On the virtues of the "shame lane"

Matteo Richiardi*

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Abstract

In July 2003 a new Road Code was approved by the Italian parliament. Among many reforms whose validity is not questioned here, the new law states that on three-lane motorways the right lane should not be reserved anymore to slow vehicles alone. As in two-lane roads, all vehicles must now drive on the right lane, as long as it is not occupied by other vehicles. The model developed in this paper casts doubts on the validity of such a change, suggesting that reserving a separate lane for slow vehicles is generally better, in terms of number of accidents and slow-downs, than the new one. This conclusion has a general validity beyond the Italian case. Moreover, it is shown to be extremely robust to refinements of the main assumptions concerning driving attitudes and the stochastic arrival of accidents.

Keywords: Traffic, Simulation, Italian Road Code.

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*LABORatorio Riccardo Revelli Centre for Employment Studies, via Real Collegio 30, 10024 Moncalieri (Torino), Italy. Tel: +39-011.640.2660. Fax: +39.011.647.9643. Email: m.richiardi@labor-torino.it

1 Introduction

> The paramount feature of Italian highway driving is *il sorpasso.* The word means "to pass with an automobile" and "to surpass or excel". By the way, it is not where you arrive that counts, but whom you pass on the way. The procedure is to floor your accelerator and leave it there until you come upon something you can pass. If *il sorpasso* is not immediately possible, settle in its wake at a distance of six or eight inches and blow your horn until such time as you can pass. Passing becomes possible, in the Italian theory, whenever there is not actually a car to your immediate left.
>
> (http://www.geocities.com/Heartland/Plains/6271/italy003.html)

It is possibly to change such a bad perception of Italian traffic that a new Road Code was approved, in July 2003, by the Italian Parliament. Among other major changes, such as the introduction of a driving license points system, the new Code abolishes the so-called "shame lane", *i.e.* the reservation of the right lane on three-lane motorways for slow vehicles only. With the new law, everybody should keep on the right lane, as long as it is free of other vehicles, as in all two-lane roads. According to the experts of the Transport Ministry, this change should bring down the number of slow-downs, since "normally nobody drives on the right lane, and thus Italian motorways are used less than it would be possible". The Infrastructure minister, Mr. Lunardi, is also convinced that the reform should have a positive effect on the number of accidents, since "one of the causes of the accidents is that there are slow vehicles on the middle lane".

Sounds reasonable. Unfortunately, it is not true. Simulating two 3-lane motorways, one governed by the old rule ("If you're slow, keep on the right lane and move on the middle lane only in order to pass a slower vehicle in front of you; if you're not slow, keep on the middle lane and move on the left lane only in order to pass a slower vehicle in front of you") and the other by the new one ("Always keep on the further right lane available; move left only in order to pass a slower vehicle in front of you") brings evidence that the opposite is actually the case. The new rule brings more accidents and a little more speed variance, *i.e.* the number of slow-downs actually increases. Finally, these findings remain generally true also when the simulation allows for occasional right pass (which is obviously strictly forbidden with both rules). The results are also robust to other changes in driving attitude.

The paper is structured as follows. Section 2 reviews the existing literature on the topic, with a particular regard to the economic issues involved. Section 3 describes the simulation set-up. Section 4 explains in more details the results. Section 5, 6 and 7 investigate relaxations of the assumptions (namely, the possibility of right pass, the introduction of endogenous distraction probabilities and the possibility of front crashing in addition to lateral crashing), in order to reproduce more realistic driving patterns. Section 8 concludes.

2 The Literature

Traffic problems are analyzed from various perspectives. Economists are mainly interested in the external effects involved, such as congestion, while traffic engineers are more interested in issues like the stability of traffic flows. The economic analysis of congestion (a forthcoming survey is [11]) is based on a standard demand and supply framework. Congestion arises because drivers do not consider the external cost they impose to other drivers, and not because supply is too limited. To this respect, the standard Pigou-Knight analysis ([12, 10]) suggests that expanding road capacity as a remedy to congestion is not only ineffective, but often counterproductive: if the capacity of the road network is increased, whether by road construction or traffic management measurements, its utilization will increase until a similar congestion level is reached again. Congestion charges should therefore be the optimal policy.

