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Differentiation of infrastructure charges – potential and impacts

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1. Special issue introduction

This special issue of *European Transport* contains a selection of six papers that are all based on the findings of the DIFFERENT project. DIFFERENT was a two-year project, co-funded by the European Commission's DGTREN under the Sixth Framework Programme of Research.

DIFFERENT started from the premise that in the European Union, levels and structures of transport infrastructure charges vary strongly across transport modes and countries. In the presence of unsolved difficulties in funding transport investment and serious concerns about the envisaged application of marginal social cost pricing, any convergence is slow. Furthermore, existing charging regimes are often far from internalising external costs and rarely based on efficiency principles. In this situation, differentiation of existing charges appeared to be a sensible intermediate step that merited dedicated research based on four building blocks: economic theory and behavioural theory provide the foundations, while the main pillars are empirical research based on case studies and modelling work.

The first of the six papers, by *Jasper Knockaert, Christos Evangelinos, Piet Rietveld and Bernhard Wieland* starts with an explanation of the economic theory, in particular the concepts of normative and positive theory, but then continues to explore the empirical evidence to establish how different factors affect infrastructure pricing as described by theory; these factors are: aims of the pricing scheme, user demand, cost structure, the cost of price differentiation, but also political factors. To this end information was collected from 27 case studies, and a cross-case analysis was carried out based on a number of hypotheses that were drawn from the theoretical framework. Testing for the hypotheses using the case study information allowed identifying how key aspects of the theory of price differentiation are dealt with in the setting of actual implementations and helped establishing an overview of the current state of differentiated infrastructure charging. One of the key conclusions of the paper is that

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lobby activities are a major explanatory variable for the differentiated charging structure.

The second foundation of the DIFFERENT project, behavioural theory, is the basis for the paper by *Lars Rößger, Jens Schade and Terje Tretvik* and applied here in the context of freight operators. While it is often argued that behavioural aspects are only important for passengers, and freight operators will base their decisions on purely rational aspects, the authors found here that a positive attitude is also for this group an important factor for prospective success and effectiveness of a pricing scheme. This finding was based on 18 telephone interviews with hauliers operating in an urban environment and questionnaires filled in by 17 involved in interurban transport. More generally, the results show that a global index of acceptability of differentiation elements is particularly strongly correlated with the likelihood of future behavioural changes in the medium term as well as in the long term.

The case studies used for the empirical work in DIFFERENT covered all four transport modes: waterborne, air, rail and road; however, of the four remaining papers in this issue, two address road user charges and two rail charges.

The first one of the papers related to road charging, by *Davide Fiorello and Angelo Martino* focuses on charges for motorways, with some alternative options also charging on national roads. The two test beds used are the Brenner Corridor, which has mainly through-traffic and no capacity problems, and the Padana region with two motorways with mainly local traffic and high levels of congestion. For the Brenner Corridor, an “environmental” differentiation of charges leads to an increase of travel time in all tested scenarios, because part of the traffic shifts onto the ordinary roads, with an overall worsening of congestion. The best results here were achieved when truck motorway tolls were reduced and, at the same time, goods vehicles were tolled on ordinary roads, since this caused a cross-shift of cars from the motorway to the ordinary roads and vice-versa for goods vehicles and, as a result, both segments benefited from less congestion and reduced travel costs. For the Padana region it was found that total costs for travellers exceeded the benefits and, furthermore, that pollution was increased in all scenarios. Hence, the key recommendation in this paper is to fully investigate the overall network effects before introducing any charge on part of the network.

The second paper concerning road user charges, by *Peter Bonsall and Mike Maher*, is also based on modelling work, but compares the effects of motorway charges, urban road charges and schemes that combine both in metropolitan areas, where both road systems are closely interwoven. A wide range of scenarios was modelled for a network that was loosely based on the City of Edinburgh, covering strategies including full charging on all roads, on motorways only, on motorway access roads, on urban roads only, and at cordons. One key finding was that introducing charges on motorways has much lower benefits than charges on congested urban roads. Furthermore, independent of the type of road, charges linked to congestion turned out to be much more beneficial than per kilometre charges. The highest benefits overall could be achieved with “first best” charges, i.e. charges that reflect the social marginal cost of each vehicle on each link. However, when implementation costs are taken into account, the best performing scheme was a cordon charge combined with a per-km charge for use of motorways outside the cordon.

Within the first of the two papers related to rail charges *Bryan Matthews, Christos Evangelinos, Daniel Johnson and David Meunier*, focus, more specifically, on rail freight. The paper starts by summarising some findings from the very limited existing

literature on the effects of differentiated charging schemes, before continuing to investigate how users react to different charging schemes in the real world through 25 stakeholder interviews as well as observation of reactions in the British and French freight market and of the take-up of the Channel Tunnel. Furthermore, the effect of changes in rail access charge regimes on rail and road traffic in Britain have been modelled. In the real world, the relationship between charging structure, and even overall charging level, and demand for rail transport has been impossible to prove conclusively, in part due to problems accessing relevant data. However, the modelling indicated that different structures of access charges could incentivise rail traffic at least to some extent for longer transport distances.

The final, and second paper related to rail, comes from *David Meunier and Emile Quinet*; while focussing on just one transport mode they, at the same time, complete the circle back to economic theory. They explore the optimal infrastructure charges where the infrastructure manager sells the use of the infrastructure to operators, who act in an imperfectly competitive market and provide services to a downstream market made up of an infinite number of end users; thereby they focus in particular on Short-Run Marginal Cost Pricing. Following on from explaining the general concepts that apply in this situation, the authors then simulate a range of scenarios. In general, they established that in cases of imperfect competition the optimal tariff is highly dependent on the specificities of the situation, including the level of the cost of public funds, the nature of competition and the demand functions. More poignantly, they found that in many cases marginal cost pricing leads to non-negligible welfare losses. However, the final conclusion from this paper, as already implied in others before, is that more research is needed to fully explain the relationship between infrastructure charges, user reaction and overall impacts.



Differentiated infrastructure charging: a comparison of theory and practise

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Abstract

In the European Union, the infrastructure charging regimes that can be observed are often far from internalising external costs and are rarely based on efficiency principles. In this situation differentiation of existing charges appears to be a sensible intermediate step.

In this paper we study the empirical evidence of the different aspects that affect infrastructure pricing as described by theory. In order to do so information was collected from a number of case studies, and a set of indicators was defined, not only to allow for the analysis of price differentiation practise with respect to the degree of differentiation, but also to account for the level of ambition of the price setting actors.

The cross-case analysis was based on a number of hypotheses that were drawn from the theoretical framework. Testing for the hypotheses using the case study information allowed us to establish an overview of the current state of differentiated infrastructure charging.

Keywords: Price differentiation; Infrastructure; Special interest groups; Normative economics; Positive economics.

1. Introduction

In the European Union, levels and structures of transport infrastructure charges vary strongly across transport modes and countries. Some degree of convergence exists on the intention to apply the principle of marginal cost pricing in various transport sectors, but, in the presence of unsolved difficulties in funding transport investment and even serious concerns about marginal social cost pricing in several countries, any such

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convergence is slow. At present, the charging regimes that can be observed are often far from internalising external costs and are rarely based on efficiency principles.

In this situation differentiation of existing charges appears to be a sensible intermediate step. A possible way to increase the efficiency of pricing structures would be to take existing structures as a starting point and try to increase their efficiency by making them more differentiated. This may, however, lead to a number of questions such as: how differentiated should these price structures be in order to lead to efficiency gains, how will users react, what are the effects on equity and revenues, etc. The effects on revenues deserve particular emphasis here, because in many countries plans exist to replace the existing system of taxed based infrastructure financing with a system based on user charges.

Economic theory has brought us an ample set of considerations with respect to differentiated prices. Pigou showed already in 1920 in his economic analysis of road pricing and congestion costs that a levy equal to the marginal external costs should be levied in order to correct for suboptimal behaviour of individual road users. Over the decades, scholars have elaborated on behavioural, technical, political, and many other impacts on the optimal form of differentiated infrastructure prices.

In this paper we study the empirical evidence of the different factors that affect infrastructure pricing as described by theory. In order to do so information was collected from a number of case studies that were conducted in the DIFFERENT project. The case studies concern both real world implementations as well as desk based research of the introduction of differentiated infrastructure charges. A cross case analysis allows us to identify how key aspects of the theory of price differentiation are dealt with in the setting of actual implementations.

The theoretical framework that we use as a basis for our study is represented in figure 1.

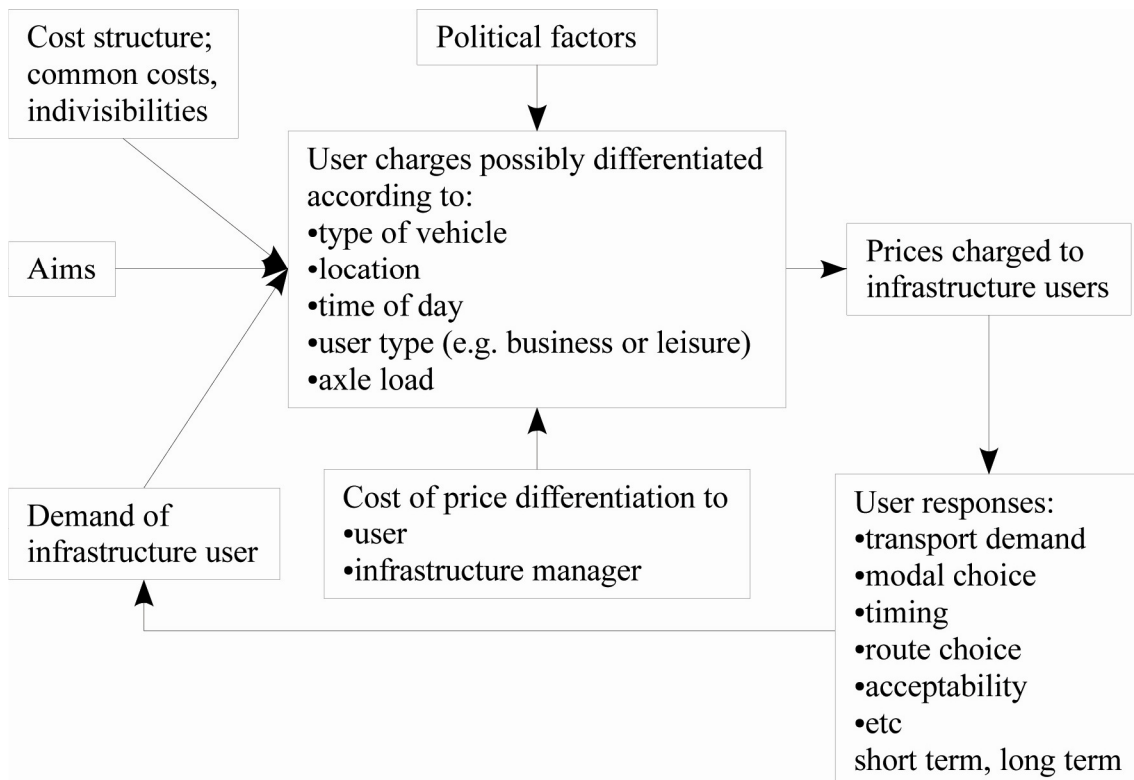


Figure 1: Analytical framework.

Figure 1 identifies five different factors that affect price differentiation. The left-hand side of the framework gives three (normative) arguments which may explain differences in price setting: objectives among infrastructure managers and operators may be different, with economic theory focussing on the role of economic efficiency and equity. Also the implications of the particular cost structure of the transport industry for pricing are being studied, as well as the demand of the infrastructure user.

But there are also other issues that are relevant for user charge differentiation. Policy makers may well affect price setting in transport. This is where the positive branch of economic theory of price differentiation comes in (at the top of figure 1). The normative approach assumes that all politicians or regulators maximize welfare, but, at the same time, they may also pursue their own goals (e.g. re-election). Consequently, interest groups can have substantial influence on them. Considerations like these are of particular relevance as they may considerably affect the differentiation of user charges.

Finally also practical issues are important (in the middle of figure 1). For instance, a highly differentiated first best pricing scheme may have large implementation costs, if technically feasible at all. A high degree of sophistication also implies significant decision costs for the infrastructure user. We refer to the GRACE project for more information on the appropriate degree of complexity in transport charges (see e.g. Bonsall, et al., 2006). Moreover, in an economy suggesting that less variety is sometimes better (Norwood, 2006), more choices (a consequence of a higher degree of differentiation) may also lead to more search costs.

In order to conduct our cross case analysis we needed to collect information in a consistent form. To do so a fact sheet was completed for all case studies. These case studies were drawn from the DIFFERENT project. The DIFFERENT research project was carried out from 2006 through 2008 in the 6th Framework Programme of the EU Commission. The objective of the project was to improve the understanding of user reactions to differentiated infrastructure prices in order to determine efficient charging schemes for infrastructure use. The project investigated user reactions to differentiated pricing through empirical as well as inter-related theoretical work. The empirical work encompassed real world case studies, as well as stated and revealed preference research. The scope of the theoretical work included normative and positive economic theory, and behavioural theory.

