**Robot cars in the bottleneck model: the effects on capacity, value of time and preference heterogeneity**

Vincent A.C. van den Berg  
Erik T. Verhoef  
Silvia Bleker  

VU University, Amsterdam, & Tinbergen Institute

**Extended abstract**

‘Robot cars’—also referred to as self-driving or autonomous cars—are cars that drive themselves. They can drive closer together and at a more uniform speed than human driver ‘normal cars’ and thereby raise the capacity of roads. But besides this capacity effect, people who use a robot car instead of a normal car will also gain a decrease in their value of time (VOT) because the time in the car can now be spent on other activities besides driving. This will also mean that the VOT will become (more) heterogeneous (unless all drivers use a normal or robot car). Such VOT heterogeneity has important effects, as was also found by Arnott et al. (1994), Lindsey (2004) and Van den Berg and Verhoef (2011ab) when only considering only normal cars.

To investigate the effects of robot cars, we use the bottleneck congestion model. In the base model, there is one VOT for normal cars and another lower VOT for robot cars. Normal and robot car users travel separated over time because they have different VOTs, with the robot car preferring the centre peak. We focus on the case without congestion pricing.

Increasing the share of users with a robot car not only raises capacity and lowers VOTs, but it also hurts users who already had a robot car because the switching users now have a lower VOT and this increases their congestion externalities (Lindsey, 2004; Van den Berg and Verhoef, 2011a). A lowered VOT means that users need a steeper travel time change over time for them to be in user equilibrium and thus they impose longer travel times on users who travel more towards the centre of the peak. Thus increasing the share with a robot car not only lowers travel cost by increasing capacity and lowering the VOT of the switching users, but also raises total bottleneck congestion cost via the heterogeneity effect (if the share gets large enough). Robot cars lead to distributional effects, and, if the heterogeneity effect is strong enough and robot cars sufficiently more expensive to produce than a normal car, it may be socially optimal for only a fraction of users to have a robot car. Without the heterogeneity effect, it is either optimal for all users to have a robot car or none if robot cars are prohibitively expensive. Buying a robot imposes a positive externality, in that it lowers the cost for other users when the capacity effect dominates, or it imposes or negative externality,
in that it raises the cost for other users when the heterogeneity effect dominates. The numerical sensitivity analyses show that the former positive externality case is most likely, but that a negative externality may occur if the effect on capacity of robot cars is small (e.g. a 25% increase, where the literature review suggests that such a small effect can occur if robot cars do not communicate and cooperate effectively).

Besides socially-optimal provision of robot cars, we also study provision at marginal production cost and monopolistic provisions. Due to externality it is not (second-best) socially optimal to provide robot cars at marginal cost and typically a subsidy is needed. The monopolistic car supplier adds a mark-up to its price and tends to leads to an even larger undersupply.

In an extension, we allow for pre-existing heterogeneity in the VOT and a heterogeneous effect of a robot car on the VOT of a user. Then, normal and robot car users will travel mixed and we will also allow the capacity effect to be an increasing and convex function of the share such that the majority of the capacity increase due to robot cars is between going from 80% robot cars to a 100%, which is in accordance with the pre-existing literature using car-following models.

References