The Pigou-Knight model of traffic congestion refers to the stationary state behavior of a population of homogeneous drivers using the same road. Traffic density determines traffic speed by means of an aggregate relationship (the speed-flow curve), which in turns determines transportation time and thus traveling costs. The cost function is taken as a primitive concept. Recent developments (see [13]) consider heterogeneous individual drivers behaving in accordance with the speed choice theory. This theory states that a driver chooses his speed by trading off the benefits of a higher speed (reduced travel time) against the cost of (higher accident risk). The accident risk is related to traffic speed and density.

A different approach is taken by bottleneck models, building on the seminal work of Vickrey ([16]), which analyzes the behavior of drivers in queues (see [2] for a survey). One central question in this literature is whether the flow of cars through the bottleneck is less than the maximum possible flow ([15]). Bottleneck models are in general based on the car following theory. The intuitive idea that forms the basis of car following theory is that drivers react to the behavior of the vehicle immediately in front of them so as to avoid accidents. Car following theory ([6]) was elaborated mainly by traffic engineers, which were interested in phenomena such as shock waves. Thus, the idea has not been elaborated by means of models in which costs and benefits associated with a particular speed choice are traded-off against each other leading to a decision to accelerate or decelerate, as an economist would be inclined to do. Instead, it was meant for descriptive purposes, in order to model actual driver behavior. A trend is now under way to bridge the gap between the two literatures, and provide normative foundations to the car-following theory.

On the other hand, engineers are less troubled by purely behavioristic models, and have been more concerned with the inclusion of other realistic features of driving attitudes, in order to build reliable models of traffic flows. Thus, lane changing and gap acceptance models have been added to car-following models, following the seminal Gipps models ([7, 8]). However, realistic descriptions of vehicle's behavior have proved difficult to integrate in analytical models, which moreover can generally provide solutions only for stationary (*i.e.* equilibrium) conditions. On the contrary, micro-simulations have proved to be both powerful and versatile.

> When Nagel and Schreckenberg presented their cellular automaton model of traffic flow in 1992, allowing for a more than real-time simulation of the entire road system of large cities, they probably did not anticipate the resulting flood of publications and the enthusiasm among scientists on the subject of traffic theory. By treating huge numbers of interacting vehicles similar to classical many-particle systems, physicists have recently contributed to a better understanding of traffic flow. The mathematical tools that they use, stemming mainly from statistical physics and nonlinear dynamics, have proved their interdisciplinary value many times. [9].

Transport simulation models are now common. As an example, CORSIM – a computer simulation model of street and highway traffic – is the quasi-official platform used by the U.S. Department of Transportation to analyze traffic behavior and compare competing strategies for signal control before implementing them in the field ([1]). Other leading micro-simulators of traffic dynamics include AIMSUN ([3]) and PARAMICS ([4]). A survey of agent-based traffic simulators can be found in [5].

The purpose of the present paper is much less general than the works reviewed here. I do not want to build a comprehensive model of traffic behavior, neither I wish to contribute to a more general theory of driving attitudes, by considering the endogenous character of some relevant variable. I simply want to investigate the effects of a small change in the (external) driving rules. This work has some features of the traffic engineering literature, due to the attention to the dynamic properties of the model, but relies on a number of strongly simplifying assumptions, as often done by economists. In particular, I abstract altogether from car following considerations. The distance between a vehicle and its leader is kept constant throughout each simulation run, and is exogenously defined. While this assumption may of course be criticized, I believe it is appropriate for the purpose of the work. Its main implication is that the normal causal relationship between traffic density, speed and car following distance (a higher density implying lower average speed and smaller distance between vehicles) is somehow reversed, a smaller exogenously imposed distance allowing for higher traffic density and thus lower average speed. However, the model is able to reproduce the correct relationship between these variables, as will be shown below. I do not see any reason why including a variable car following specification should modify the results of the study. Moreover, I relax this assumption in a later section, by allowing the possibility of crashing into a leading vehicle and assuming it depends on the decrease in speed of the other vehicle, and I do not find any change in the simulation results. However, the effects of introducing a more realistic car following theory in the model should be tested. This is left for future developments. Speed choice is also very stylized. All vehicles have different desired speed. They never go faster than that. They decelerate only when some slower vehicle is on the way, if it is not possible to pass it. The next section introduces the simulation set-up more in details.