Furthermore, a set of indicators was defined in order to analyse price differentiation practise with respect to the degree of differentiation as well as to account for the level of ambition of the price setting actors.

The cross-case analysis was based on a number of hypotheses that were drawn from the theoretical framework. Testing for the hypotheses using the case study information allowed us to establish an overview of the current state of differentiated infrastructure charging.

2. Economic theory

Economic theory provides a contribution to differentiated infrastructure pricing along two main lines. The first contribution concerns the formulation of the optimal framework (the normative approach) for transport charges differentiation. This framework can be determined by pursuing economic efficiency, a concept derived from

welfare economics, according to which transport charges (prices) should be equal to marginal social costs in order to obtain maximum social welfare. According to this theory, prices should be equal to marginal social costs (throughout the economy) in order to achieve this goal.

The positive economic theory of price differentiation examines price differentiation from a different point of view: politicians are no longer assumed to be benevolent welfare maximisers, they are pursuing their own goals. So, instead of maximizing collective utility, they tend to maximize individual utility, in particular since they want to be re-elected. This makes decision makers dependent on interest groups.

Departing from the axiom of welfare maximization means that the question of how transport prices are actually set under real world conditions is more relevant than the question of how transport pricing should be set. How this affects pricing-regulation has been demonstrated in the past in a long series of models (Stigler, Becker, Keeler, Posner, Grossman-Helpman). In this part of the analysis of our paper we go one step further and examine the way in which the interaction between Special Interest Groups (SIGs) and decision makers is reflected in the adopted structures of transport pricing.

This change of perspective from normative to positive theory does not mean that the two approaches have no connection (in the sense of two different “schools” of economic theory or the like). First, many cases exist where both approaches make the same predictions, and second, every policy-maker needs to take normative considerations into account, if he wants to be re-elected (von Weizsäcker, 1982). In other words, the two approaches are complementary, or one may also say that one is a special case of the other, depending on perspective.

2.1. Normative economics

In this subsection we will introduce a selection of topics relating to price setting actors maximising welfare. The format is that of *capita selecta*. For a more extended introduction we refer to the literature or the project report.

Efficiency: marginal social cost pricing

The concept of economic efficiency is derived from the theory of welfare economics, and is related to the allocation of resources in an economy. Welfare economics takes a rather wide view of pricing, considering pricing as a method of resource allocation, maximising social welfare rather than simply the welfare of the supplier (Button, 1993). According to this view, prices should equal marginal social cost in order to maximise social welfare. By pricing at marginal cost, in effect, transport services are being provided up to the point where the benefit for the marginal unit is equal to the costs of providing that unit (Button, 1993). In some cases, private provision of the good or service may also result in maximising the social welfare. If not, regulatory policies may be formulated so that private companies will change their pricing policy, so that social, rather than private welfare, is maximised.

A market equilibrium under this optimal pricing rule only can exist under a stringent set of conditions. Clearly, this equilibrium will not exist in reality. This makes first-best pricing very much a theoretical result, which is often used as a benchmark for other, more realistic, pricing approaches.

The transport market is characterised by several market imperfections which makes it very unlikely that the market, without regulation, will set transport prices equal to marginal social costs and, therefore, social welfare will not be optimised. Besides market failures, governments may also have other reasons to intervene and adjust prices. Equity is an important reason that deserves attention in the context of price differentiation.

Constraints in transport pricing

Social marginal cost pricing assumes a theoretical first-best world. Such first-best pricing is increasingly recognised as being of limited practical relevance, but it might serve as a useful theoretical benchmark. Besides the previously described reasons for market failures, various constraints and barriers may exist that prevent a regulator from charging (optimal) prices that it ideally would prefer. Verhoef (2002) mentions the following important constraints:

- Technological and practical constraints: first-best pricing requires charges that vary continuously over time, place, route chosen, type of vehicle, driving style etc, which might be too sophisticated and not understood by drivers or impossible to implement under available charging technologies;
- Acceptability constraints; there may be too much resistance and uncertainty (e.g. about objective and necessity of the measure) that may make it preferable to start with a few small-scale demonstration projects;
- Institutional constraints; one example is where local or regional governments cannot affect some transport charges that are set by a higher level government;
- Legal constraints; ideal prices might not be possible on the basis of legal arguments (e.g. when taxes should be predictable)
- Financial constraints; for instance the prior definition of minimum or maximum tax revenue sums to be collected;
- Market interaction constraints; transport taxes will have many consequences for other markets, among the most important is the labour market;
- Political constraints: charges may become a political issue much more than an economic question.

Under such conditions, the regulator has to resort to second-best pricing: setting the prices that are available optimally, under the existing constraints.

Equity

Finally, transportation often raises equity concerns that seem to conflict with marginal cost pricing. Marginal cost pricing may result in very differentiated charges with the consequence that no one transport user pays the same price; this may be perceived as unfair. Equity is important in the context of acceptability of pricing. Many stakeholders raise objections about pricing measures that they perceive as unfair. If a pricing measure is unfair either to themselves in relation to other people or to people who are considered to be less well off in society, significant acceptability problems could occur. Transport pricing is often perceived as a form of regressive taxation, allowing only those with enough money to access a resource (e.g. infrastructure) that was once considered free.

Implementation strategies that allow certain groups within a community to be exempted from pricing, or compensate some groups with a lump-sum transfer are therefore discussed. The problem of who should receive extra benefits (e.g. tax exemption) and the wider problem of making sure price measures are both equitable and perceived to be so, are important issues to be included in any successful implementation strategy. Then, price discrimination becomes relevant. In public transport, for instance, it is common that different prices are charged for the same service. Particular groups in society, e.g. the elderly, may benefit from the fare policy of governments .

The public finance and tax literature makes a distinction between horizontal equity and vertical equity. Horizontal equity refers to the principle which states that those who are in identical or similar circumstances should pay identical or similar amounts in taxes (Stiglitz and Driffill, 2000). It requires that those with equal status - whether measured by ability or some other appropriate scale - should be treated the same. If, for instance, income were the only measure of a person, then two persons with equal incomes would be treated as equals. Vertical equity states that people who are better off should pay more taxes (Stiglitz and Driffill, 2000). This generally requires that those with less ability to pay are treated favourably relative to those with greater ability.

User responses

People's responses to transport pricing are not straightforward. Price increases may not necessarily lead to trip suppression, it may also induce travellers to change their modal use or change their departure time, depending on the type of measure. A wide variety of transport pricing measures exists, having different consequences for travel behaviour. Price measures are considered as one of the major tools for policy-makers to influence transport development. The design of measures will generally depend on the objectives.

The response of infrastructure users will to a considerable extent depend on the exact design of the pricing scheme (e.g. a yearly tax on car ownership can be expected to affect kilometrage of a given vehicle relatively weakly, compared to a kilometre charge). Equally important, however, is the price sensitivity (often expressed as elasticities by economists) of transport users for the various relevant types of user reactions that together define transport behaviour. People have various possibilities to change transport behaviour, and can be expected to react differently to different pricing schemes. The possible outcomes (in terms of behavioural responses) of pricing can be the following:

- Trip suppression (travel frequency choice);
- Departure time choice (and scheduling of daily activities);
- Different route choice;
- Changes in modal split;
- Changes in vehicle occupancy;
- Spatial choices related to relocation;
- Change in driving style (e.g. speed choice);
- Vehicle ownership;
- Technology choice;
- Changes in destination choice;
- Class choice (for public transport).

Elasticities can provide indicative and useful answers to the questions on the effectiveness of policy measures. However, policy makers must realise that no unique value of the elasticity of one particular measure does exist. Elasticities of travel demand will vary with circumstances and very much depend on the context. Relevant circumstances include geographical scale of the study, the short-term or long-term, existing price levels and alternatives, and the composition of the population. The types of change in travel times and costs might also be relevant (e.g. small or big change, increase or decrease, and gradual or drastic change). This makes it difficult to compare and interpret different elasticities. Comparison of elasticities only is useful when a clear description of the dependent and independent variables (which price changes and which demand is affected) exists.

2.2. Positive economics

This part of the analysis first gives a brief overview of the positive economic theory of regulation.¹ Subsequently, the positive approach will be linked to transport pricing. Finally, the dimensions of price differentiation will be presented.

To start with the existence of Special Interest Groups (SIGs), Noll (1989) states that the reason for the existence of SIGs is mainly due to the lack of power of single voters and the desire to control politicians. To solve the problem of lack of power, voters can unite in SIGs which represent their political preferences better than the simple voting process. Also the costs of influencing and controlling politicians' activities are far too high for a single person, but not for a whole group pursuing the same interests where costs can be distributed over all members of the SIG. However, SIGs often face the problem of free riding. Olson (1965) notes in this respect that small and well organized interest groups are more efficient in lobbying because the free rider problem is much smaller.

To motivate the use of the positive theory of regulation in this paper it is necessary to give a brief historical overview of the emergence of the positive economic literature. In the 60s more and more economists observed that decision makers failed to regulate industries effectively. In fact, regulation in many markets served the interests of the industry it was supposed to regulate. The initiating empirical study by Stigler and Friedland (Stigler and Friedland, 1962) that mainly resulted in the Stigler/Peltzmann model and other theories on regulatory capture gained acceptance among economists in the 70s. The main proposition of these models is that regulators gain from supplying regulation and industries gain from regulation through restriction of competition. The underlying assumption is that consumers are not well organized and informed but producers can form small but well organized interest groups.

Thus, the widely known Stigler/Peltzmann Model assumes that decision makers maximize their political support (political support is assumed to be a function of industry profits and the respective price). In the equilibrium politicians will impose regulations on unregulated industries or partly deregulate completely regulated industries. Although at present much deeper positive economic models exist, the Stigler/Peltzmann economic contribution comprises a result, which has proven to be robust in most models of this type: The outcome of the political process is a compromise between total regulation and total deregulation.

¹ An overview of political economy can for instance be found in Noll (1989).

The next major contribution in the positive economic theory was provided by Gary Becker (Becker, 1983, 1985). Becker extended the above mentioned models by incorporating the idea that more than one SIG (with partially conflicting interests) influences the political process. According to Becker, regulation thus occurs as a result of battling SIGs. Becker ignores the politician's own preferences. However the outcome of his model comprises a politician's decision, in which all SIGs preferences are (at least partly) incorporated. In the equilibrium the regulator implements a policy which is a weighted sum of the involved SIGs' preferences. Several researchers (Tullock, 1971) dealt with this topic from a different point of view: SIGs know that policy makers have the power to distribute rents resulting from regulation and will therefore compete for these rents. Due to the existence of rent-seeking behaviour, only one SIG will win the regulatory game, an element which is strongly connected to the degree of political power of the participating SIGs.

Curiously, at the time these theories were being developed, a process of deregulation all over the world set in. As a result of this deregulation movement taking place in the last three decades, many economists concluded that positive theory is of limited importance and has little explanatory power. This idea was picked up by Keeler, who argued that positive theory can allow for deregulation. Keeler (Keeler, 1984) combined elements of both positive economic models described above (by using the consumer surplus of more than one SIG) with normative economic elements (by using a social welfare function). Although from the modelling point of view Keeler's idea needed to be improved, in many cases modern positive economic literature is based on the simple insight that the implemented policy is a mix of normative and positive policy elements.

Modern theory of political economy focuses on elections, the provision of information and campaign contributions as the main fields in which SIGs concentrate their activities of interfering in the political process.

Grossman and Helpman (2000) formalized Keeler's main axiom so that the adopted policy package incorporates both normative and positive policy elements more fully. Their research concentrates on political interaction between policy-makers and interest groups. Using advanced game theoretical methods Grossman and Helpmann showed that SIGs will "educate" voters in the pre-election period, will provide credible information to policy-makers and will make contributions to politicians and parties in order to achieve their favourite policy set. On the other hand policy makers will select those SIGs which are most valuable to them, and will maximize their probability to get re-elected. This causes decision makers only to deviate from their personally most favoured optimal policy set, if they receive enough campaign contributions without worsening their re-election chances.

All these presented models have in common that they attempt to describe the decision-making process under the influence of special interest groups. Although methodically different, the outcome of the models is a set of policies, selected by the decision-maker, containing the element of compromise. Since the transport sector is a traditionally highly regulated sector, this kind of analysis could be applied to transport markets. In all transport modes there are major or minor SIGs trying to interfere with the political process (e.g. drivers associations, environmental organisations, airline and airport associations etc). The first implication from the positive theory point of view is that in transport markets SIGs will try to interfere with the political process of decision-making to achieve the best outcome for their members. Naturally SIGs and also regulators prefer regulation. However, a simple regulation of transport markets is

usually not possible. First, nowadays, it is difficult to impose apparent unnecessary regulations, because voters are much better informed than they used to be in the past. Second, in almost all cases in European transport there are at least two major SIGs with contrary interests intervening in the political game. Take for instance the construction of a new airport runway. Airport administration and (perhaps) airlines will certainly push the construction plans. In contrast, the inhabitants of neighbouring towns will oppose to these plans (due to noise pollution). Usually these inhabitants will be very successful in their opposition because of their ability to form an interest group quickly and efficiently. The outcome in many of the cases like the one just described is that the runway is constructed, but with substantial flight restrictions (e.g. night flights). This is exactly the element of compromise we mentioned above.

