



Options for road user charges – two Italian case studies

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Abstract

This paper discusses the impact that tolling schemes with a higher degree of differentiation of tariffs among demand categories can have on road demand. The question addressed in the paper is whether the differentiation of inter-urban road tolls can help to manage demand and meet targets like alleviating congestion, reducing emissions or making feasible project financing schemes, where toll revenues are used to cover construction and operating costs. The paper is mainly based on the results of the DIFFERENT research project, co-funded by the European Commission DG TREN, where a number of modelling tests have been carried out using two different transport network models. Based on modelling results we conclude that a trade-off between alternative targets of toll differentiation exists and that results vary according to the specific context of the application. In non-congested corridors charge differentiation can raise money, but there is little room for social benefits, whereas in congested areas travel speed on the road network can be improved by introducing charges on congested non-motorway links. Additionally, achievement of benefits from differentiated charges may require the co-ordinated introduction of charges on ordinary roads as well as on motorways.

Keywords: Road charging; Modelling; Project financing; Transport externalities.

1. Introduction

Motorways tolls are already applied in many European countries to contribute to finance the total operating cost, including investment and return on investment, for the various concessionaires. Countrywide toll schemes, with some levels of differentiation, have been recently introduced on German, Czech and Austrian motorways and on the road network of Switzerland. Rules for road charges in Europe are going to be changed on the basis of the EC strategy for the internalisation of external costs of all modes of transport, as specified in the Greening Transport Package issued on July 2008. It is then expected that higher degrees of tolls differentiation will be soon introduced in the European road network.

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The paper discusses the impact that tolling schemes with a higher degree of differentiation of tariffs among demand categories can have on road demand. The question addressed in the paper is whether the differentiation of inter-urban road tolls can help to manage demand and meet targets like alleviating congestions, reducing emissions or making feasible project financing schemes, where tolls revenues are used to cover construction and operating costs. Alternative criteria that can be used to introduce differentiation are compared. The paper is mainly based on the results of the DIFFERENT research project, co-funded by the European Commission DG TREN. The project has investigated the role of differentiated prices for all modes of transport from a theoretical and empirical perspective. Within DIFFERENT, several tests have been carried out to assess the impact of various differentiation schemes on interurban road transport using two simulation models: of the Brenner corridor and of the Padana region in Italy. The paper reports the main outcomes of these simulations, which are relevant for the design of transport policies.

The paper has the following structure. In section 2 the modelling tools used for the simulations are described. The modelling tests carried out in DIFFERENT are introduced in section 3, while section 4 presents the main results. Finally, section 5 draws conclusions and makes some reflection on policy issues.

2. Description of the modelling tools

The modelling applications, developed for the Brenner corridor and the Padana region, were used as test-bed to simulate tolls differentiation. The reason for using these two models is threefold: first, an initial version of both was already accessible to the authors. Second, the two models are considered well representative of two quite different conditions: the Brenner model relates to a major international corridor mainly used by through traffic and which has no significant capacity problems, while the Padana region is a complex and often congested network dominated by local traffic. Third, the Padana region model includes some planned infrastructures that should be built according to project financing schemes, whose feasibility heavily depends on toll revenues.

A common feature of the two models that is important to clarify is that they do not handle long term effects which may happen when differentiated road tariffs are applied. For instance, when more polluting vehicles are overcharged, the vehicle fleet could evolve quickly, with more charged vehicle types replaced by others. Also, when a differentiation scheme gives rise to higher average tolls reactions might happen on the logistics side, e.g. empty trips might be reduced, etc. These kind of impacts are not modelled. Another type of decision that the two transport models do not tackle is the application of differentiation schemes based on aspects like the day of the week or the period of the year. A differentiation of tolls in e.g. summer week-ends with respect to other periods of the year could actually lead some demand to change route, but also to shift the trip to another period or to change destination and these choices are beyond the scope of the model.

2.1. The Brenner Corridor Model

The Brenner corridor is one of the main gates for trans-Alpine traffic for both passenger and freight. Thus, a significant amount of crossing demand (with a substantial proportion of long distance HGV traffic) contributes to the traffic on the tolled motorway connecting Verona to Innsbruck and beyond. At the same time, especially in the Italian part, the corridor is also used for (relatively) short-distance trips within the study area. A national road runs parallel to the motorway and can be considered as an alternative route (especially for local trips). A major railway is also available on the corridor and a new rail tunnel is planned within the TENs projects.

The Brenner model builds on an existing integrated transport and land use model of the Italian section of the corridor (Alto Adige/South Tyrol)¹. The model is implemented using the Meplan software package and simulates both modal split and route choice of both passenger and freight demand during the morning peak. Two alternative road paths are considered – although in a simplified manner - for long-distance traffic: one is the corridor through St. Gotthard tunnel, the other is the Tarvisio pass. The Origin/Destination matrix was estimated using existing databases and origin-destination matrices (the South Tyrol integrated land-use and transport model, the CAFT Alps Crossing database², the ETIS database³, the SCENES model⁴).

The zoning system includes 42 zones (33 being part of the study region and the rest as external zones) defined with the objective of simulating local traffic as well as crossing traffic on the corridor. Two parallel segmentations of demand are used in the model, one concerning vehicles and one concerning individuals or transported goods. Vehicles are categorised according to their EURO emissions standard (consistently with the COPERT⁵ classification) and, in the case of trucks, their size.

Passenger demand is segmented according to trip purpose (business, commuting, tourism, and personal trips) and the average length of trips (crossing traffic; short and long distance traffic). Some combinations of trip purpose and length are not considered because they are regarded as unlikely or irrelevant (e.g. crossing trips for personal purpose) and thus 8 demand segments are used (table 1). Each of the 8 segments has a separate elasticity value and is further crossed with the 4 emission classes giving a total of 32 (8 x 4) demand segments.

¹ The South Tyrol integrated land-use and transport model was originally built in 1993 as a supporting tool for the Transport Master Plan. The model was updated in 2001 for the assessment of the Regional Transport Plan.