Finally, there is a story that could be told to defend this extremely simplified nature of the model. I proposed some traffic engineers to test in their simulation models the effects of the change in the Road Code investigated here. They were very interested but refused, since - they said - making the appropriate modifications in the lane change rules embedded in their model would have taken weeks of an expert programmer's time!

3 The Simulation

In order to compare the performances of the two rules, I develop an agent-based discrete-time simulation, written in java code using JAS libraries [14]. Two 3-lane motorways are simulated. At each time period, n new vehicles are created. Each vehicle is instantiated in two copies: one enters the old rule motorway, the other one the new rule motorway. Then, all vehicles are moved. Although in reality all vehicles move at the same time, the nature of the simulation requires the vehicles to be moved sequentially. Front vehicles are then moved first; among adjacent vehicles, those on the farther left lane are moved first.

3.1 Motorways

The two motorways are essentially a grid, with a predefined length and a width of 3 cells (the three lanes). Vehicles can move right, forward or left, but they obviously cannot move backwards.

3.2 Vehicle characteristics

Each vehicle has an exogenous desired speed, s_i. If possible, at each time period it moves forward of exactly s_i cells. Vehicles with a desired speed below s_{slow} are considered slow, and in the old rule motorway have to follow the indications for slow vehicles. Let's define r, m and l as the maximum distance that can be covered on the three lanes (the right, middle and left lane). If no other vehicles are on the way, $r = m = l = s_i$. If for instance a vehicle is on the right lane, just one cell forward, then $r = 0$. A vehicle is currently at position (x_t, y_t), where y is the lane and x the distance from the origin. After the move, the vehicle is at (x_{t+1}, y_{t+1}), with $x_{t+1} = x_t + s$, s being the actual vehicle speed.

The distribution of the desired speed is uniform between s_{min} and s_{max}. The introduction of a speed limit constrains all vehicles with a greater desired speed to the limit, thus increasing the density at the maximum allowed speed.

3.3 Passing Rules

Vehicles behavior changes according to the different rules. For the sake of clarity, I distinguish three cases for each rule, depending on the lane currently occupied by the vehicle.

3.3.1 New rule

(r) Right lane:

1. if straight is free, move forward, with speed $s = min(r, m, l)$ [1];
2. if straight is not free, move left (on the middle lane), with speed $s = min(m, l)$.

(m) Middle lane:

1. if straight is free, and right is free, move right, with speed $s = l$;
2. if straight is free, but right is not free, move forward, with speed $s = l$;
3. if straight is not free, move left, with speed $s = l$.

(l) Left lane:

[1] Since no right pass is permitted, the position of the closest vehicle on the middle lane limits how far a vehicle on the right lane can go

1. if right is free, and straight is free, move right (on the middle lane), with speed $s = l = m$;
2. else, move forward, with speed $s = l$.

3.3.2 Old rule, fast vehicles

(r) Right Lane:

1. if straight is free, move forward, with speed $s = min(r, m, l)$;
2. if straight is not free, move left (on the middle lane), with speed $s = min(m, l)$.

(m) Middle lane:

1. if straight is free, move forward, with speed $s = l$;
2. if straight is not free, move left, with speed $s = l$.