These considerations have two major implications. First, in most of the cases a compromise will be the only way to achieve some degree of consensus among all participating actors. Second, powerful SIGs should find more subtle means than claiming the introduction of regulation in order to enhance the welfare of their members.

One possibility to take the welfare of all (major) SIGs into account is the construction of infrastructure charging structures that reflect the interests of the participating SIGs. Price differentiation plays a major role here. On the one hand, additional differentiation can appease protests. On the other hand maximising social welfare and taking into account the interests of the involved (most powerful) SIG's will also lead to additional differentiation. In the example above with the runway construction this would mean additional surcharges for night flights.

It seems that up to now the "political economy aspect" of regulated tariffs has been addressed rarely in the literature. Laffont/Tirole (Laffont and Tirole, 2000) emphasised the danger of political manipulation of Ramsey pricing, if (positive) externalities are to be included in the Ramsey formula. The most important contribution up to now seems to be a formal model in which Laffont (2000) compared the Smith pricing rule with an optional tariff in terms of expected welfare in a scenario where two SIGs alternate in power with a certain probability. He arrives at the surprising result that the inclusion of political distortions by SIGs can lead to superiority of the Smith rule.

In a subsequent section this analysis will be applied to the empirical evidence concerning the effects of lobbying for price differentiation.

3. Case studies

The previous section discussed the theoretical backgrounds of price differentiation in transport. It not only gives us a better understanding of the concept, it also allows us to identify important aspects for the assessment of the case studies. Various elements have been identified that may be relevant for the success or failure of a particular case study where price differentiation is implemented in practice.

In this section we will provide a summary overview of the case studies carried out in the DIFFERENT project. We will also briefly address the methodology used for data collection and define indicators to be used in our cross case analysis carried out in the next section where we test the hypotheses.

In order to collect data from the case studies in a generic way, a factsheet form was designed. The fact sheet consisted of the main dimensions relevant to price differentiation. The aim is to provide common ground for the comparison of outcomes of the case studies, for example in terms of testing hypotheses on differentiated pricing. The complete factsheet design is documented in the project report.

3.1. Generalities

In this section we provide an overview of the case studies based on the information collected through the factsheets. Factsheet data were provided for 27 case studies (see table 1). In our discussion we consider five different types of differentiated infrastructure charging case studies:

- Airlines (5)
- Shipping (8)
- Railways (4)
- Road haulage (4)
- Car drivers (6)

The case studies are spread over in all EU-countries plus Switzerland and Norway. The wide geographic scope together with the various user types leads to a heterogeneous collection of case studies.

The information collected is not fully homogenous. For three case studies the factsheet was completed only partially. We will nevertheless include the available information from these three cases in our analysis. On the other hand, for one case study two factsheets were completed, one for passenger and one for freight transport. We will consider them as separate cases in the subsequent analysis.

Throughout our analysis the number of case studies considered may vary as a result of both the heterogeneous character of the information collected as well as the inherently heterogeneous character of the different case studies. This will be discussed in a subsequent section.

Whereas in our discussion most attention will be paid to answers that fit in the predefined answering alternatives of the factsheet form, we will report on other dimensions where appropriate.

3.2. Objectives of the price setting agents

Cost coverage is the most cited objective for price differentiation, closely followed by efficiency and environment (figure 2). Legislative requirements and safety are considered as an objective in relatively few cases. If we consider different case study types, we observe that the overall ranking broadly holds for the individual types, be it with some noteworthy exceptions.

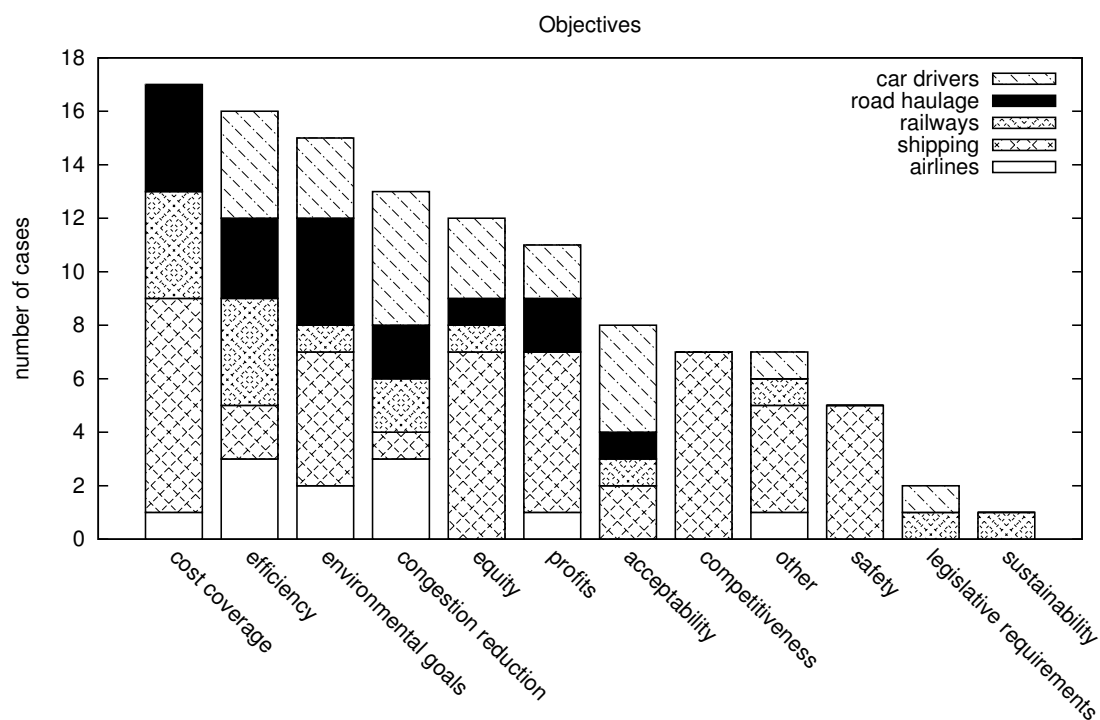


Figure 2: Main Objectives of Price Differentiation.

Safety and competitiveness are considered only by port cases. Especially for safety this seems odd, given the important safety problems in road traffic. Port cases do generally not consider congestion, which probably fits the specific situation where congestion is a relatively small or even non-existent problem.

One surprising observation in railway cases is that in only one case environmental objectives are represented in setting differentiated prices. Given the choice that operators generally have between old, unregulated and heavily polluting diesel powered rolling stock or clean electrical ones, there certainly would be a case for environmental incentives in the price schedule.

The car drivers' cases tend to focus on congestion, pay more than average attention to acceptability and any cost coverage objective is absent. This seems to fit the stereotypically setting of a congestion charge.

The average number of objectives per case is about the same for road and rail cases, but is larger for shipping cases and smaller for airport cases. Obviously, the large variance in the number of objectives should have its impact on the corresponding differentiated pricing schemes. In order to have a measure for the number of objectives addressed in the case study, we define the degree of ambition, which is simply the number of objectives reported (see table 1).

3.3. Dimensions of price differentiation

We will first have a look at the behavioural dimensions along which price differentiation is considered in the case studies. In a next step we will introduce an indicator for price differentiation and discuss the application of this indicator to the case study data.

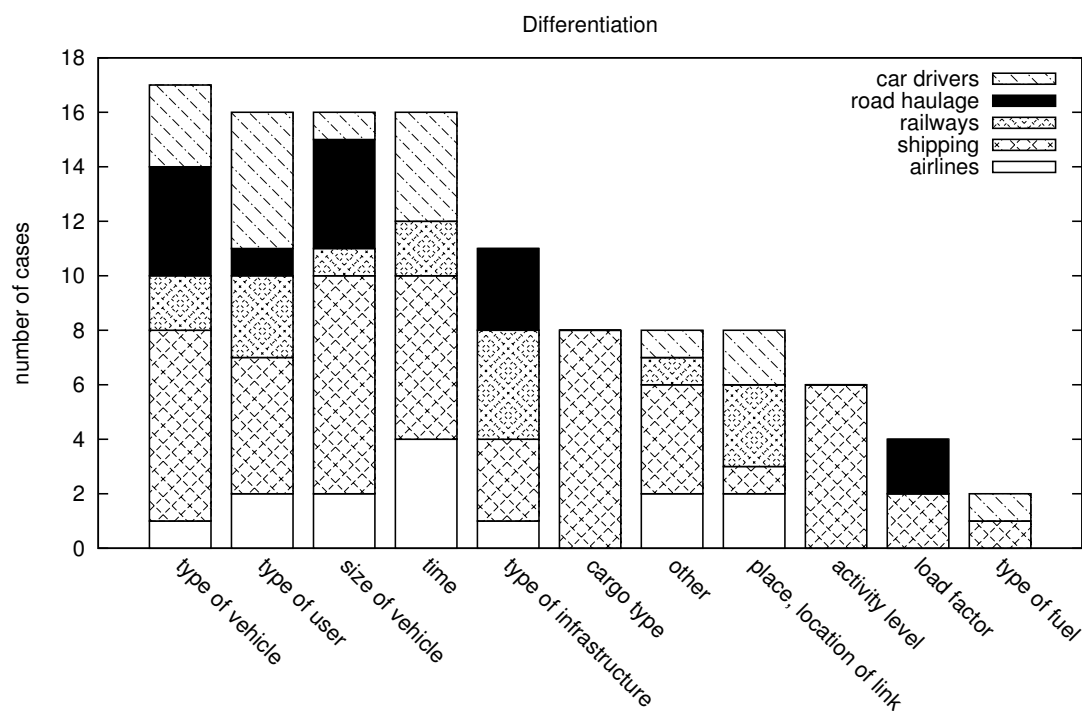


Figure 3: Types of Differentiation.

The most often cited dimensions of price differentiation are: type of vehicle, type of user, size of vehicle and time of travel (figure 3). At the other side of the spectrum we find the dimensions: load factor (or occupancy rate in passenger transport) and type of fuel.

Looking at oddities in the occurrence of differentiation dimensions, we observe that cargo type and activity level are only used for price differentiation in port cases. The differentiation along activity level obviously stems from the negotiable character of port prices. As for cargo type, it may both depend on costs related to handling or differences in demand elasticities (or willingness to pay).

Payload related price differentiation (load factor for freight, occupancy rate for passengers) is limited to freight transport only. The motivations for such a differentiation are not very clear, given that most (internal and external) infrastructure use costs are function of the vehicle rather than its load. But it deserves to be noted that occupancy rate infrastructure use differentiation does exist in the form of carpool lanes, locally known as diamond lanes or high-occupancy vehicle lanes, and ubiquitous in many larger US urban areas.

The relative absence of fuel type differentiation may be explained by prices already being differentiated in the reference case (road transport) or most vehicles using the same fuel (air transport). It should however be noted that existing differentiations in fuel taxes usually do not correlate to differences in external costs. This would justify further research on fuel price differentiation.

Airline cases typically focus on time of travel (day versus night), probably with the intention to alleviate airport congestion or to abate noise pollution.

Road haulage cases somewhat surprisingly do not differentiate as a function of time of travel. Differentiation along type of user is the most often reported dimension in car

driver cases. The underlying dynamic is that these urban congestion charge case studies typically feature a myriad of user classes which are exempt from the charge. Where differentiation along user class exists in non-road cases, this is motivated by demand based arguments (elasticities, willingness-to-pay).

As with the number of objectives per case study, we also observe a larger than average number of differentiation dimensions for the seaport cases, whereas airlines and urban congestion charge schemes typically feature a smaller than average number of pricing dimensions, the latter probably explained by the inclusion of the Spitsmijden experimental scheme.

A simple measure for degree of differentiation would be to count the number of dimensions along which price differentiation is proposed. However, such a measure would classify two schedules with a different number of price levels along the same number of dimensions as equally differentiated. Intuition suggests that this is typically not what we are aiming at.

To account for the number of price levels along each dimension, we first look at a fictitious schedule that is differentiated along one dimension. The minimum number of price levels is one (provided that zero is also a level), in which case the schedule is not differentiated and the indicator should reach a minimum level. The maximum number of price levels is infinite (in the case of the price being a continuous function of the behavioural dimension), in which case the indicator should reach a maximum level. We normalise minimum level to zero and maximum level to unity.

We still need to determine the functional form between both extreme points. Intuition tells us that the first additional price level (i.e. from one to two price levels) adds more to the degree of differentiation than let us say the 999th. We therefore want a functional form that is concave over the interval considered. Furthermore, we learn from literature on time optimal congestion charging (cfr. discussion in Arnott, de Palma and Lindsey, 1993) that about half of the maximum welfare gain is obtainable with the simplest case of a differentiated charge (i.e. two levels).

The simplest functional form that fulfils the requirements set out above (extreme points, convex, half the maximum value at two levels) is $1-1/n$ with n the number of price levels.

To aggregate the values along the individual dimensions we simply add them up (hence our choice to normalise the minimum level to zero). This is a rather coarse approach. Not only do we assume that differentiation along the different dimensions is equally important, moreover we assume that the different dimensions are not correlated, which is highly unlikely e.g. for fuel and vehicle type.