² The Alps Crossing database is one result of a monitoring project managed by the countries of the Alps region (France, Switzerland, Austria and, lately, Italy). Each five years, a traffic survey is carried out on main Alps passes in order to collect information on the amount of road and rail freight traffic and its features (freight type, containerisation, etc.). A report of the latest survey can be found at: <http://www.uvek.admin.ch/dokumentation/00655/00895/01152/index.html?lang=it>.

³ Within the European Transport policy Information System (ETIS) project, ETIS-BASE developed a database of passenger and transport data which is expected to become the reference database for European strategic modelling. More information on ETIS and ETIS BASE can be found at: <http://www.iccr-international.org/etis/>.

⁴ See Ying *et al.*, 2005.

⁵ COPERT is the acronym of “COMputer Programme to calculate Emissions from Road Transport”. The program has been developed by the European Environment Agency. The emissions functions developed in COPERT are a widely used reference in European studies. For more details on COPERT see <http://lat.eng.auth.gr/copert/>.

Table 1: Demand/Groups Combinations – Passengers.

Purpose	Average Trip Length		
	Crossing	Short Distance	Long Distance
Business		X	X
Commuting		X	X
Tourism	X	X	X
Personal trips		X	

Table 2: Demand/Groups Combinations – Freight.

Commodity	Average Trip Length	
	Crossing	Short-Long Distance
High Unitised (HU)	X	X
High Not Unitised (HNU)	X	X
Low (LOW)		X

Freight demand is segmented according to commodity groups (high value goods unitised; high value goods not unitised e.g. machinery, vehicles; low value goods) and average trip length. As for passengers, not all possible combinations are actually used in the model. The demand groups are further split into 12 categories of vehicles obtained by combining the four emission classes and the three weight categories. Eventually, 44 demand segments are used for freight demand.

The Brenner corridor model is multimodal and, even though the focus is on road transport tolls, alternative modes are included in the model in order to simulate modal shift as reaction to the tolling measures. Four transport modes are available for passengers: car (only driver); car (driver + passengers); coach; train. The two alternative car modes are considered because one possible response to pricing policies is car pooling⁶.

For freight, train is the only alternative to road modes. The alternative is modelled only for those demand segments correspondent to a large truck (>16 tonnes). The assumption is that deliveries using lighter vehicles are too small in volume and too frequent in time to have rail as a realistic alternative.

In addition to the attention paid to the realism of traffic flows and mode split on the corridor, the model was calibrated in order to reproducing sound elasticities (i.e. comparable to literature values) of demand with respect to cost.

2.2 The Padana Region Motorway Model

The Padana Region Motorway model has been the results of the update of an existing road transport model, implemented using the Meplan software package, elaborated in order to test the impacts of further toll differentiation on the complex motorway network existing in its study area (see figure 1), which comprehends Lombardia, Emilia Romagna and Veneto regions.

The Padana Region is one of the main gates for both passenger and freight traffic and his motorway network is composed by the following motorways: A4 Milano–Venezia,

⁶ For trip purpose “tourism” only the driver + passengers alternative is modelled.

A1 Milano - Bologna, A22, Brennero-Modena, A21 Piacenza–Brescia, A13 Padova–Bologna, Cremona–Mantova axis (in project), Brescia–Bergamo–Milano axis (in project), Pedemontana axis (in project), Tirreno–Brennero axis (in project). Population and economic activities density is very high in the model region, so that the motorway network is intensively used for local trips also.

The model simulates route choice for both passenger and freight demand. None of the other modes is considered as alternative to road transport. Since in the modelled scenarios, at least some demand segments experience higher tolls, mode shift can be expected at some extent. The Padana region model cannot capture this effect and therefore absolute values of demand and revenues estimated with the model can be overestimated. At the same time, the interest placed in the comparison of results between the alternative scenarios, it seems reasonable that the absence of competing modes does not hinder to draw conclusions from the simulations.

The toll differentiation tests have been implemented at the year 2020, when all the new motorway projects are supposed to be available. Different matrices concerning various configurations of the vehicle fleet have been produced in order to simulate the effect of its evolution on the toll analysis.

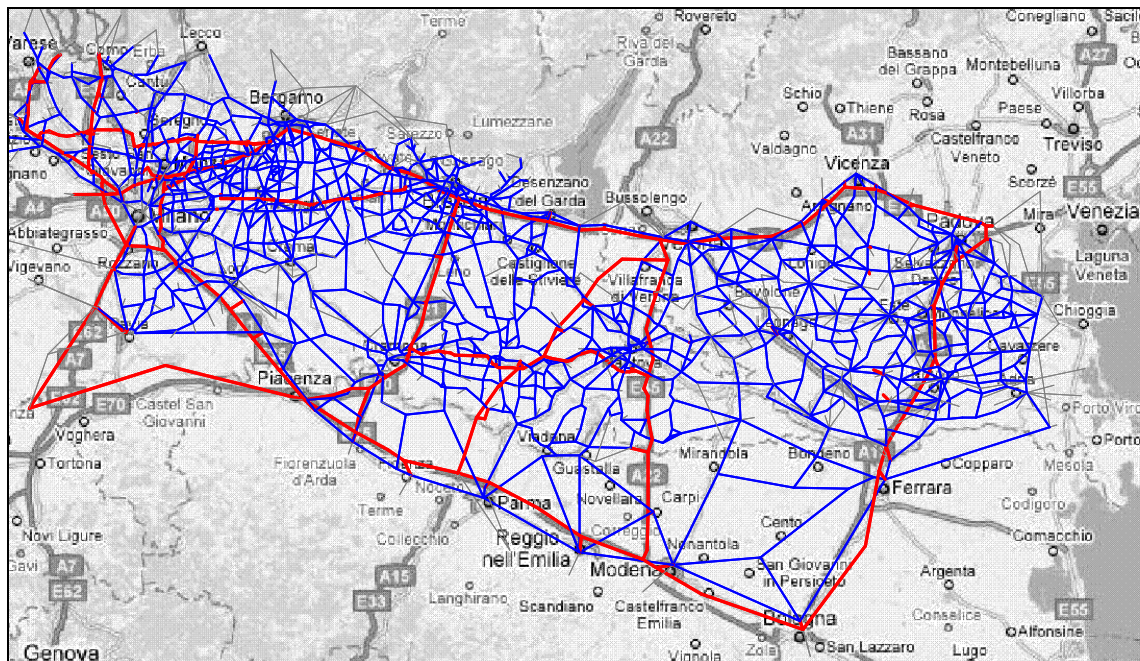


Figure 1: The Padana Region Motorway Model Network.