(l) Left lane:

1. if right is free, and straight is free, move right (on the middle lane), with speed $s = l = m$;
2. else, move forward, with speed $s = l$;

The only difference with respect to the new rule is that here fast vehicles on the middle lane do not move on the right lane, even when it is empty.

3.3.3 Old rule, slow vehicles

(r) Right Lane:

1. if straight is free, move forward, with speed $s = min(r, m, l)$;
2. if straight is not free, move left (on the middle lane), with speed $s = min(m, l)$.

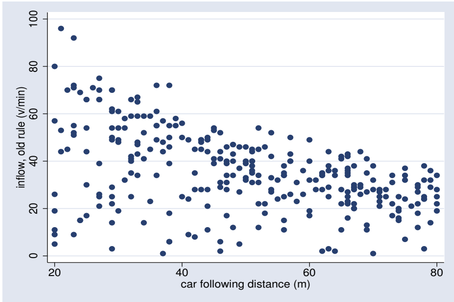
(m) Middle lane:

1. if straight is free, and right is free, move right, with speed $s = l$;
2. if straight is free, but right is not free, move forward, with speed $s = l$;
3. if straight is full, move forward, with speed $s = min(m, l)$.

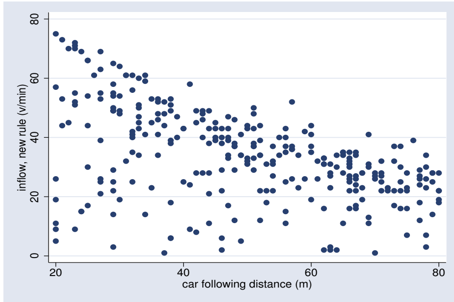
3.4 Accidents

Accidents occur because when a vehicle moves right or left, with a probability p it does not look properly whether there is any other vehicle on its immediate right or left. Suppose a vehicle is on the middle lane at (x, m) and wants to move left, because some other vehicle is on its way on the middle lane. If such a distraction occurs, it may have no consequences, in case no other vehicle is on (x, l), or it may cause an accident, in case the cell (x, l) is occupied. Note that the probability of a distraction is exogenously defined, and thus independent of the speed of the two vehicles that could be involved in the accident. This is clearly a simplification, and will be relaxed later on. Note also that there are no other possibilities to cause an accident. In particular, it is not possible to bump into a slower vehicle driving ahead. Again, this is a simplification, and will be relaxed by allowing such a possibility, and by letting it be dependent of the vehicle speed and the front vehicle *variation* in speed (*i.e.* by considering explicitly the danger of slow-downs).

Vehicles involved in accidents are immediately removed from the motorways, and thus do not cause queues or delays. Again, this is not realistic; however, since it will be shown that the new rule leads to more accidents, the introduction of negative accident externalities would push even more the results in favor of the old rule.



(a) Old rule



(b) New rule

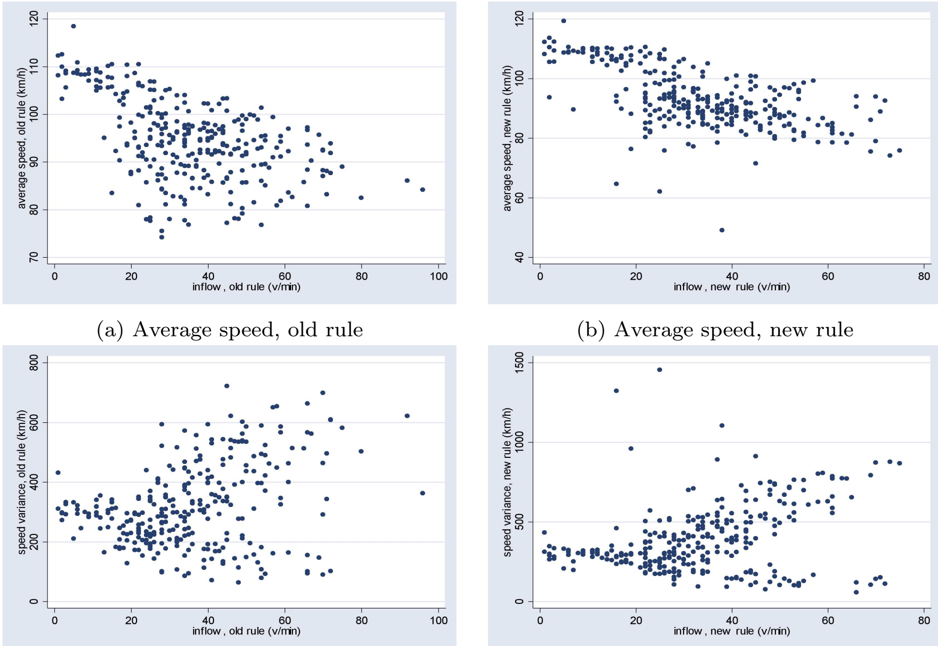
Figure 1: Inflow rate vs. cell length.