With respect to the first point above we can only argue that this is the best we can get for a generic approach given the heterogeneity of case studies. With respect to the second point, it seems safe to assume that price schedules are not randomly defined and that any price setting agent will refrain from schedules that introduce cognitive burden by pricing along heavily correlated dimensions.²

The resulting indicator for degree of differentiation is presented in table 1.

² Provided the limitations that are identified with respect to correlation and other issues and that apply to both the indicator for degree of ambition and degree of differentiation, it would be an interesting exercise to test for different specifications of said indicators to assess the robustness of the conclusions drawn here. Unfortunately the dataset we use does not provide sufficient information to allow for alternative (and potentially more refined) specifications to be established.

Table 1: List of case studies.

Name of Case Study	Case Study Type	Degree of Ambition	Degree of Differentiation
Port of Amsterdam	shipping	6	6,6
Port of Hamburg	shipping	7	5,1
Port of Gothenburg	shipping	6	5,0
Lerwick - Shetland Islands	shipping	5	4,4
Port of Valencia	shipping	10	4,4
Port of Duisburg - (Duisport)	shipping	4	3,5
France rail infra charge	railways	8	3,0
Trondheim road charge	car drivers	3	3,0
Scalloway, Shetland Islands	shipping	5	3,0
Effects of differentiated charges at Airport Hamburg	airlines	1	2,7
German Railways	railways	4	2,4
Stockholm City	car drivers	7	2,2
London City Centre	car drivers	5	2,2
The German HGV Toll	road haulage	4	2,2
Edinburgh road pricing	car drivers	6	2,0
Brenner TEN-T (freight)	road haulage	5	1,9
Brenner TEN-T (passenger)	road haulage	5	1,8
Swiss Heavy Vehicle Fee (HVF)	road haulage	3	1,7
Sullom Voe, Shetland Islands	shipping	5	1,6
Ljubljana Airport Case Study	airlines	3	1,2
Rail infrastructure charges in Austria	railways	2	1,2
Spitsmijden	car drivers	3	0,7
London airports	airlines	3	
Madrid Barajas Airport	airlines	2	
Rail infrastructure charges in Britain	railways	2	
Gran Canaria Airport	airlines	2	
Rome road pricing	car drivers	1	

With the exception of the Brenner cases all entries in table 1 for which a degree of differentiation is provided, concern real world implementations. For a number of cases we did not assess the degree of differentiation. This was either because sufficient information was lacking or because the setup of the case study did not allow for the calculation of an unambiguous value, especially where the case study focused on simulating an extended number of schemes.

We observe that the port cases typically carry a lot of price differentiation (with the exception of Sullom Voe). At the other end of the spectrum is the Spitsmijden case which concerns a limited time scientific experiment: in such a setting one typically wants to focus on a concise number of influences hence the low level of differentiation.

Urban congestion schemes (i.e. “car driver” in the table) typically feature an intermediate level of differentiation. While this may seem counterintuitive given the need to avoid cognitive burden, these schemes typically carry a number of excepted user classes which adds to the degree of differentiation.

There is no clear reason why shipping cases should carry more differentiation than e.g. road haulage cases. The figures do however suggest that there is much heterogeneity in price setting practise across the different transport modes. There seems to be no obvious difference in differentiation between freight and passenger transport cases (note that railway infrastructure pricing concerns both).

4. Hypotheses

In this section we use the theoretical framework presented above as a base to define hypotheses with respect to infrastructure price differentiation practise, and proceed to a cross-case testing of these hypotheses.

In the setting of this paper we will limit the discussion to a selection of hypotheses that proved to be insightful. For a full overview of all hypotheses tested we refer to the project report (Knockaert et al., 2008).

In the formulation of the hypotheses we focus on two research questions:

- What explains the adoption of certain differentiated price structures?
- What are the consequences of differentiated prices for travel behaviour, welfare and acceptance?

In a first subsection we will present and test the hypotheses related to normative economics. In a subsequent subsection the focus will be on the hypotheses stemming from positive economics.

4.1. Normative Economics

For each of the research questions formulated we first present a general hypothesis. In a next step we present a number of specific hypotheses based on the corresponding general hypothesis. Each hypothesis is discussed with respect to the theoretical framework and subsequently tested for using the case study information.

General hypothesis A The degree of price differentiation adopted by a certain actor depends on factors such as the aims of actors setting the prices (infrastructure managers, transport companies, governments), demand parameters and cost structure.

The first general hypothesis addresses the determinants of the choice for differentiated price structures. We will discuss two specific hypotheses: one considering the role of aims of the price setting agents, and one considering the role of cost structures in price setting. Specific hypotheses on the role of the demand side in price setting were also formulated, but testing them proved not to be clarifying so we do not discuss them here.

Specific hypothesis A-1 The degree of differentiation of pricing schemes increases with the ambition of price setting actors.

We observe a large variance in the number of objectives or degree of ambition across the case studies. In order to optimise a pricing scheme for a given number of objectives (assumed to be independent), one needs to tune a number of (independent) pricing dimensions that is (at least) the same.

In figure 4 the relation between degree of ambition and degree of differentiation is plotted. The positive relation suggested by the hypothesis is confirmed by the trend reflected in the figure.

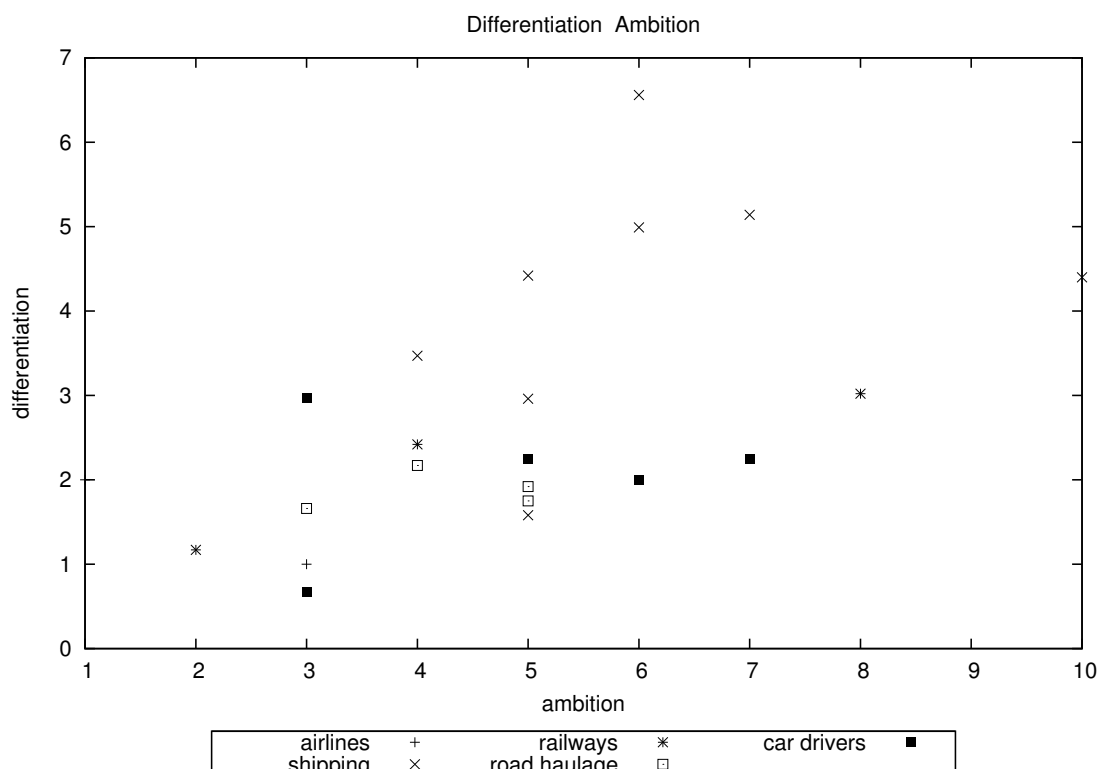


Figure 4: Degree of differentiation versus degree of ambition.

While the hypothesis is motivated by basic mathematical evidence rather than specific economic theory, we use it as a starting point since the revealed relationship will prove to be very useful in controlling for heterogeneity in degree of ambition in our further analysis.

Specific hypothesis A-2 The higher price setting actors value equity considerations, the more they will be inclined to apply price differentiation, where users that deserve support from an equity perspective will be confronted with lower charges than other users.

Different user categories will be confronted with different charge levels simply because differentiation across user types is applied, or because pricing is differentiated across a variable that is correlated with user type.

The hypothesis closely follows our definition of vertical equity. We conduct a qualitative comparison between the equity objective in the case study and the users

which are exempt from or being favoured by the scheme. We consider the following types of user support: favouring frequent users, users that live in a geographically confined area and handicapped users.

Across all types of cases where equity is an objective, we find that frequent users tend to be favoured. It is unclear from an equity perspective why frequent users should deserve support (there may be some degree of correlation).

Another type of user that is favoured under equity considerations, are users that live in a geographically confined area. In passenger transport cases, this mostly corresponds to the political influence of these users (but again there may or may not be correlation with equity). In the other cases, where freight transport companies pay the charge, we mostly observe protectionism tendencies in the favoured user types.

A last type of user being favoured in all equity driven car driver cases are handicapped users. This is a category that, from a (vertical) equity perspective, should deserve support

To summarise we conclude that the hypothesis is confirmed in private car driver cases. In other cases where companies pay the charge, equity motivation may be a disguise for protectionism tendencies.

Specific hypothesis A-3 When the costs of price differentiated charging mechanisms are high for the price setting agents, they will choose simple (cheaper) charging mechanisms as second best strategies.

The idea behind the hypothesis is that the costs of an upgraded charging mechanism are prohibitive compared to the expected (social) benefits by the larger degree of differentiation. The studied relationship is plotted in figure 5.

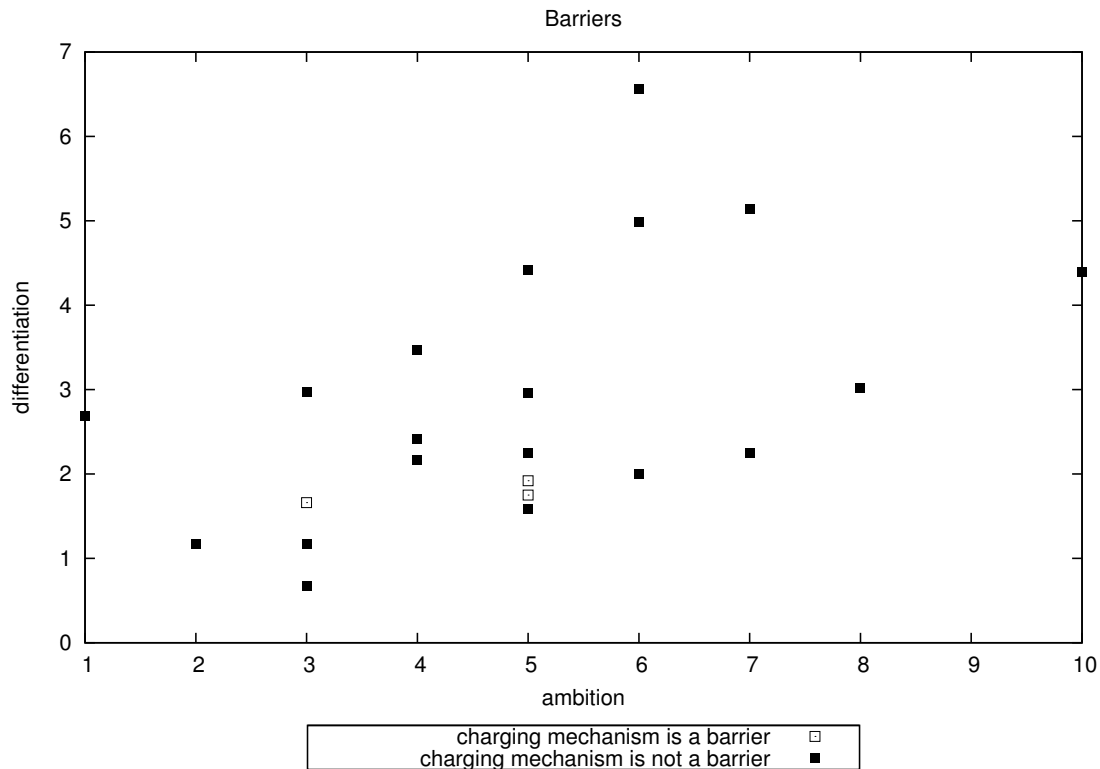


Figure 5: The charging mechanism as a barrier towards further differentiation.

Although one may expect the hypothesis to implicitly assume a constant degree of ambition, it may well be that price setting actors moderate their ambition when faced with the limitations of an existing charging mechanism. We should hence check for the degree of differentiation independently from ambition. We then observe that the cases where the mechanism is a barrier tend to the bottom of the differentiation spectrum.

We therefore conclude that the case study data is in line with the hypothesis.

General hypothesis B The degree of differentiation of transport prices has an effect on user responses in terms of travel behaviour (for example modal choice, trip generation, temporal choice) resulting in changes in transport flows, the efficiency of the pricing measures and the level of acceptance of these measures.