For the purpose of this study, the model was updated introducing vehicle differentiation for both freight and passenger, in order to permit the introduction of differentiated toll. The adopted segmentation is consistent to the one used for the Brenner model and includes : four emission categories – or Euro standards - for cars and trucks (EURO-I or less, EURO-II, EURO-III, EURO-IV) and three size categories of freight vehicles (<3.5 tons; 3.5-16 tons; >16 tons). As a result, passenger demand is segmented according to the standard EURO of the vehicle, while for freight demand the combination of size and standard EURO is considered. In the end, 4 segments are used for passenger and $4 \times 3 = 12$ segments for freight demand.

3. Differentiation scenarios

The differentiation schemes were defined according to:

- The variable used to differentiate tolls (e.g. vehicle size, emissions category);
- The level of differentiation (i.e. the difference between each toll level);
- The size of the tolls (i.e. for a given relative difference between each toll level, the absolute values can be larger or smaller).

Four types of scenarios were simulated:

- A set of scenarios where motorway tolls are differentiated according to vehicles emissions class (named E-scenarios);
- A set of scenarios where motorway tolls discriminate trucks on the basis of their size (named S-scenarios);
- A set of scenarios where also the ordinary road network is tolled (named R-scenarios);
- A final set of eight alternative scenarios where all the criteria (emissions class, truck size and road type) are used at the same time (see table 3)⁷.

Table 3: Summary Description of the Mixed Scenarios in the Brenner Corridor model.

Test	EURO Category	Vehicle Size	Road Type
1	Disincentives for most polluting vehicles (with a larger difference for cars than for trucks).	Discounted tolls for light vehicles, higher tolls than the current ones for heavy vehicles.	State road tolled for all freight vehicles (50% of current motorway charge). 25% discount on the motorway for all trucks.
2	25% discount for EURO 4 cars.	Same as test 1.	The toll for trucks on the state road increases (100% of current motorway charge).
3	EURO 2 cars are no longer charged a premium.	Rise in the discount for light lorries. Current toll for heavy trucks	Same as test 2.
4	10% discount for EURO 2 cars with respect to the current charge.	Light lorries are not discounted anymore.	25% discount on the motorway for all trucks.
5	20% discount for EURO 2 cars with respect to the current charge.	Light lorries receive a 25% discount.	Cars using ordinary roads are charged 40% of current motorway toll. 10% premium on trucks using the motorway.
6	Premium for EURO 3 cars is lower than in test 5. 10% discount for EURO 2 cars with respect to the current charge.	Same as test 5.	Same as test 5.
7	Same as test 6.	Same as test 6.	Cars and trucks using ordinary roads are charged 50% of current motorway toll. Cars toll on motorway discounted by 25% Truck toll on motorway discounted by 10%
8	Same as test 6.	Same as test 6.	Cars and trucks using ordinary roads are charged 50% of current motorway toll. Cars toll on motorway discounted by 25% Truck toll on motorway discounted by 15%

⁷ All these eight scenarios were simulated with the Brenner model, while only the first six scenarios reported in table 3 were tested (with some minor adaptation) also in the Padana Region model.

In all scenarios some demand segments enjoy a toll reduction whereas others face a toll increase. However, scenarios are not neutral, i.e. increments and decrements do not balance each other. Especially where tolls are extended to the road network (in addition to the motorway network), the average tariff is actually larger than in the reference scenario. It should be clear that scenarios were not designed with the aim of keeping the average toll level fixed, but to discriminate between demand segments when, for instance, higher tolls are levied to internalise external costs or to recover investment costs.

4. Modelling results

4.1. Results from the Brenner Corridor Model

Figure 2 to 4 provide a summary of the outcomes⁸ of the simulations of the first three sets of scenarios.

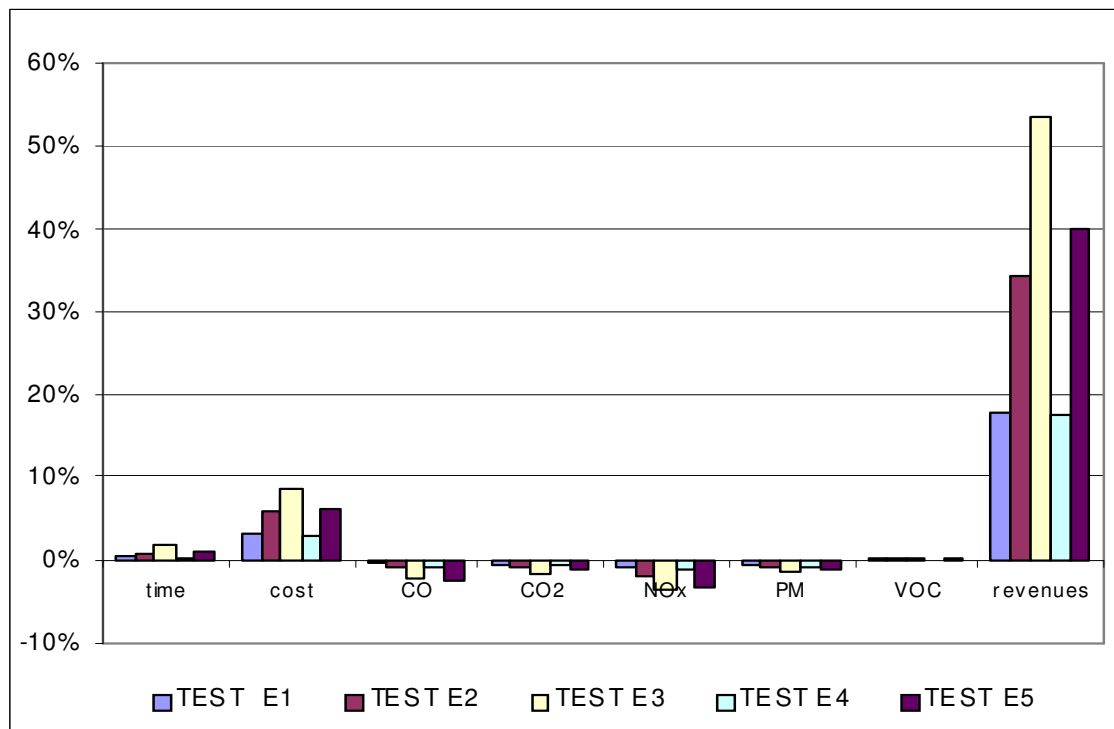


Figure 2: Summary Results of the E-Scenarios in the Brenner Corridor Model: Differentiation According to Emissions Level.