4 System behavior

In analyzing simulation results, 1 period is meant to last 1 minute. Since normally freeways cannot sustain a flux of more than 2,000 vehicles per hour per lane [2], this means that the influx of new vehicles must be constrained to an upper bound of 100 vehicles per period (6,000 vehicles per hour). Cells length has little implications in the model, but for the fact that a higher cell length (greater distance between vehicles) allows for a greater vehicle flux, as depicted in fig. 1. In the simulation runs, cell length is randomly extracted between 20 and 80 meters. Desired speed is uniformly distributed between 80 and 160 km/h, but is constrained to a maximum of 130 km/h by the speed limit. 300 runs are performed; each run lasts for 500 periods, and produces 1 observation with the values of the last period.

As expected, more traffic implies slower average speed and more speed variance with both rules (fig. 2). Moreover, the relationship between density and speed is almost linear, as observed in reality. To compare the performance of

[2] Urban freeways are able to sustain a higher flux of around 2,500-3,000 vehicles per hour per lane, because drivers "learn" that in order to go (collectively) faster they have to restrain from passing slower vehicles! These estimates have been provided verbally by transport engineers at CSST - Centro Studi sui Sistemi di Trasporto - a private Italian company involved in research, planning and engineering applied to travelers and freight transport systems.



(a) Average speed, old rule

(b) Average speed, new rule

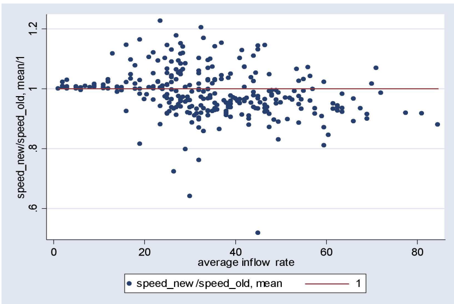
(c) Speed variance, old rule

(b) Speed variance, new rule

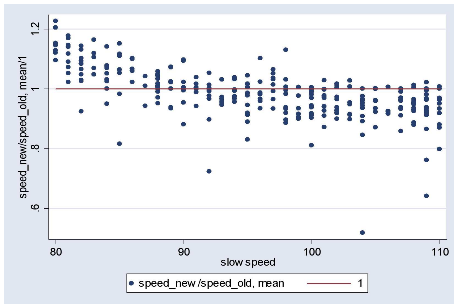
Figure 2: Traffic behavior, no accidents.

the two rules, it is possible to look at the ratio of the average speed with the new rule to the average speed with the old rule: values greater than 1 show the new rule allows on average higher speed. This is shown in fig. 3. With very little traffic the two rules are roughly equivalent. The new rule performs better, in terms of average speed, in light-to-medium traffic conditions (fig. 3a) and when the definition of slow vehicles is very strict (fig. 3b), but is worse as traffic increases, or as more vehicles are confined to the right lane in the old rule. Moreover, speed variance is generally higher with the new rule (fig. 3c,d): in the 300 runs, the average ratio of speed variance with the new and with the old rule is 1.29, while the median of the ratio is 1.10 .