The second general hypothesis addresses the consequences of differentiated pricing. Again will we discuss a selection of three specific hypotheses. Other hypotheses can be found in the project report (Knockaert et al., 2008).

Specific hypothesis B-1 Effectiveness of a price measure increases with the level of differentiation, but above a certain level, the effectiveness stabilises or may even decrease. The negative counter effect is stronger for individuals (e.g. car drivers) paying the charge than for companies (e.g. rail freight operators). And it is stronger for frequent users than for infrequent users.

The initial increase in effectiveness as a function of degree of differentiation is a direct result from convergence towards the first best optimal pricing schedule for which effectiveness reaches its maximum level by definition.

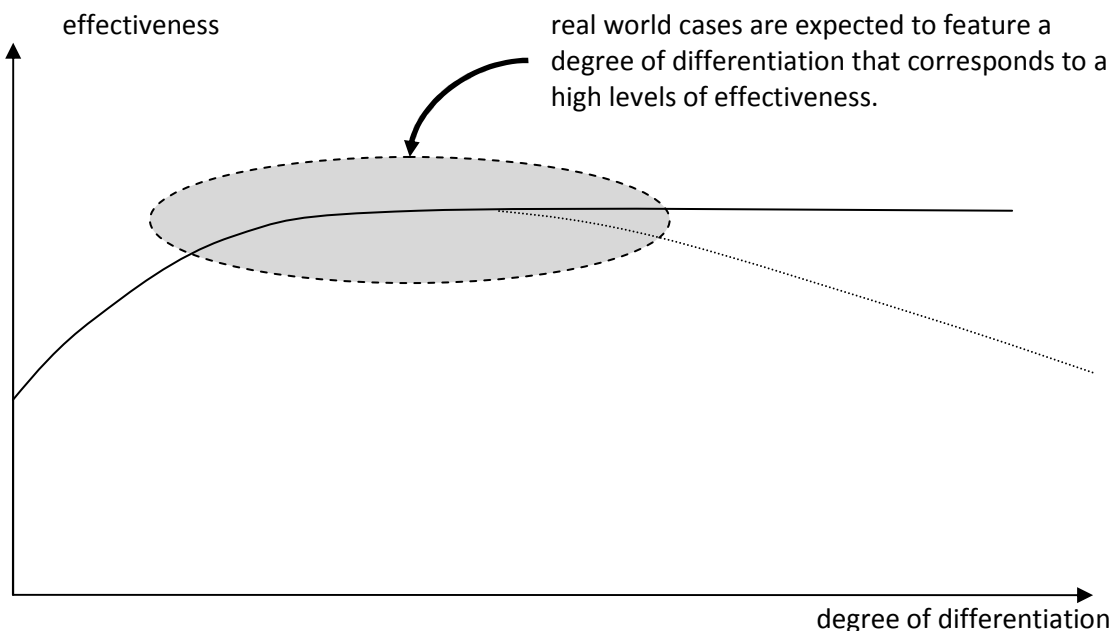


Figure 6: The relationship between degree of differentiation and effectiveness.

As we stated earlier, in order to realise a given number of (independent) objectives, one needs to differentiate prices along (at least) the same number of (independent) behavioural dimensions. This is mathematically determined. As such, the initial increase

in effectiveness is dependent on the degree of ambition (i.e. the number of objectives to fulfil). For a smaller number of objectives, the initial increase will be stronger and reach the (first best determined) maximum value for effectiveness earlier than with a larger number of objectives.

The intuition behind the expected decrease in effectiveness is based on the various decision making costs users incur due to differentiation. These decision making costs are likely to increase as an exponential function of the differentiation level and independently from the degree of ambition.

We expect the negative counter effect to be mitigated to some extent by companies as they have more opportunities to invest in expertise with respect to dealing with a larger degree of differentiation. Frequent users at the other hand can build up experience with the scheme and are hence expected to have smaller marginal decision making costs than infrequent users. Although there probably is some correlation between both categorisations, companies are likely to be more frequent users than individuals.

A way to test the hypothesis would be to compare degrees of ambition and differentiation to the impact of the charge. Only a limited number of cases have an impact that is not or only partially in accordance with the aims set. Failure to meet the objectives is in some of these cases attributed to lobbying, which is clearly not what we are looking for here.

Considering the fact that most cases are real world pricing schemes, it seems safe to assume that they are designed to be (close to) optimal. As we have already seen in comparing the observed degree of ambition to the observed degree of differentiation, there seems to be a relation (figure 6). This relation indicates that a given degree of ambition corresponds to an optimal level of differentiation, which is basically what the hypothesis poses.

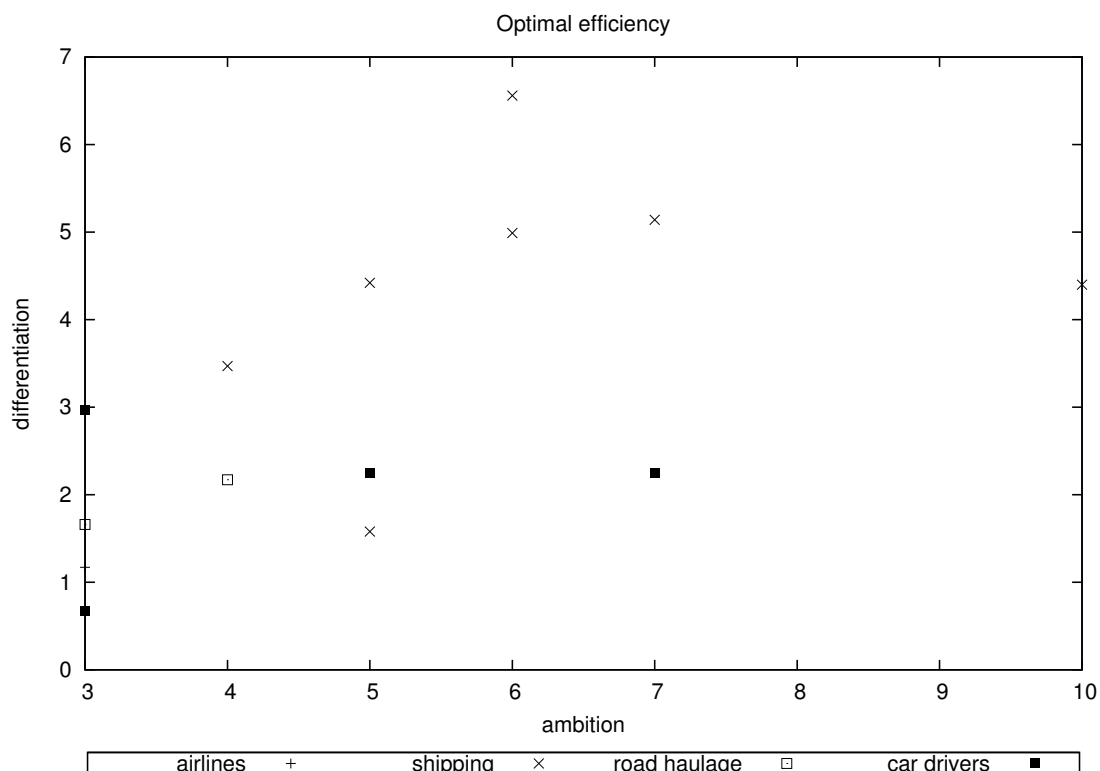


Figure 7: Case studies for which the impact of the charging scheme is reported to be in accordance with the aims set.

By redrawing the relationship between differentiation and ambition and limiting to the cases that have an impact in accordance to the aims set, the picture even becomes clearer (see figure 7). For smaller levels of ambition the optimal level of differentiation increases with ambition. For larger levels, the increase becomes smaller, which is an indication that the decision making costs play a role. And for a given level of ambition, the optimal level of differentiation is smaller for car drivers than for companies.

We therefore consider the case study data to be in line with the hypothesis.

Specific hypothesis A-2 When price differentiation takes place in a certain domain (for example time differentiated tolls), the strongest behavioural response takes place within the same domain (change in departure time). Effects in other domains tend to be smaller.

The basic assumption behind the hypothesis is that consumers try to optimise their behaviour in such a way that maximum utility is obtained with minimum effort. In reaction to a differentiated infrastructure price schedule, the traveller will try to mitigate the pricing impact while minimising the discomfort of behavioural adaptations.

The hypothesis then basically states that the easiest way to adapt behavioural activity along a given dimension is primarily to change behaviour along that same dimension and minimise efforts along other dimensions.

The setting in which the hypothesis is formulated is rather artificial as compared to the reality of the case studies: most case studies carry differentiation along different dimensions and many case studies do not provide information on the relative importance of the different behavioural reactions (and neither on the ranking of the price differentiation dimensions).

Moreover, the link between behavioural reactions and pricing dimensions is not always unique. Especially with respect to spatial differentiation, many pricing dimensions (place, infrastructure) are connected with many behavioural domains (routing, destination, location).

In the case studies, the most often reported reaction to time differentiation is a change in trip timing. The example provided in the hypothesis is confirmed here.

Differentiation of infrastructure prices along spatial dimensions (place, infrastructure) is mainly linked to route choice behavioural responses. Again, this is in line with the hypothesis.

Price differentiation based on vehicle technology is somewhat surprisingly linked to route choice responses. That seems somewhat pointless. This is in part explained by cases where a combination of vehicle technology and spatial dimensions is used for price differentiation. There are however a number of cases where route change is reported to be an important user reaction whereas no spatial differentiation dimension is reported. It is our guess that the user reaction considered relates to route changes of trips to infrastructure outside the geographical area to which the differentiated pricing scheme is confined. This guess is in line with the observation that route change seems generally over-represented in the user responses reported by the case studies.

Abstracting from the route choice issue discussed above, we observe that the second most reported user response to differentiation along vehicle technology dimensions (size, type, fuel) is choice of vehicle technology related domains. It should be noted here that the different dimensions considered (size, type, fuel) are heavily correlated. As such, the hypothesis seems to be confirmed again.

Given the earlier discussed heterogeneity between case studies as well as the caveats related to the real world setting of most cases, we consider the case study findings to be a confirmation of the hypothesis.

Specific hypothesis B-3 In the case of equity oriented pricing policies, the level of acceptance of pricing schemes increases with the degree of differentiation.

Although not stated explicitly, this hypothesis assumes a constant degree of ambition.

In order to check the hypothesis against the case study information, we select the cases where equity is an objective, which report on acceptability and in which a value is available for the degree of differentiation and ambition. The resulting subset consists of ten case studies, which we plotted in figure 8.

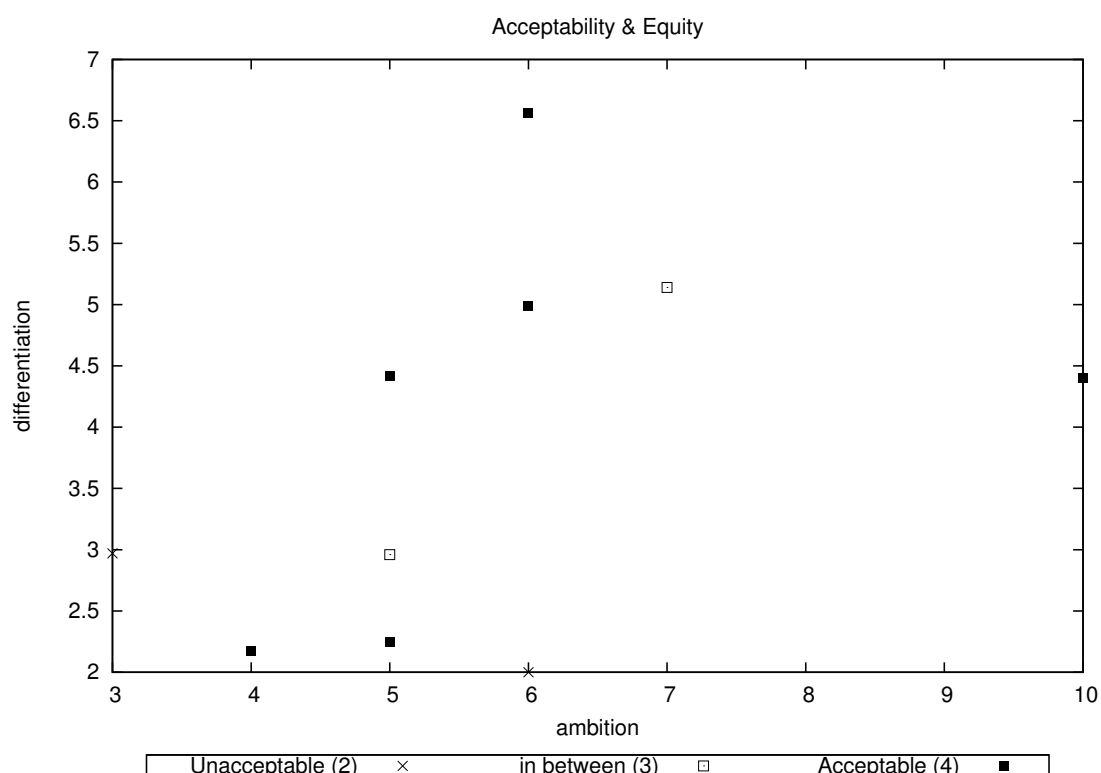


Figure 8: Acceptability in cases where equity is an objective (rated on a scale from 1 to 5, with 1 meaning very unacceptable and 5 meaning very acceptable).

