinsic effects refer to the effect on the accident involvement of each car by using daytime running lights. The most recent studies indicate far smaller effects than older studies; see Table 1 in Elvik et al. (2003).
2. There is no dose–response pattern with respect to the effects of an increasing use of daytime running lights in a country; see Fig. 7 in Elvik et al. (2003). In other words, an increase in the share of cars using daytime running lights from e.g. 30% to 90% is not associated with a greater change in the number of accidents than an increase in the share of cars using daytime running lights from e.g. 80% to 90%.
3. Not all studies that have evaluated the effects of laws requiring the use of daytime running lights (DRL-laws) find an effect on accidents. On the contrary, the methodologically best evaluation studies find no change in the number of accidents associated with DRL-laws. An example is the most recent Danish evaluation study (Hansen, 1995).

Can these anomalies be explained? This paper argues that they are consistent with a game-theoretic model of the effects of daytime running lights as stated in terms of Schelling-diagrams. This model offers an alternative interpretation of the findings of studies that have evaluated the effects on safety of DRL. It should be stressed, however, that the game-theoretic reading of the DRL-literature presented in this paper is only intended to show an

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alternative perspective on this literature. It is not claimed that it is the only possible interpretation of DRL-studies.

2. Games modelled by Schelling-diagrams

Schelling-diagrams (Schelling, 1978) are used to model binary choices that have external effects. A binary choice is a choice between two options. The choice made will have impacts not just on those who make the choice, but on others as well. To explain how to understand a Schelling-diagram, an example is given in Fig. 1.

Fig. 1 shows the benefits of vaccination as a function of the percentage of the population who vaccinate. The benefits of vaccinating are shown by the upper line. These benefits are assumed to be a linear function of the share of the population who vaccinate and reach maximum when everybody is vaccinated. Vaccination, however, also benefits those who do not vaccinate, i.e. it has positive external effects. These effects are shown by the lower line, which shows the benefits of vaccination for those who do not vaccinate. The external benefits of vaccination for an individual who does not vaccinate increase as the share of the population who vaccinates increases, up to the point where everybody except one individual has vaccinated. The total external benefits of vaccination depend on the share of the population who has vaccinated and reach their maximum when about 75% of the population are vaccinated. The rest of the population are then so well protected that it might not be necessary for them to vaccinate. This is indicated by the dashed line in Fig. 1.

3. Internal and external impacts of using daytime running lights

Daytime running lights have positive internal effects and negative external effects. Each vehicle using daytime running lights becomes more conspicuous and thus easier to see. This would be expected to reduce accident involvement. On the other hand, vehicles not using daytime running lights become relatively less conspicuous. This is particularly the case when a high share of vehicles uses daytime running lights. Road users may then come to rely on the sight of lights as a clue for identifying a vehicle and may therefore be less able to identify vehicles that do have their daytime running lights on.

These effects have been shown experimentally. Hole and Tyrrell (1995) studied how quickly a motorcycle was detected depending on whether its headlights were lit or not. Two experiments were conducted. In the first experiment two groups of participants were shown 24 pictures of a motorcycle. In one group the participants were shown 23 pictures of a motorcycle with its headlights off, followed by a 24th picture of a motorcycle with its headlights on. Reaction time to the 24th picture was compared to the mean reaction time to the previous 23 pictures. The other group was shown 23 pictures of a motorcycle with its headlights on and then a 24th picture of a motorcycle with its headlights also on. Reaction time to the last picture was again compared to the previous 23 pictures.

In both these cases, the mean reaction time to the 24th picture was shorter than to the other 23. For the group that saw pictures of motorcycles with headlights off, this shows that when headlights are on, detection is quicker. For the group that saw pictures of motorcycles with headlights on, it shows that consistent exposure to headlights is not associated with an erosion of the gain in reaction time brought about by lit headlights. In Fig. 2, these results have been converted to percentage changes in reaction time.

The data point on the left represents a 4% use of daytime running lights (1 out 24 using DRL). Reaction time was shortened by about 14%. The data point to the right represents 100% use of daytime running lights (24 out of 24). Even then, reaction time to the last picture was shorter than to the previous 23. The two data points located at the bottom of the diagram are based on experiment 1.

In the second experiment, subjects were shown 25 pictures of motorcycles. In one of the series 15 pictures showed a motorcycle with headlights on, 10 showed a motorcycle with headlights off. This was intended to simulate 60% use of headlights. Following the 25 pictures, subjects were shown a picture of a motorcycle with headlights off. Reaction times were compared as in the first experiment. In a second series of pictures, 24 out of 25 pictures showed a motorcycle with headlights on. This simulated 96% use of headlights. The 26th picture showed a motorcycle with headlights off. Fig. 2 shows the percentage difference in reaction time to the last picture compared to the previous 25 for these two experimental conditions. The two upper data points in Fig. 2 are based on experiment 2.

It is seen that reaction time to a motorcycle with headlights off increases when 60% or 96% of motorcycles have headlights on. This shows the negative external effects of daytime running lights. Other studies (e.g. Brouwer et al., 2004) have compared the conspicuity of motorcycles to cars, in order to determine if cars with lit headlights can mask motorcycles without lit headlights. Such a comparison was, however, not relevant in the study by Hole and Tyrrell, since all pictures showed motorcycles exclusively.

4. Schelling-diagram of DRL-effects

Based on the study of Hole and Tyrrell (1995), Fig. 3 shows a Schelling-diagram of the effects of daytime running lights.

The lower curve shows the relative accident rate for cars using DRL. It has been assumed that using DRL is associated with a safety benefit. This safety benefit is largest when the share of cars using DRL is low. Cars using DRL will then stand out from the crowd and clearly be more visible than other cars. However, as long as few cars use DRL, road users cannot rely on the sight of headlights to identify a car. The negative external effect will therefore hardly be noticeable. As the share of cars using DRL increases, the safety benefit becomes smaller, but it never disappears. The negative external effect on cars not using DRL becomes larger. When the percentage using DRL becomes very high, the negative external effects may become larger, as road users start to use the sight of headlights as a clue for identifying cars. The shape of the lower curve is based on the findings of evaluation studies, see below. The upper curve, in particular at high levels of DRL-use, is less known. However, once the use of DRL reaches 100%, one should expect the negative external effect to disappear.

The curves in Fig. 3 have been drawn so that changes in the use of DRL will not have an effect on the total number of accidents. The total number of accidents is indicated by the thick dotted horizontal line located between the risk curves for cars with and without DRL. It is of course not a logical necessity that the curves should look like this. The presence of negative external effects of DRL does not necessarily imply that a net gain in safety cannot exist. However, the shape of the curves in Fig. 3 shows that it is not logically impossible for a safety measure to be both effective and ineffective at the same time. Cars using DRL will always have a lower accident rate than cars not using DRL. It is still possible that an increasing use of DRL will not have an effect on the number of accidents, if the negative external effect of DRL exactly balances the favourable internal effect.

5. Review of anomalous findings in DRL-studies

All studies that have compared the accident involvement of cars using DRL to the accident involvement of cars not using DRL have found that cars using DRL are less involved in accidents. This finding