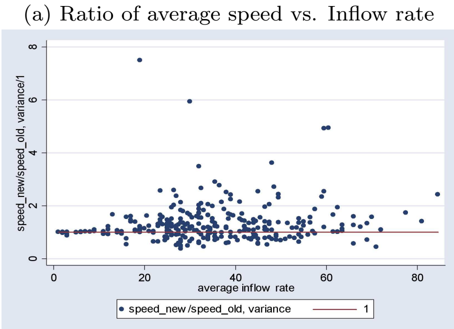
A distraction probability of 0.01 (*i.e.* one in a hundred probability of changing lane without looking) is then considered. It is easy to see that the new rule



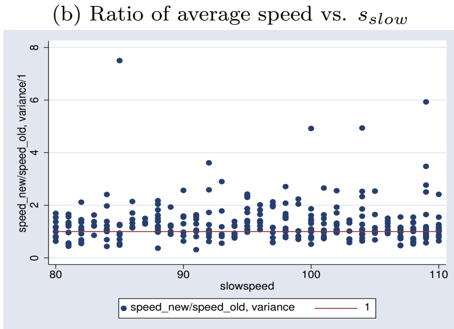
(a) Ratio of average speed vs. Inflow rate



(b) Ratio of average speed vs. s_{slow}



(c) Ratio of speed variance vs. Inflow rate



Ratio of speed variance vs. s_{slow}

Figure 3: Relative performance of the two rules, no accidents.

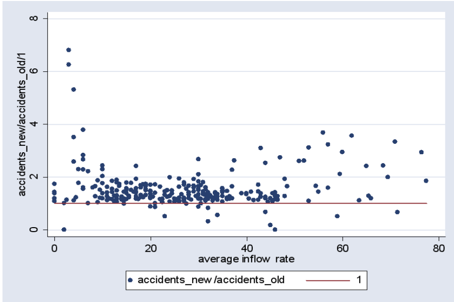


Figure 4: Relative accident frequency, lateral crashes considered.

is much worse, in terms of the number of accidents (fig. 4). Changing the value for the distraction probability does not affect the results: the coefficient of an OLS regression of the ratio of the total number of accidents with the two rules on the distraction probability is not significantly different from 0.

How is this (at first striking) result possible? Doesn't the new rule allow a more rational use of the highway? The answer is: the new rule implies many more lane changes than the old rule. In the model, lane changes are the only possible sources of accidents, hence the result. Note that these conclusions are not trivial. Supporters of the new rule could argue that, if everybody moves right whenever possible, the probability of a pass lane being occupied should go down. Thus distractions should have fatal consequences less frequently, and the probability of being 'trapped' in slow lanes should also diminish. This is true, but as the traffic becomes heavier, a small frequency of slow vehicles is enough to overturn this argument, and make the old rule outperform the new one.

The main objection to the analysis above is that the superiority of the old rule stands from considering only lane changes as a cause for accidents. Note first that also in the real world lane changes are a major source of troubles. However, in the next sections I refine the stochastic modeling of accidents, in order to test the robustness of the conclusions presented here.

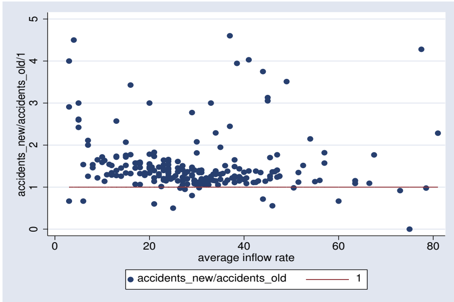


Figure 5: Relative accident frequency, right pass considered.