⁸ Outcomes reported include: total travel times on the network (*time*); total variable operating costs plus toll costs (*cost*); emissions of: Carbon Oxide (*CO*), Carbon Dioxide (*CO₂*), Oxides of nitrogen (*NO_x*), Particulate matters (*PM*), Volatile Organic Compounds (*VOC*); Total toll revenues (*Revenues*).

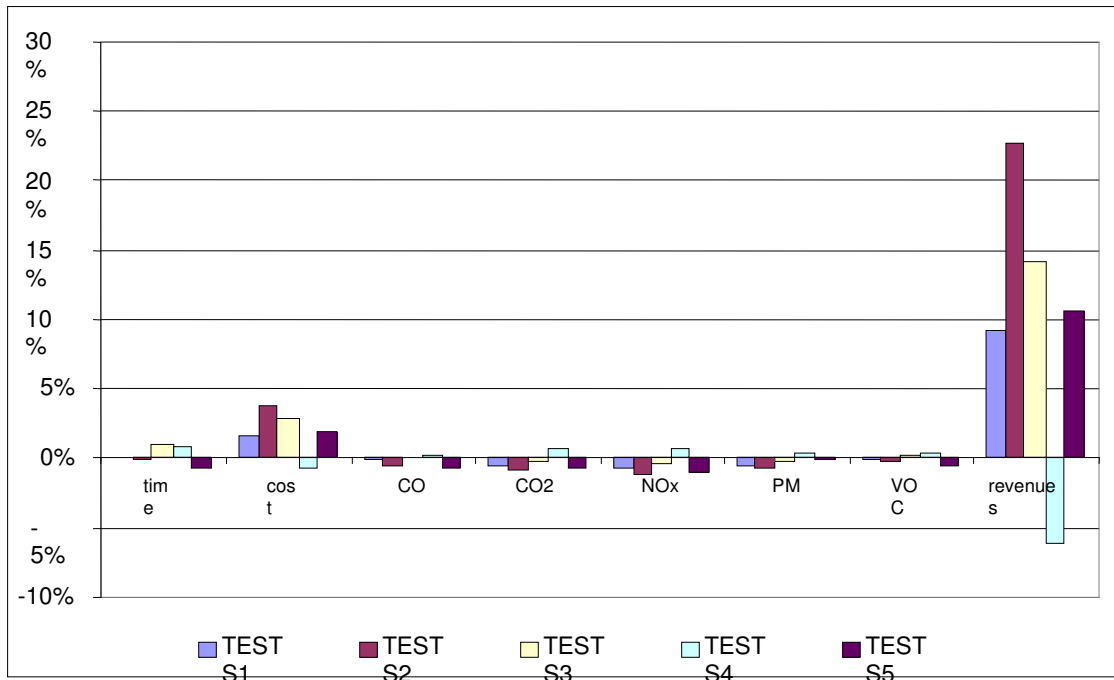


Figure 3: Summary Results of the S-Scenarios in the Brenner Corridor Model: Differentiation According to Vehicle Size.

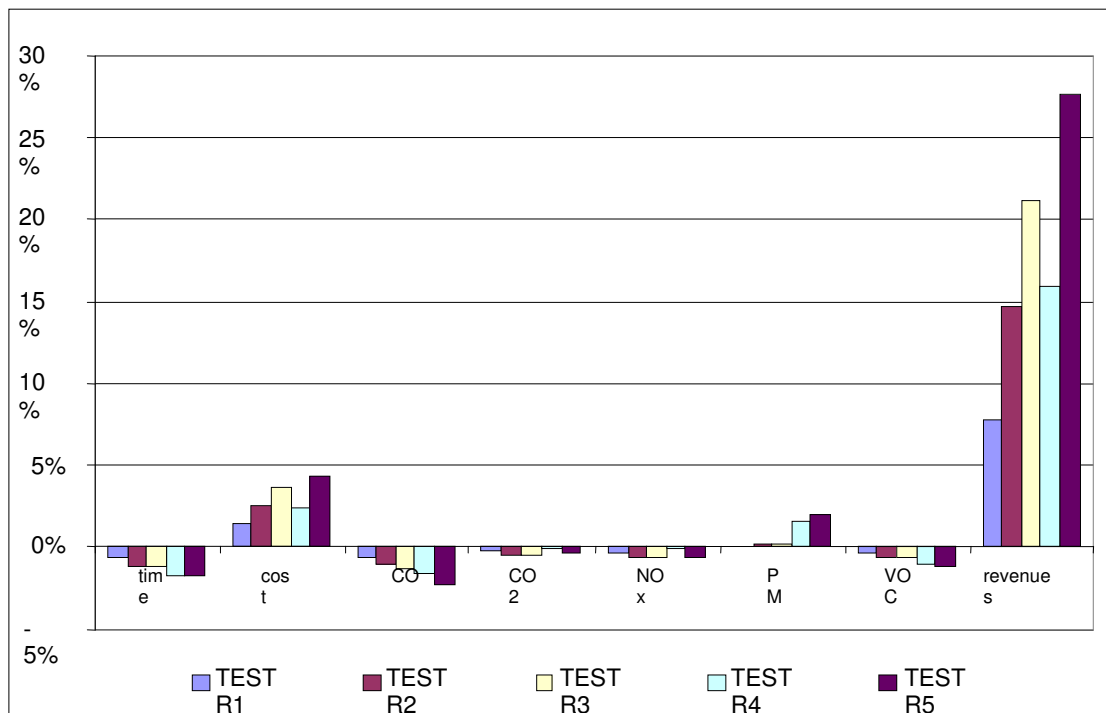


Figure 4: Summary Results of the R-Scenarios in the Brenner Corridor Model: Differentiation According to Road Type.