Although not very sharp, there is an indication that the cases with a lower level of acceptability (two or three on a scale from one to five) correspond to lower levels of degree of differentiation. The higher level of acceptability (four) occurs with all levels of degree of differentiation.

Although the information used is somewhat limited in scope, it does seem to fit in with the hypothesis.

4.2. Positive economics

In the theoretical section, we formulated the conjecture that in reality transport prices are to a large extent the result of political compromises. In the following we shall try to show in more detail how the various pricing schemes that have been developed in

normative price theory can easily be manipulated by politicians and interest groups. We will now substantiate the discussion by means of empirical findings from the DIFFERENT project.

In our discussion of the topic we first elaborate on practical implications of the positive economics' theoretic framework. These findings will result in two hypotheses which will subsequently be tested by using the case study dataset.

Practical implications

We shall first start with cost based pricing structures (marginal cost pricing and fully distributed cost pricing) and then move on to demand based pricing structures (Ramsey pricing, multipart tariffs).

Starting with marginal cost pricing, it is clear that –when applied consistently- this pricing principle would result in very finely differentiated and very complex charges. It is this very postulate of maximum differentiation which opens the door for SIGs to intervene and manipulate the pricing structure. This assertion, however, is too coarse and needs to be refined. The finally implemented tariff structure will depend on the relative political power³ of the various SIGs. If a highly differentiated pricing scheme leads to substantial increases of expenses for the members of a certain (powerful) SIG, it will depend on its relative political power whether this pricing scheme will be implemented or not. A simple example of this case could be HGV tolls. A high degree of differentiation between private cars and heavy goods vehicles would most likely translate into higher bills for truckers. Private car drivers would favour a very differentiated pricing scheme for truckers and a less differentiated and lower price structure for themselves. (In Germany the current toll for private cars on motorways is even zero.) In that way they could shift the major part of infrastructure financing to hauliers. If, however, in this situation truckers are more effective in lobbying, or if the HGV manufacturing industry is important for policy-makers, the tariff structure which is finally implemented will be less differentiated than private car users would want it to be.

Fully distributed cost tariffs, once implemented, are (as shown by Laffont 2000) less amenable to political manipulation than marginal cost prices. On this basis one would expect that the activity of SIGs will be directed more towards manipulating the cost calculation method. It can be expected, for instance, that SIGs will debate the costing methodology (accounting based vs. pure economical methods), the allowed rate of return as well as the degree of detail of the cost calculation. This too can result in a higher degree of price differentiation.

A recent example are the developments of the German HGV toll: a more detailed cost calculation led to a marginally higher tolling level.⁴

Sometimes pricing schemes based on Fully Distributed Costs are amplified by incentive compatible pricing elements. Again, the German HGV toll may serve as an example. The charging structure incorporates reductions and penalties for the use of environmentally friendly vehicles.⁵ This led to a much higher degree of differentiation

³ Political power of an interest group can be defined first in terms of voting power (e.g. the number of members of the SIG), or in terms of financial power (e.g. the wealth of the single members of the SIG).

⁴ The new calculation method was developed by IWW/Infras. The calculation reports infrastructure costs of HGV at one cent higher than in the original calculation of 2002.

⁵ This calculation was made by means of a toxicity comparison method of the respective emission classes.

than the pure FDC methodology for the allocation of infrastructure cost would have implied. The winners of the new charging structure (effective from the beginning of January 2009) are the German hauliers, who in most of the cases use governmental subsidies to purchase environmental friendly vehicles and therefore pay a lower effective charge, which gives them a relative competitive advantage compared to foreign hauliers.

In contrast to cost based pricing schemes, demand based charging structures take differences in the behavioural patterns of the infrastructure users as a point of departure.

Let us begin with Ramsey pricing. Ramsey pricing takes price elasticities of user groups into account. The traditional principle of “value of service pricing” scheme of railroads may be interpreted in this way: by charging higher tariffs for high value goods, railroads exploit the lower elasticity of demand of the corresponding shippers. But Ramsey pricing is applied in other areas of transport too, although this may not be obvious at first glance. The reason for this apparent paradox lies in political influence. Political influence often results in the very opposite of the Ramsey principle that price should be higher for the inelastic demand. For example, in many European countries commuters can subtract a certain amount of money (based on the daily travelled distance) from their taxable income. Taking into account that commuters are in general less elastic in their travel behaviour than other travellers, this would seem to be more a case of inverse Ramsey pricing than of Ramsey pricing itself. Policy makers usually justify inverse Ramsey pricing with positive externalities (e.g. welfare effects of commuting mobility) as well as equity arguments. However commuters are also voters who are traditionally very well represented in the political process via automobile clubs and other organisations. Abolishing commuting subsidies would automatically decrease a politician’s re-election chances substantially. Germany, for instance, has just seen the re-introduction of commuting-subsidies after attempts to reduce them to a far lower level.

In this case it is clear, that SIGs have taken advantage of their political power and achieved to impose differentiation in line with their interests.

Examples like this seem to fit very well into the framework of positive economics. Since Ramsey pricing translates into different prices for different user groups it is very likely that the group paying the higher price will lobby in order to pay less. Keeping in mind that the policy-maker aims at re-election, politicians will try to avoid disadvantaging major SIGs. This means that, if disadvantaged user groups have high political power, policy makers will try to appease them in one way or another. The most likely way to do this is to create subgroups and impose additional price differentiation. From the perspective of positive economics, Ramsey pricing is therefore a policy which should be applied with caution, because it may invite interference of SIGs in the “wrong direction”.

Another useful pricing scheme for transport could be peak-load pricing in situations where travel demand fluctuates predictably. For SIGs it is much more difficult to manipulate peak-load pricing, since peaks are clearly recognizable and therefore not manipulable. For this pricing scheme it is therefore to be expected, that disadvantaged SIGs will centre their activities at first on avoiding peak-load pricing altogether. This seems to be the case in air transport. In the very few situations where peak-load pricing

on airports was implemented (Schank, 2005), legacy carriers engaged in heavy and successful lobbying to remove it.⁶

A further reaction of interest groups to peak-load pricing could be the attempt to influence the methodology of calculating marginal and capacity costs (see the case of FDC-pricing above). The peak-users would have an incentive to shift part of their capacity costs to the off-peak users. Commuters for instance would lobby in order to pay only the incremental infrastructure costs, or to exaggerate common costs with off-peak users.

Non-linear tariffs contain a fixed component (ideally reflecting the fixed costs) and at least one variable component (ideally reflecting marginal costs). Optional tariffs are a combination of at least two two-part tariffs, where the user can choose the one tariff fitting best to his/her preferences. Since users minimize their spending, they select a tariff according to their level of consumption. Therefore optional tariffs can also be seen as multipart tariffs. As stated in the theoretical section, Laffont's results show that there are cases where political distortions make linear tariffs superior to optional tariffs. The reason for this result lies basically in the self-selection possibilities of SIGs to consume more or less than they would do in the welfare optimum and in that way to shift the financial burden to other users. In addition, a higher degree of differentiation of the variable components of the charge will multiply the possibilities of decision-makers to burden particularly weaker user groups.⁷ Another additional possibility for political influence related to non-linear tariffs, is the possibility to change the proportions between the fixed and the variable proportions of the charge. Take for instance airport pricing: the typical charge on European airports consists of a fixed charge (determined by MTOW) and a variable charge (determined by the number of passengers). Legacy carriers favour a regime that contains only variable charges for two reasons: First, paying only a price per passenger implies that risks resulting from demand fluctuations are (partly) transferred to airports. Second, paying only a variable charge is in line with the business model of legacy carriers to capture the passenger's time sensitivity, which translates into a high service frequency and relative small aircraft size. In contrast, low-cost-carriers (LCC's) prefer to pay one price per take-off or landing, rather than a price per passenger, since they usually fly with high load factors. As a result, it is very likely that LCC's and legacy carriers will try to influence the pricing policy of airports with respect to the variable and fixed component of non-linear tariffs. The result again will depend upon the balance of political power.

Summarising this section so far leads to the formulation of the following conjecture:

General Hypothesis 1 The setting of infrastructure-tariffs is subject to a strong political element. The positive theory aspect of setting infrastructure charges is therefore

⁶ In just one case lobbying did not succeed to oppose peak-pricing efficiently. This case refers to La Guardia airport in year 1968, which experienced after the introduction of peak-pricing a massive exit of regional airlines to Teterboro airport.

⁷ Laffont's result applies to outputs which are end-products. In talking about infrastructure user charges we are, however, dealing with intermediate products. It is well known that for end-products non-linear tariffs are pareto-superior to linear tariffs (apart from marginal cost pricing). With respect to intermediate products this is not necessarily the case (Ordover and Panzar, 1982) Frequently economists overlook this difficulty and use the so called "Willig theorem" for intermediate goods too, such as transport infrastructure services. Nevertheless it is still an open question whether Laffont's result applies to intermediate goods in the strict sense too.

highly relevant. Lobbying activities will be a major explanatory variable for the tariff structure that will finally be implemented.

General Hypothesis 2 Policy makers will react to lobbying influences and implement a “SIG equilibrium” (“a compromise”). Infrastructure charges which correspond to such an equilibrium may be labelled as “politically acceptable”. This means that in reality cases where charges conform the “textbook model” of a certain pricing-scheme (like marginal cost pricing or Ramsey pricing) will be rare. In most cases this rules out tariff-structures which increase the welfare (as compared to the status quo ante) of only one SIG, even if total welfare effects would be positive.

Specific Hypotheses

With respect to the finally implemented charging structure, our analysis shows that different pricing rules lead to different SIG behaviour regarding different transport modes. In order to generate testable hypotheses concerning the effects of SIG behaviour on the finally implemented tariff structure, a framework of very detailed and differentiated hypotheses would be necessary. For practical reasons however and due to the limited amount of existing data (see the previous section), we limit ourselves to the formulation of two rough hypotheses, which reflect the main ideas of the theoretical analysis above. As stated before, price differentiation plays an important role for SIGs and policy makers in most pricing rules. In almost all pricing rules the number of SIGs as well as the distribution of their political power will be decisive for the final policy outcome:

Specific Hypothesis 1 The higher the number of participating SIGs and the more balanced the distribution of their political power, the higher the degree of differentiation of the charge. If the number of SIGs becomes very high, however, the situation will approximate a regime of polypolistic competition where no SIG will be able to wield a decisive influence on the political process. Therefore, in this case the predictions of positive theory will be identical with the predictions of normative theory.

Corollary The smaller the number of participating SIGs and the more unbalanced the distribution of their political power, the lower the degree of differentiation of the charge.

In the following we will present the empirical results from the case studies in order to test these two hypotheses. The first major finding is that in almost none of the case studies a clear “textbook” pricing rule can be found. Most charging structures mix cost and demand elements in an opaque way, without recognizing the initial pricing rule. But this is only a first hint of the influence of SIGs. To deal with this issue more deeply a type of Delphi study was conducted within the DIFFERENT group with the various partners of the project acting as experts for their country.

The first goal was to identify the political dimensions of the pricing scheme. From the answers obtained, it is clearly recognisable that the political dimension plays a decisive role. In 87 percent of all case studies the political factor is recognised as a crucial factor in pricing issues. The range of the political dimensions covers all transport modes and all countries concerned. There is only one case in which there is clearly no political

dimension at all, namely the Spitsmijden case. However, this case is based on experimental design and therefore cannot give evidence of any political dimensions at all. The large share of case studies indicating political dimensions supports General Hypothesis 1 above.

Turning to the issue of political acceptability, the picture obtained by the case studies is very similar to the one with respect to the relevance of the political dimensions. The vast majority of all case studies (77 percent) showed evidence of the relevance of political acceptability. It was also clearly observable that politically accepted charges can be found in all transport modes. Even though lobby activity does not lead to politically accepted charges in every single case study, it can be safely stated that lobby activity in most cases achieves political compromises and therefore results in politically accepted charges. Additionally, both findings conform to Corollary 1. A majority of cases shows the relevance of the political dimension in infrastructure charging. At the same time a vast majority of cases detects politically accepted charges (little complaints and therefore little ex post lobby activities). One may assume therefore, that these charges represent a SIG equilibrium.

Given that political influence is important in setting infrastructure tariffs, it is also important to take a closer look at the type of actors who benefit from the price structure. The results were as expected. Infrastructure companies seem to be unambiguously the “losers” of the political game of setting infrastructure charges. In most of the cases (12 out of 22) users were recognized as the beneficiaries of the charging structure. This result was expected, since in almost all European countries infrastructure users have well organized interest groups. For instance car drivers are organised in automobile clubs which do not only provide technical assistance but also intervene with transport policy. Their political influence seems to be very high due to campaigns and printed media. Also, particular shippers (mostly oil-industry related, like in the case studies on ports) are favoured by the price structure. Some shippers managed to form small but very effective interest groups and therefore are in the position to keep the free rider problem under control. This means that shippers also have incentives to contribute to their lobby group in financial terms. With respect to the rest of the cases, results depend on the type of infrastructure analysed. Airport charges for instance are relevant for airlines and tour operators (as the major users). An interesting finding is that infrastructure companies do not seem to be able to establish their favoured tariff structure (see above). As privatisation progresses, infrastructure companies are expected to be the “winners” of the tariff-setting process (Betancor and Rendeiro, 2000) in more and more cases. Therefore, lobbying is expected to rise in the future. For the rest of the cases the picture was not clear enough since the researchers could not answer who benefits from the current tariff structure. Apparently, in these cases the political power was not clearly distributed and therefore no SIG could exclusively benefit from the tariff structure. This is an additional hint that the political balance of power is decisive for differentiation. In nine cases shifting of financial burden to other users was observed.