5 Right Pass

Supporters of the new rule say that the old one had the disadvantage of inducing drivers in temptation. The main temptation, when there is a slow vehicle ahead and no room for a proper pass on the left, being of course a right pass. With the new rule, there should be no vehicles at all leaving empty space on their right, or at least there should be less incentive to break the law and do a right pass. But how much less? Is this sufficient to overturn the advantage of the old rule, as described in the previous section? In order to answer this question, I have added a (small) probability of performing a right pass, in case the left lane is full but the right one is free. As expected, the new rule now performs better, relatively to the old one. However, even by assuming a very high propensity for right passes, the old rule generally remains better (fig. 5). The reason is that, even with the new rule, the incentives for a right pass do not vanish completely, in particular in heavy traffic conditions. Suppose for instance there is a slow vehicle far ahead, with many cars queuing to pass it on the left. The respectful driver should slow down, move to the left and wait for his turn to pass the slow vehicle. However, he may found convenient to go straight ahead, right-pass all vehicles on his left, and finally move to the left only when he eventually reaches the slow vehicle ahead.

6 Speed Dependent Distraction Probabilities

In this section, I keep on adding realism to the simulation by considering that the probability of having an accident is higher when driving faster. Note that it is not obvious that the distraction probability should be higher for faster vehicles, since drivers could pay more attention. However, the consequences of an accident are obviously more severe, the faster the cars involved. Since it would be not worthy to introduce a distinction between different types of accidents, the model simply mimics the empirical evidence by considering that faster vehicles are more accident-prone because they have a higher distraction probability. This is also in line with the predictions of the speed choice theory, as outlined above. It is assumed that the distraction probability increases with the square of the actual speed:

$$p_i = p\left(\frac{s_i}{s_{max}}\right)^2 \tag{1}$$

where p_i is the individual distraction probability, p the reference value for the distraction probability (which is attributed to cars driving at the maximum speed s_{max}) and s is the individual speed. This means that a car driving at 80 km/h has only a quarter of the risk of a car driving at the maximum speed of 160 km/h, while for a car driving at 120 km/h the risk has already jumped up to more than 55%. The new rule still performs generally worse (fig. 6).

7 Front Crashes

Supporters of the new rule could still claim that with the old rule there should be a higher density of vehicles in the middle and left lanes, thus increasing the probability of bumping into the vehicle ahead. Thus, the last extension of the model considers this possibility explicitly. For the sake of realism, this

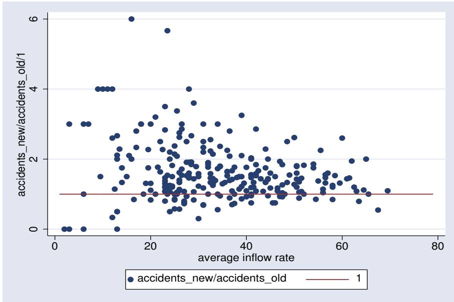


Figure 6: Relative accident frequency, speed dependent crash probability.

probability is assumed to depend on the decrease in speed of the preceding vehicle:

$$p_i = \begin{cases} p\left(1 - \left(\frac{s_{i,t-1}}{s_{i,t}}\right)^2\right) & \text{if} \quad s_{i,t-1} \geq s_{i,t} \\ 0 & \text{if} \quad s_{i,t-1} < s_{i,t} \end{cases}$$

where p is the reference value for the distraction probability. For instance, if a vehicle j ahead decreases its speed from 130 km/h to 100 km/h, the probability of vehicle i crashing into it is around 0.41 p, while if vehicle j has reduced only to 110, the probability goes down to a mere 0.28 p.

However, allowing front crashes doesn't make the new rule appear much better. The argument of the supporters of the new rule can in fact be turned around: if all vehicles have to drive as much on the right as they can, it becomes more likely to have someone on the way ahead, in the same lane. The density on the right lane surely goes up, while the effect on the middle lane remains unclear. Moreover, since the new rule causes more slow-downs, as described in section 3 above, it becomes more likely not to see that a vehicle ahead is reducing speed. Simulations confirm this intuition (fig. 7).