Some relevant results can be summarised as follows. First, in all tested scenarios, an “environmental” differentiation of charges leads to an increase of travel time because part of the traffic shifts onto the ordinary roads, with an overall worsening of congestion. Second, just increasing tolls for heavy vehicles produces higher revenues for the motorway operator but traffic conditions are slightly worsened (tests S1 to S3),

while coupling discounted tolls for light vehicles with slightly higher tolls for the heaviest vehicles (test S4) can give rise to positive effects: travel times in the area are reduced as traffic on ordinary road is decreased, without any effect on the motorway operator revenues. Third, when freight vehicles are charged on the ordinary roads (tests R1 to R3), truck drivers are induced to leave the ordinary road for the motorway, with positive effects in terms of traffic congestion on the ordinary network and lower travel times also for trucks (because the motorway is less congested). Total revenues (motorways + ordinary road) increase as well. When both cars and trucks are charged on the ordinary road and the latter receive a discount on current motorway charge (scenarios R4 and R5), route shift is larger and so is the benefit for road congestion. Discounting tolls for trucks on the motorway when the ordinary road is also charged seems also not detrimental for the total toll revenues, however environmental impacts are adverse because of the higher speed of trucks on the network.

Figure 5 provides summary results of the final set of scenarios, where all criteria are used at the same time, trying to keep the good results of the previous scenarios and minimise undesired effects. However, the evidence from this last set of tests shows that only limited emissions and travel time reductions can be achieved using toll differentiation schemes and travel costs are often increased. Since all these scenarios include ordinary road tolls, operators revenues are increased, sometimes greatly.

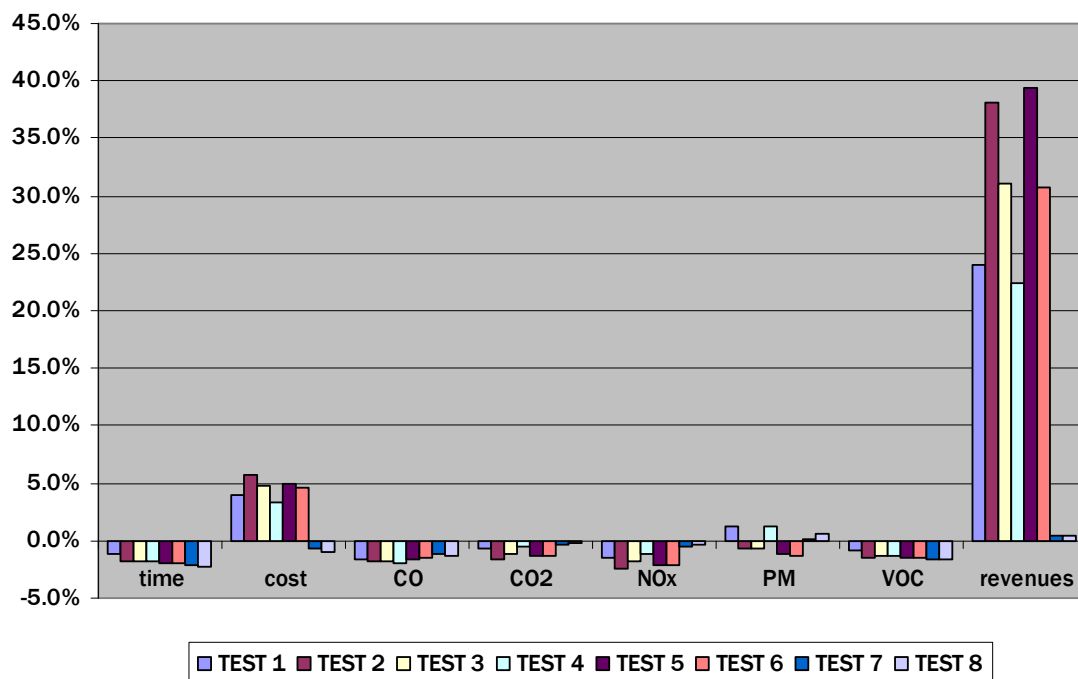


Figure 5: Summary Results of the Mixed Scenarios in the Brenner Corridor model.

Given these results, one may ask whether there is a real payoff for the higher travel costs. In order to address these questions, scenarios were compared using a measure of net benefit which included user costs together with a valuation of travel time and of pollutant emissions (note that this is not a full cost-benefit analysis because it excludes implementation costs and does not discount costs and benefits over time).

The values used in this exercise are reported in Table 5. The values of travel times for freight were derived from values in Euro/ton*hour estimated in the SCENES project (Ying *et al*, 2005). The values of travel times for passengers were estimated using

results of direct surveys carried out by TRT in Italy. The marginal costs of polluting emissions were estimations made for the ASTRA-Italia project (Centro Studi Federtrasporto, 2002) starting from literature values (INFRAS-IWW, 2000).

Table 4: Values used for the Estimation of the Net Economic Benefit of Scenarios.

	<i>VOT*</i>	<i>CO**</i>	<i>CO2**</i>	<i>NOx**</i>	<i>PM**</i>	<i>VOC**</i>
Cars	11.7	3.1	87.2	6 863.2	173 276.5	1 073.7
Trucks	20.9					

Notes: *Euro per hour; **Euro per ton.

Figure 6 shows the results for the mixed scenarios in terms of total benefits enjoyed by the society in comparison to the BAU scenario. Positive values imply a gain in social welfare (lower costs), while negative values represent a loss (higher costs).

Most scenarios present a negative economic benefit because the higher travel costs outweigh any reduction of travel times and emissions. The two scenarios yielding positive results are those in which a saving-oriented toll differentiation scheme (whereby truck motorway tolls are reduced and, at the same time, goods vehicles are tolled on ordinary roads) is applied. This scheme causes a cross shift of cars from the motorway to the ordinary roads and vice-versa for goods vehicles and, as a result, both segments benefit from less congestion and reduced travel costs.