Summarizing the empirical evidence so far, we conclude that lobby activities play a key role when designing tariff structures. In the vast majority of the cases concerned users of infrastructure facilities are favoured by the tariff structure.

The next step is to link the degree of differentiation (as defined before) with lobbying activities and the political power of SIGs. Figure 9 depicts the first relation. The abscissa in this figure depicts the existence of lobbying activities (Yes/No) and the

ordinate depicts the degree of differentiation as defined above. The trend in this figure is clear: the degree of differentiation increases when lobby activities take place. However, the degree of differentiation has a relatively wide range. Hence, we can not safely conclude that the degree of differentiation increases with increasing lobbying activity per se. It is apparent that also other factors, such as voting power of the participating SIGs, play a key role.

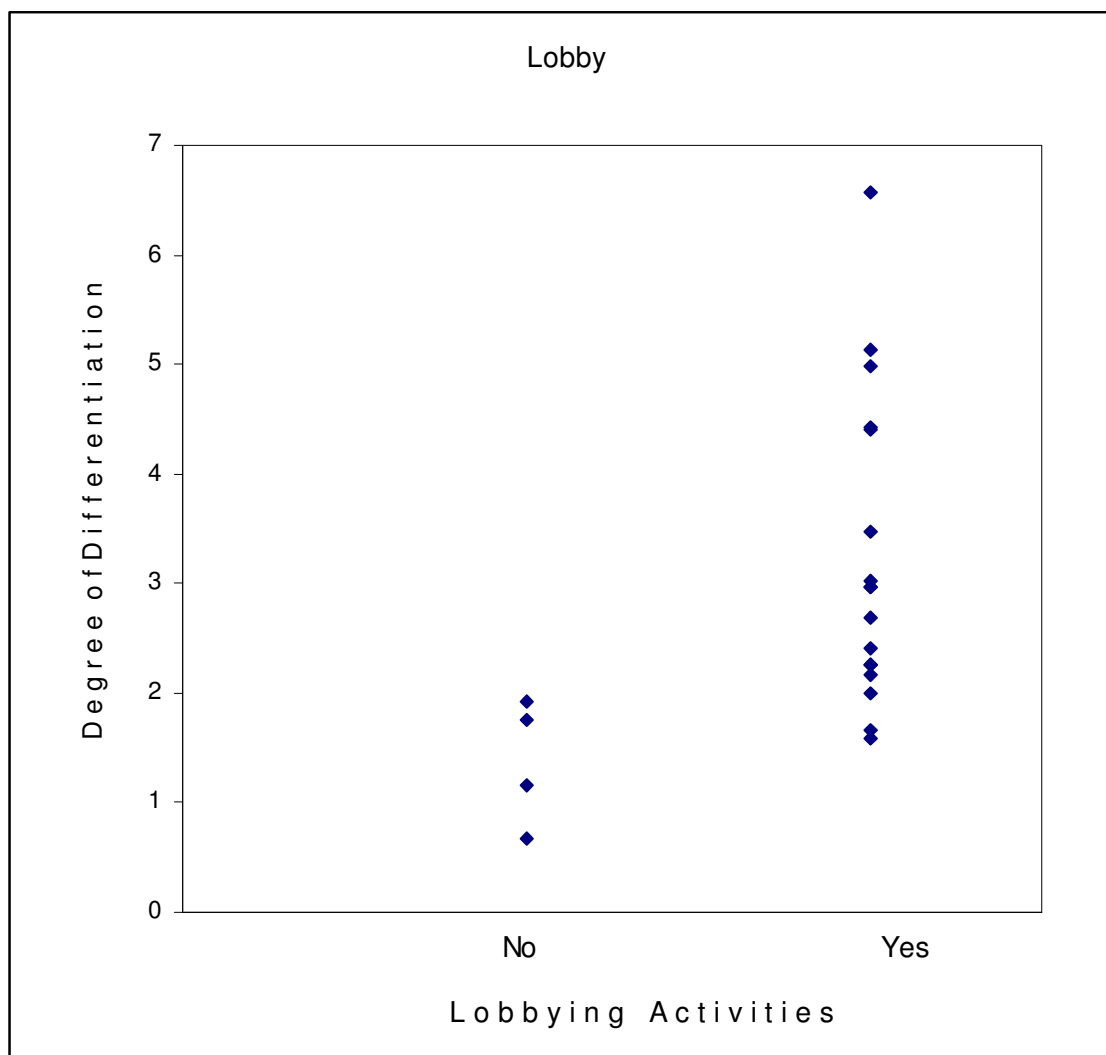


Figure 9: Degree of differentiation and lobbying activities. Source: Author's own calculations.

In order to account for at least one of these factors we included voting power in the analysis. To do this we plot the degree of differentiation against the three possible levels of political power (as indicated by the case study leaders). Figure 10 shows a differentiated picture: first, the low number of cases (two cases) with low political power of the respective SIG does not allow for drawing safe conclusions; second, if political power of the dominant SIG is high, the degree of differentiation tends to decrease. This can happen because only one SIG will prevail at the end and hence the finally implemented charge will reflect the welfare of the members of this particular SIG; third, if political power of SIGs is medium, it can be safely stated that more than one SIG is active. In this case, decision makers will take into account the welfare of the

most powerful ones. Thus, the degree of differentiation tends to be higher than in all other cases.

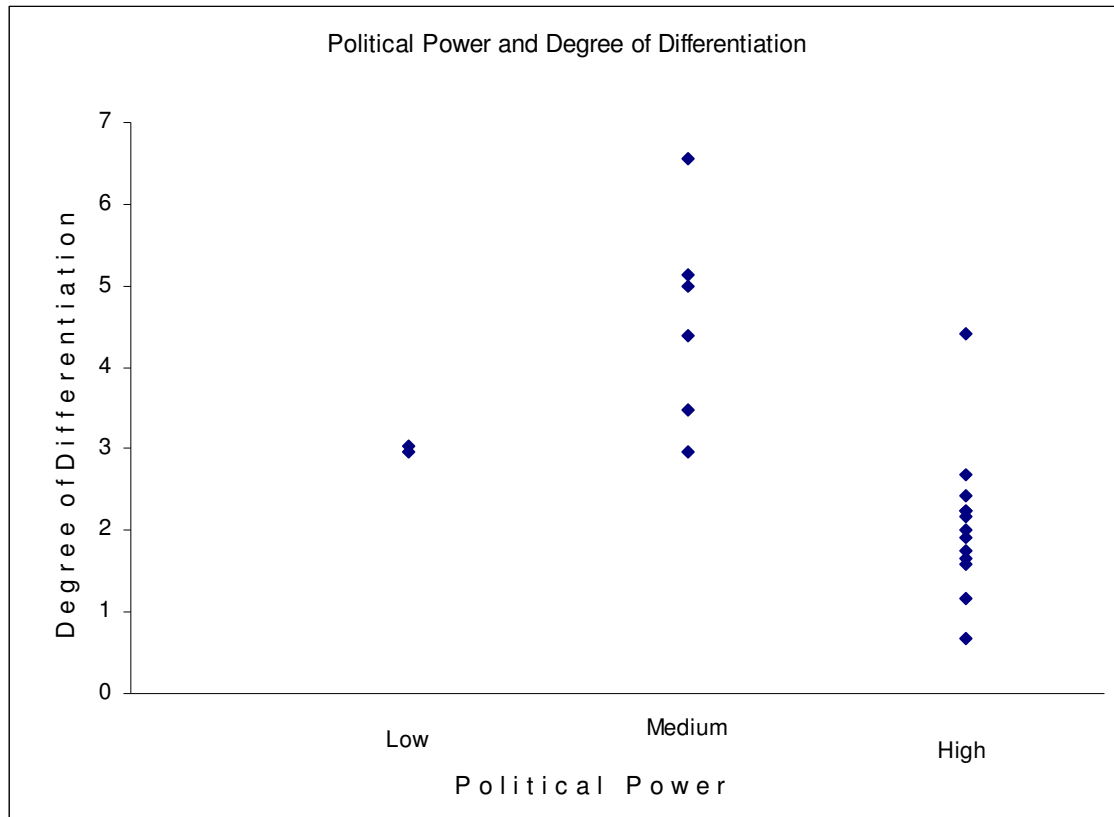


Figure 10: Degree of differentiation and political power.
Source: Author's own calculations.

At this point it has to be stated that the limited number of cases does not allow a test for each single pricing rule as described above. Additionally, the balance of political power is different in each single transport mode. In air transport for instance legacy carriers traditionally have much more political power than low cost carriers. Finally, in each transport mode there are different parameters defining the activities of interest groups. The degree of competition in the market, or the nature of regulation are two prominent examples of this. However, these first results give a safe impression on the outcome of the political process, when designing infrastructure charges.

With respect to the impact of lobbying in terms of overall welfare effects, it is difficult at this stage to draw safe conclusions. If only one major SIG prevails (as figure 10 shows), the degree of differentiation of the charge decreases, apparently below the optimal level. In contrary, if more than one SIG interacts in the political game, the degree of differentiation increases, apparently above the optimal level. In both cases welfare losses take place (see also specific hypothesis B-1 of the normative economics framework). These welfare losses are increased by transaction costs of organizing and running an SIG. Safe conclusions can however only be drawn if the optimal level of price differentiation is clearly defined. Defining this optimal level needs further research.

5. Conclusions

In our analysis we covered a broad range of topics on infrastructure charge differentiation. Two strands of economic theory were explored: the positive and the normative economics approach. It was argued that both theoretical frameworks are not mutually exclusive: positive theory describes how policy makers maximise their personal utility but at the same time take into account normative elements such as general welfare.

An analysis of the practise of differentiated infrastructure pricing was conducted on a set of case studies. The case studies covered an extended scope of infrastructure and user types and hence carried much heterogeneity. To allow for a cross case analysis, it was necessary to somehow control for this heterogeneity. Two generic indicators were introduced. The first one captured the degree of ambition and was used in the analysis as a variable to control for heterogeneity in the aims of price setting actors. A second indicator captured the degree of price differentiation and proved to be useful as a dependent variable in our analysis of the charging schemes.

As for the impact of the aims of price setting actors, we revealed that a higher level of ambition relates to a higher degree of differentiation. While the described relationship is straightforward, it supports our use of the degree of ambition as a proxy for case study heterogeneity.

Furthermore we showed that the actual charging mechanisms may pose a practical barrier towards more differentiation where a degree of differentiation is observed that is lower than expected for a given level of ambition.

If we look at the relationship of the degree of differentiation and effectiveness, we observe that in practise the decision costs play a role in reducing the optimal level of differentiation for higher levels of ambition. This effect is stronger for car drivers than for companies paying the charge.

The cross case study analysis made clear that user reactions are expected to occur in behavioural domains that directly correspond to the dimensions of the pricing differentiation. While again this may sound trivial, this has important practical implications with respect to potential effectiveness and efficiency of pricing schemes that focus on charge differentiation across dimensions that depart from the intended behavioural change.

The analysis revealed that equity objectives can influence differentiated pricing schemes in many ways. The impact of the normative theoretical framework is confirmed by the observation that a higher value given to equity considerations (by price setting actors) results in lower charges for private car users that deserve support from an equity point of view. But in cases where companies are paying the infrastructure charge, protectionist tendencies seem to have a larger explanatory power for the distinction between the favoured users and the non-favoured ones. In this case, the positive theoretical framework describes how a powerful SIG can manipulate a scheme that is based on equity objectives.

Furthermore, we observe that a higher degree of differentiation increases the acceptability in equity oriented cases. While again the relationship can be explained from a normative point of view, relating a higher level of political acceptability to lobbying of SIGs which result in a higher degree of differentiation can also be explained by the positive theory.

The positive economics framework implies that different pricing schemes result in different manipulation possibilities by SIGs. Qualitative analysis showed that variabilisation is a major issue in air transport, whereas inverse Ramsey pricing is likely to play a role in city tolling systems and a more differentiated two part tariff in the shipping sector.

The case studies further indicate that lobby activities are a major explanatory variable for the differentiated charging structure. Moreover, political acceptability of a certain pricing scheme can only be achieved if the most powerful SIGs do not object. As a result, the actual tariff structure reflects the political power of the SIGs. Whereas the presence of a larger number of SIGs (with a smaller amount of political power each) necessitates for a brokered compromise that carries much differentiation, a single powerful SIG may overrule the other SIGs in the lobbying process and hence allow for a political compromise on a less differentiated scheme.