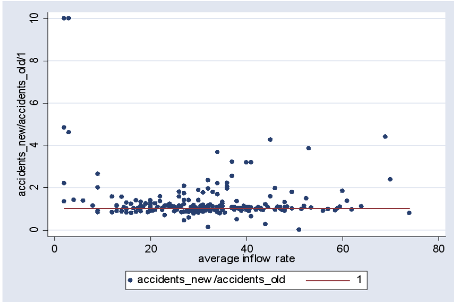


Figure 7: Relative accident frequency, front crashes considered.

8 Summary and Conclusions

In July 2003 a new Road Code was approved by the Italian parliament. Among many reforms whose validity is not questioned here, the new law states that on three-lane motorways the right lane should not be reserved anymore to slow vehicles alone. As in two-lane roads, all vehicles must now drive on the right lane, as long as it is not occupied by other vehicles. The model developed in this paper is an agent-based model, characterized by a very simple speed choice rule (each vehicle goes at its desired speed unless forced to decelerate because some slower vehicle is on the way) and without explicit modeling of car following (the distance from the preceding vehicles is kept constant but in the last section, when the possibility of crashing into vehicles ahead is considered). Simulation results cast doubts on the validity of the change, suggesting that reserving a separate lane for slow vehicles in three-lane highways leads to fewer accidents and less variance in vehicle speed. This conclusion is shown to be extremely robust to refinements of the main assumptions concerning driving attitudes and the stochastic arrival of accidents. This is summarized in tables 1 and 2. Table 1 refers to *accidents*. Columns (2) and (3) report the ratio of the average number of accidents occurring with the new and with the old rule. The mean and the median of this ratio across all simulation runs are shown. Numbers are always above 1, meaning that we should expect more accidents (about 50% more) with the new rule [3]. Table 2 refers to *speed.* Columns (2) and (3) report the ratio of the average speed of the vehicles driving with the new and with the old rule. Again, the mean and the median of this ratio across all simulation runs are shown. Columns (4) and (5) report the ratio of the variance in speed of the vehicles driving with the new and with the old rule. As before, the mean and the median of this ratio across all simulation runs are shown. While the average speed is roughly equivalent with the two rules, the new rule brings a little more speed variance.

Table 1: Relative performance of the two rules. Number of accidents.

		Ratio of average number of accidents	
	(1)	(2)	(3)
	runs	Mean	Median
Change lane	301	1.70	1.37
+ Right pass	242	1.61	1.34
+ Speed dependency	286	1.62	1.46
+ Front crash	301	1.51	1.06

Table 2: Relative performance of the two rules. Speed.

		Ratio of speed mean		Ratio of speed variance	
	(1)	(2)	(3)	(4)	(5)
	runs	Mean	Median	Mean	Median
Change lane	301	1.12	1.00	1.70	1.06
+ Right pass	242	1.05	1.00	1.91	1.06
+ Speed dependency	286	1.00	1.00	1.44	1.14
+ Front crash	301	.99	1.00	1.79	1.17

The main strength of this model is also its main limit: simplicity. Assumptions about speed choice do not seem to be a cause of trouble. After all, they are not so unrealistic. Instead of deriving the 'desired' speed as the solution of

[3]Of course, this is effect of the new rule alone. Other changes put forward by the new Road Code may well overturn it (and the first empirical evidence shows that they indeed do).

an optimization problem, like often done in the economic literature, its distribution is assumed from the outside. Moreover, it is quite reasonable to assume that when there is no room to pass, one has to slow down to the speed of the preceding vehicle. It is true that vehicles that wish to move faster normally adopt a more aggressive driving attitude. However, I believe that this could be left out of a simple model, without great backdrops. Assumptions about car following are more questionable. In particular, introducing more sophisticated car following specifications could help in modeling the stop-and-go effects of the two rules. However, since it is shown that the new rule – if anything – produces more variance in the speed of the vehicles, it is likely that having a better model for car following would even sharpen the results of the analysis. A test of this claim, however, should be performed in an expanded version of the model, which is left for future developments.

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