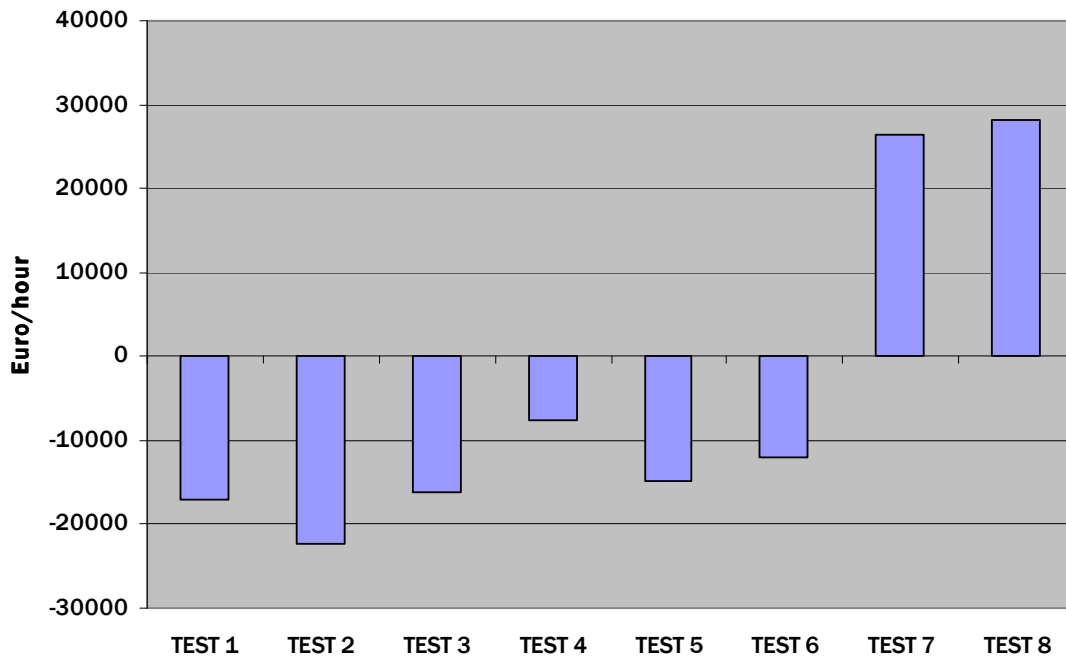


Figure 6: Net Economic Benefit of Final Scenarios in the Brenner Corridor model (1000Euros per year).

4.2. Results from the Padana Region Motorway Model

The most significant results of the tests simulated with the Padana Region model are shown in figures 7 to 9 and can be summarised as follow. In scenarios where motorway tolls are differentiated on the basis of vehicles emissions class, an increase of the time

spent on the network and of transport emissions is obtained. This result is in line with the outcomes of the tests on the Brenner model.

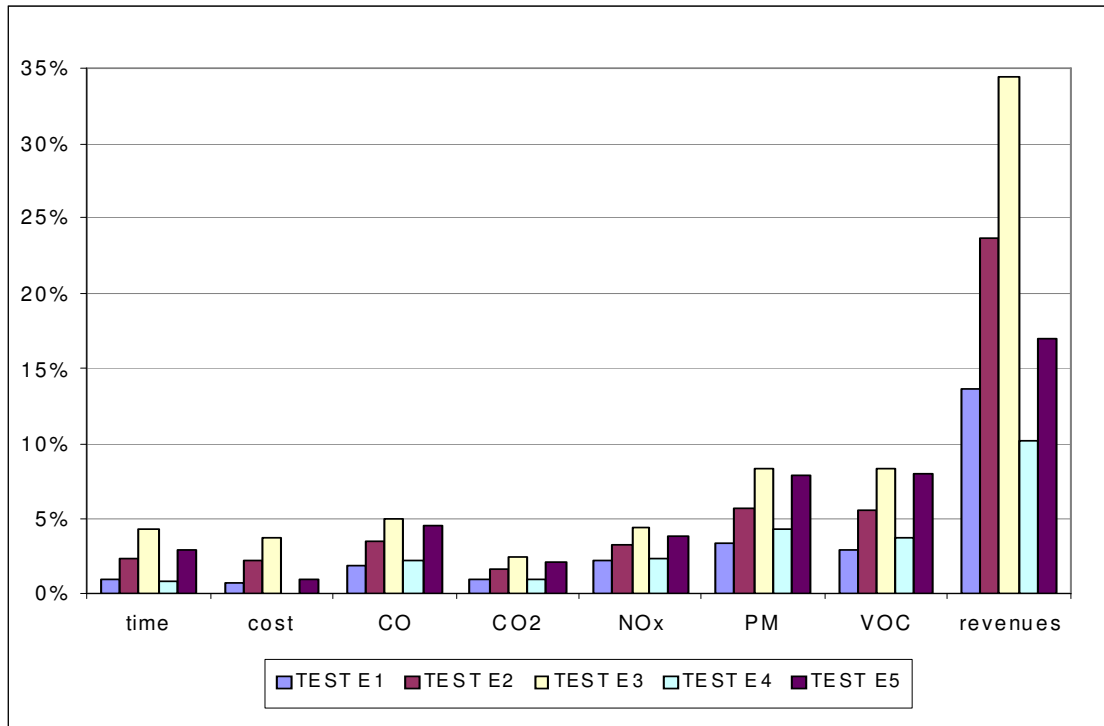


Figure 7: Summary Results of the E-Scenarios in the Padana Region Model: Differentiation According to Emissions Level.

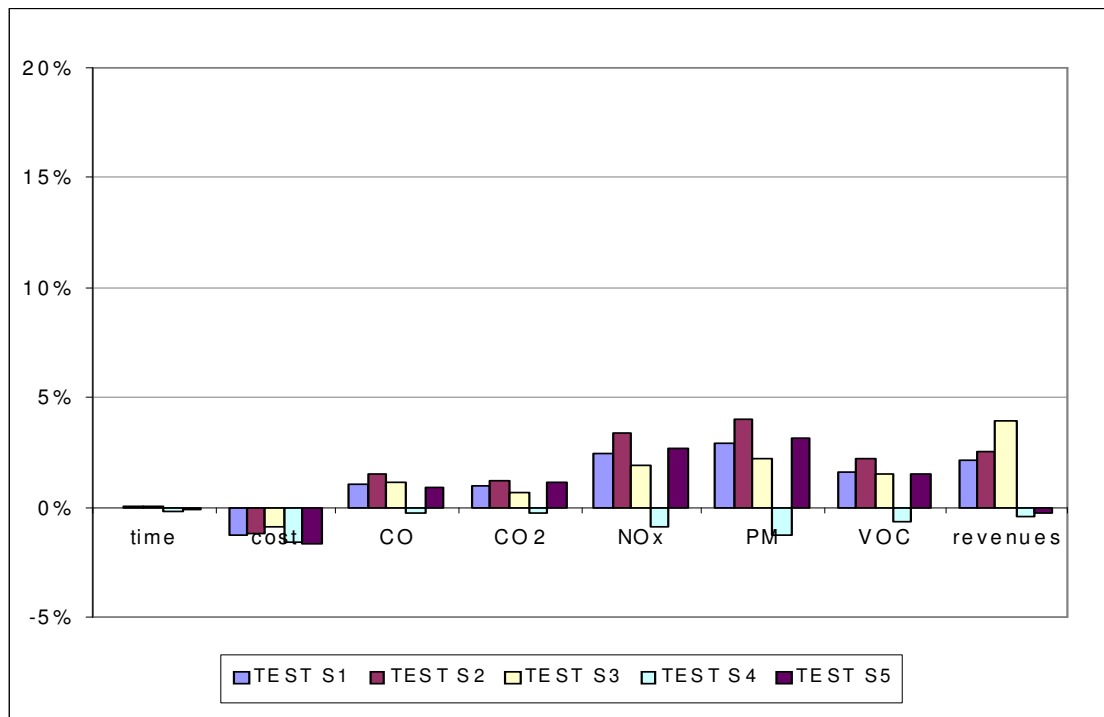


Figure 8: Summary Results of the S-Scenarios in the Padana Region Model: Differentiation According to Vehicle Size.

In the second set of scenarios, the most noticeable results concern the effect of coupling discounted tolls for light vehicles with slightly higher tolls for the heaviest vehicles (Test S5); in contrast with what was observed for the Brenner model, travel times are almost unchanged, transport emissions increase and the effect on the revenues of the motorway operator is of a slight reduction. The reason for this difference is that part of heavy vehicles (those moving on shorter distances) shift from motorway to road in reaction to larger tolls.

In the third set of scenarios, when the charge on car travellers on the motorway is increased without any tolls on the state road (tests R1 to R3), while trucks are charged on both the infrastructure types, results are in line with those obtained in the Brenner model. On the one hand car travellers shift to the state road because of the increased toll on the motorway, on the other hand truck drivers are induced to leave the state road for the motorway: these shifts lead to savings in time spent on the network for both car and trucks. Unfortunately the positive effect on time (which is much larger than in the Brenner model because the network starts from a congested configuration) does not produce positive effects on transport emissions, which increase for all the pollutants in any scenario considered. Total travel costs are almost unchanged for these three scenarios while revenues increase for the motorway operator as effect of the increased toll. When also cars are charged on the road network, while trucks receive a discount on current motorway charge (tests R4 and R5) are also similar to the results of the Brenner model.

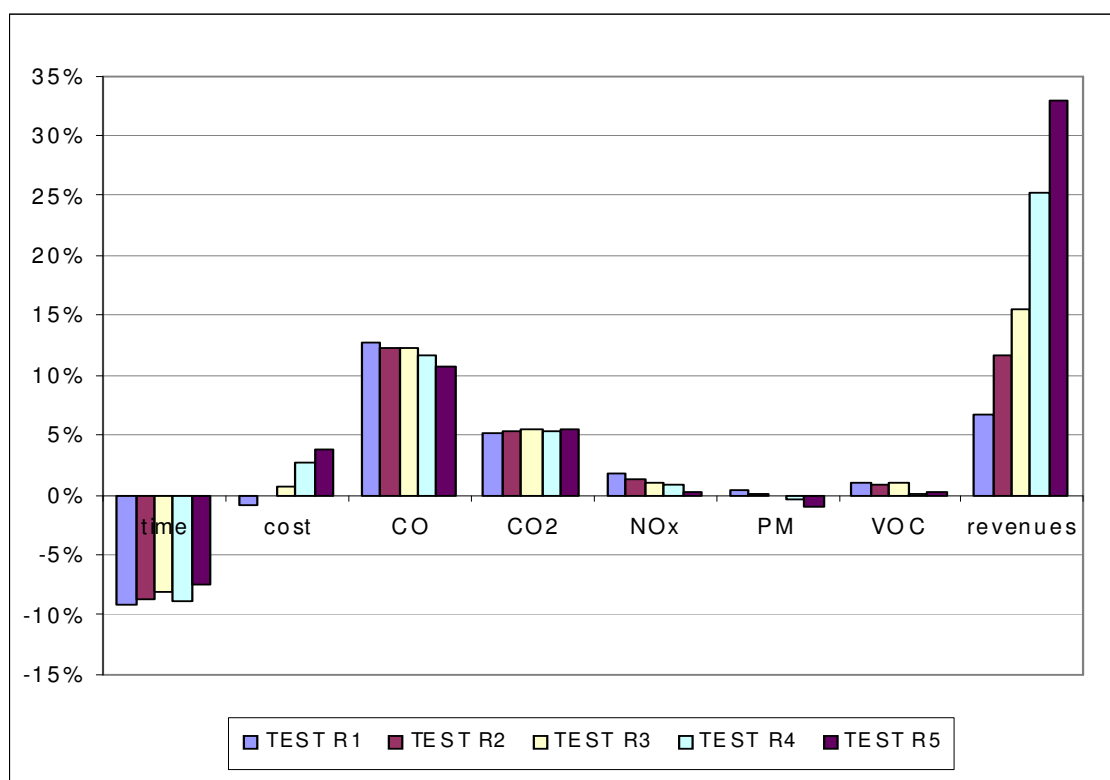


Figure 9: Summary Results of the R-Scenarios in the Padana Region Model: Differentiation According to Road Type.

When we come to the final set of scenarios, mixing all differentiation criteria, the are different from the ones obtained with the Brenner Corridor model from an important

point of view: since speed can be improved more significantly by shifting truck demand on motorways, thus alleviating a congested road network, positive results in terms of net economic benefits are obtained (figure 10). The reason of such a discrepancy can be found in the different characteristics of the study areas: the Brenner is not a very congested corridor while the Padana region complex road network is almost close to capacity. Therefore, the social costs of the increase in the level of emissions and sometimes larger transport costs are more than balanced by substantial gains in terms of time spent by travellers on the network.

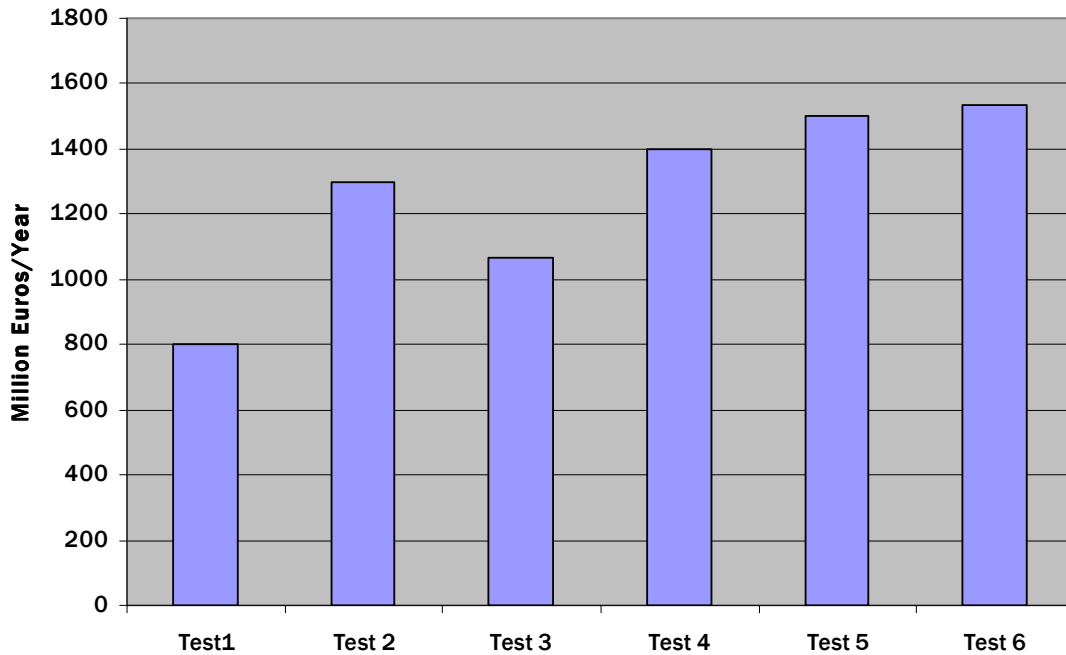


Figure 10: Net Economic Benefit of Final Scenarios in the Padana Region model (Million Euros per year).

4.3. Lessons from the comparisons of the results

Testing different toll schemes on the Brenner corridor and in the Padana region leads to some interesting results. In particular, the following points seem to be relevant.

It seems impossible to reduce significantly emissions using differentiation tolls. If more polluting vehicles are overcharged they just shift on road and more elaborated schemes are able to produce only limited savings of pollution in the Brenner corridor, while in the Padana region even such a small result is not visible.

In the Brenner corridor, where congestion is limited and a large share of traffic consists of heavy trucks crossing the whole study area, the impact of differentiation schemes on the travel speed is low. In the Padana region, where a more complex and congested network exists and demand includes many more local trips, travel speed can be improved much more significantly.

There may be a trade-off between objectives. For instance, the better scheme for improving travel time on the network can not be the best solution to reduce emissions or to maximise motorway operators revenues. For instance, in the Brenner context, scenarios oriented towards the minimisation of time spent on the network can come up

with benefits exceeding costs only if toll discounts are used, which might be undesirable from the motorway operator perspective.

Since in the Brenner corridor travel times cannot be improved, the only significant benefit from the social point of view can spring from a proper use of the revenues of the motorway operator, e.g. for developing alternative modes or boosting the renewal of the fleet.

5. Conclusions and reflections on policy

In the DIFFERENT project, a number of modelling tests have been carried out using two network models to assess at what extent inter-urban tolls differentiation can help to manage road transport demand in relation to objectives like reducing congestion and adverse environmental effects of road transport or applying project financing schemes.. The main conclusions can be summarised as follows:

- Differentiation of road tolls can induce perceptible changes in the behaviour of freight and passenger vehicle drivers.
- Differentiation of interurban tolls according to vehicles' emission category does not seem to seem to produce any significant environmental benefit in the short term.
- Results vary according to the specific context of application. In non-congested corridors charge differentiation can raise money, but there is little room for social benefits whereas, in congested areas, the travel speed on the road network can be improved by introducing charges on congested non-motorway links.
- A trade-off between alternative targets of toll differentiation exists: e.g. the most preferable scheme to raise funds in case of project financing may well be not the best scheme for improving the level of service of the network.

Given these conclusions, we think it is appropriate to make the following reflections on policy:

- It is important to consider network effects; appraising the impact of differentiated tolls without taking availability and conditions of alternative routes can be misleading.
- Even if a differentiation scheme is applied with the "neutral" objective of internalising external costs, it should first be tested extensively in order to identify undesired effects (e.g. shift of more polluting trucks onto ordinary roads)
- Achievement of benefits from differentiated charges may require the co-ordinated introduction of charges on ordinary roads as well as on motorways. This might be politically challenging and, if proven unfeasible, it is recommended to not rise motorway tolls for trucks in areas where the motorway network is used by short distance freight demand.
- Differentiation schemes do not necessarily give rise to social benefits in terms of saved travel time or reduced emissions and therefore, to achieve such benefits, some constraint on the use of revenues may be required.

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