Acknowledgements

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Motivational factors influencing behavioural responses to charging measures in freight operator sector

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Abstract

The present paper aims to provide insights into freight operators' attitudes with differentiated charges and their opinions about charges' effectiveness and future behavioural responses. Thereby, we investigate whether motivational factors, particularly acceptability towards road charges, play an important role on future behavioural adaptations according to charging schemes. Interview surveys have been conducted and have focused on freight operators and road hauliers' perception and attitudes towards differentiated transport charges and several aspects of differentiation. Results show that a global index of acceptability of differentiation elements is particularly strongly correlated to the likelihood of future behavioural changes in medium terms as well as in long terms. These findings indicate that positive attitudes towards differentiated prices are also in the freight sector relevant for prospective success and effectiveness of pricing measures. Differences in likelihood of behavioural responses between several time horizons imply that effects of differentiated pricing in the freight operator sector affect behaviour more in the long run than in short term. Further findings show that the attitudes of the surveyed freight companies towards various elements of differentiation differ. Results suggest that differentiation elements which relate to changes at vehicle side are rated as more acceptable than differentiation elements which refer to concrete behavioural changes.

Keywords: Price Differentiation; Road pricing; Freight Operators; Acceptability; Behavioural Change; Psychological Reactance.

1. Background

In the transport sector differentiated pricing is increasingly used to influence behaviour in order to manage users' demand for infrastructure capacity. However, there is a likely conflict between the theoretical desirability of highly differentiated pricing structures and the ability and the motivation of users to respond effectively to them.

Bonsall, Shires, Matthews, Maule & Beale (2004) have summarised some of the relevant cognitive aspects for pricing differentiation in transport and have drawn on

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other sectors for empirical evidence of people's response to differentiated pricing schedules. If differentiation becomes too extensive for individuals to understand, people tend to base their behaviour on a simplified and possibly erroneous mental model of the price structure. Bonsall, Stone, Stewart and Dix (2006) found that a significant proportion of consumers 'disengage' if they perceive cost structures to be too complex. This disengagement sometimes leads people to delay the decision, to avoid purchase, to opt for the simplest or least uncertain option (if there are alternatives), or just to pay up regardless. Qualitative evidence confirmed that a proportion of the population would respond to complex charges by disengaging. This disengagement will sometimes take the form of paying the charge irrespective of its size, and sometimes deciding to adopt an option which avoids exposure to the charge. This could have profound implications for the performance of pricing schemes and for the structure of models used to predict behavioural responses (Bonsall, Shires, Matthews, Maule and Beale, 2007). Rößger, Schade, Obst, Gehlert, Schlag, Bonsall and Lythgoe (2008) have shown that an increased differentiation of road pricing leads to an increased erroneous price estimation, slower response times in price estimations as well as to increased uncertainty and perceived difficulty in dealing with the schemes. In general, this study also suggests that people seem to prefer simple tariffs (e.g. flat rates) even if these tariffs are slightly more expensive than differentiated price schemes.

But there are not just cognitive aspects which relate to the ability to understand differentiated prices that have to be considered as constraints of behavioural adaptations to differentiated prices (Hoffmann, Schade, Schlag and Bonsall, 2006). Motivational factors also play an important role. I.e., even if transport users are able to understand a highly differentiated pricing system and to predict prices in advance, it does not mean that they are willing or motivated to deal with these charges and to adjust their behaviour. When people feel that they are treated unfairly (e.g. by a new pricing regime) behavioural disengagement becomes more probable, and thus, intended behavioural changes are likely to fail (Gehlert, Francke & Schlag, 2007). The Theory of Psychological Reactance (Brehm, 1966) provides a valuable approach to explain this phenomenon. The reactance theory is based on the observation that people want to perceive that their relevant behavioural options could be potentially implemented (behavioural freedom). If the behavioural freedom is perceived as threatened or restricted (e.g. by road pricing), individuals will experience an adverse motivational state called reactance. An important prerequisite for the development of reactance is that people perceive the threatening of their behavioural freedom as unfair or unreasonable. If, however, the restrictions are logical or otherwise made plausible less or no reactance is predicted (Miron & Brehm, 2006). Since reactance is an intense adverse motivational state which has strong motivational properties, experience of psychological reactance eventually leads to attempts to restore one's behavioural freedom. According to Brehm's theory, the restoration of freedom can be done in two distinguished ways. The restoration of perceived behavioural freedom via direct actions is seen as the most effective way of reducing reactance but because of situational and social constraints direct actions are less likely. Instead of direct actions, the restoration of behavioural freedom via indirect reactions is more likely. Thereby, one possibility of indirect reactions is restoration by implication. In this term implication includes refusing to act, watching others restoring the freedom or motivating others to restore freedom.

According to the noted theoretical approach and beside the cognitive aspects a central motivational factor that might influence user reaction toward differentiated pricing is

acceptability. If users do not accept the price system they may not make an effort to understand it (Rößger et al., 2008). In such cases they may not change their behaviour to the extent they could, or may even resist making any change. Acceptability is a hypothetical construct that refers to the (affirmative) attitude towards a specific attitudinal object. Within the heuristic model of acceptability by Schade and Schlag (2000, 2003) several factors have been identified which contribute to the acceptability of transport pricing measures. For the evaluation of such pricing systems, among others, relevant issues of acceptability seem to be perceived effectiveness and perceived fairness. Perceived effectiveness refers to the degree to which the aims of the measure can be reached. Whether the proposed measures are perceived as being effective or not determines the acceptability of the measure. Perceived justice or fairness also is an important prerequisite of acceptability. If fairness is tentatively operationalised as personal outcome expectations it is expected that the more people perceive advantages following the introduction of transport infrastructure use charges the more they will be willing to accept it (Schade & Schlag, 2003).

The empirical background to the above theoretical discussion is mostly research in the passenger travel market, and car drivers in particular. Freight is usually relatively essential movement (similar to commuting to work), and hence elasticities for freight movement in general can be expected to be low. But for commercial reasons, companies have various alternative options available as responses to increased transport costs, like changing vehicle type or switching to an alternative mode. Further, inaccurate perceptions and personal biases are likely to be less of a problem to freight than to most private travellers; freight operators in many cases use special software to calculate prices, or they use specialized staff for this task. These arguments would imply that actual elasticities for a particular mode in freight might be higher than for freight in general, and higher than expected from the essential nature of freight. The evidence on elasticities supports these views to an extent; see for example Graham and Glaister (2004).

Road freight is a market characterized by strong competition and well informed decision makers. Since profit maximization is a prime objective, operators are expected to act rationally to price differentiation measures. The present paper aims to examine if motivational factors like acceptability, perceived fairness and perceived effectiveness still have an effect on influencing future behavioural responses, and which factors are the most important ones.

Two interview surveys with freight operators have been conducted to obtain information on operators' views and opinions, one referring to an urban setting, and the other referring to an interurban setting. Because of the different nature of urban and interurban freight transport, the two surveys were different in the description of choice scenarios and certain options for price differentiation. For instance, an alternative free of charge route would not be available for the urban sample. The urban sample consisted in principle of local operators with local and regional distribution as their main business. The interurban sample would have long distance transport as their main business, and with international operation equally common as national operation. This sample would in general have prior experience with charging like motorway tolls and the German Maut, whilst only the Norwegian urban sample would have extensive experience with urban charging.

2. Survey 1: Interviews on urban settings

2.1. Method

The survey has been conducted by direct telephone interviews with key area managers of the firms contacted, or directly with single hauliers. Together with the official invitation to take part in the survey, a self-administered version of a questionnaire was submitted by e-mail both to assist phone meetings and give the option of self completion (Tretvik, 2007).

Questionnaire. At the start section the questionnaire asks for information about the company (turnover, transport activities, type of hauled goods, fleets etc.). The second part of the questionnaire deals with some general questions about current practise regarding road tools, among others the way to calculate tolls.

Within the third part reactions and opinions towards an example scenario adopted from the Stockholm congestion trial has been applied to the participants. Referring to the scheme, the questionnaire sought for information about the understandability of the pricing scheme, ability of precise prediction of price calculation (How accurately COULD YOU predict costs?), engagement / motivation in of price calculation (How accurately WOULD YOU predict costs?) and perceived effectiveness of the pricing schemes.

Furthermore, freight operators were asked about the likelihood of several behavioural adaptations if differentiated charges were applied in the specified local urban areas. Respondents of the survey thereby were asked to rate the likelihood of reactions in short term, medium term and long term. The following behavioural reactions have been focussed on:

- Changes in delivery time,
- Use of intermodal services,
- Changes in frequency of consignment/departures,
- Optimisation of loads by restructuring services,
- Alliances / agreements with other transport operators,
- Change of road vehicle and
- Renewing of the vehicle fleet (e.g. cleaner vehicles)

The last part of the questionnaire focused on perceived effectiveness, perceived fairness and acceptability of the following elements of differentiation, if differentiated charges were introduced in the hauliers' local area:

- Vehicle class,
- Emissions,
- Time of day/night (peak/peak off hours),
- Type of traffic (crossing/internal),
- Types of road (motorway/express/local roads),
- Period of year/day/week

Participants. The sample contained a total of $n = 18$ (5 Italian operators, 5 operators from Norway, 3 operators from the UK and 5 Polish operators). 12 out of 18 participants stated that their annual turnover is larger than 500 k uro, 2 out of 18 stated

that their turnover is between 100 k and 500 k uro. 2 operators refused the question about annual turnover. Referring to the type of urban freight transport, about 55% of respondents stated that local distribution is most common for their firms with respect to the tolled (scenario) area. About 38% (7) stated that the most common type is regional distribution for their firms. Only one respondent stated all types (Local, regional, long distance road freight transport) are common for his firm with respect to tolled area.

2.2. Results

Overall, differentiation based on emission standards or peak/off-peak hours were perceived to be the most effective in affecting road hauliers' actions, whilst measures believed to be the least effective were differentiation based on vehicle class or type of road. Interestingly, one of the measures perceived to be the most effective (emission standards) was perceived to be the most acceptable, whilst the other (peak/off-peak hours) was the most unacceptable (Figure 1). Still, only the peak/off-peak measure showed a significant correlation (at the 5 % level) between perceived acceptability and effectiveness. There were in general strong positive correlations between responses to the questions about acceptability and fairness of measures. Correlations for each measure ranged between 0,6 (significant at the 5 % level) and 0,9 (significant at the 1 % level).

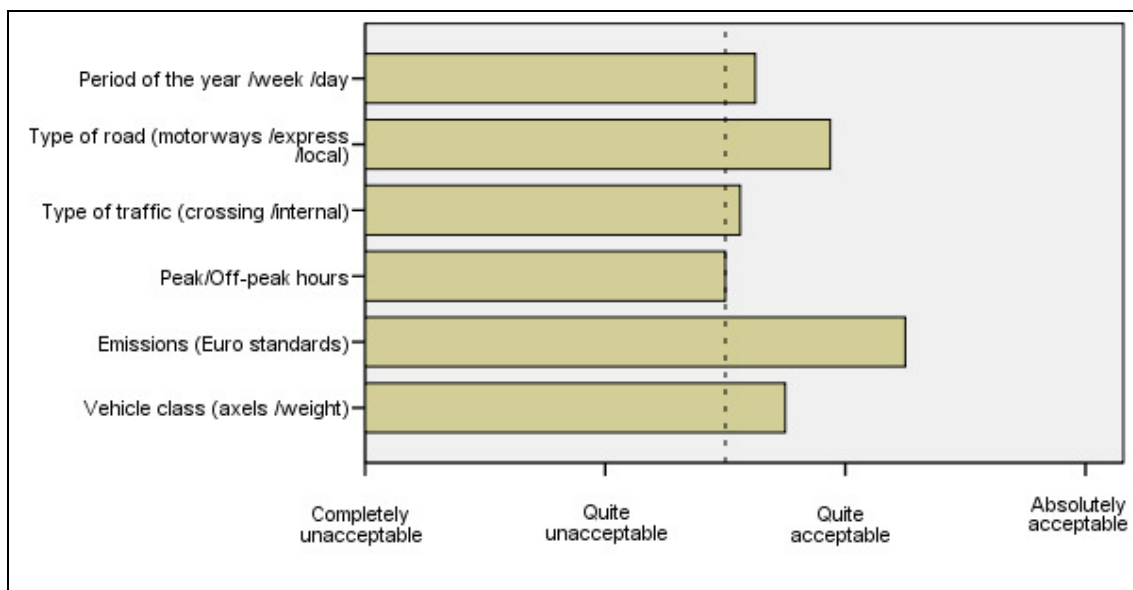


Figure 1: Acceptability toward types of differentiation in an urban setting.

Figure 2 shows clearly that long term responses were more likely than medium term responses and that medium term responses were more likely than short term responses. Overall, long term fleet renewal (according to EURO standards) was the most likely response. Even fleet renewal in the medium term ranked third overall. In the short term, the optimisation of loads and change of frequency of services were ranked highest.

Other options that ranked high overall were changes in delivery times and change of frequency of services, both in the long run. Alliances, change of vehicles and use of intermodal services, all in the short run, were the most unlikely adaptations.

Larger companies were in general more likely to indicate behavioural changes for the majority of measures, compared to smaller size companies. It was in fact only changes in delivery times in the short, medium and long term that smaller companies indicated more frequently than larger companies. This might be because larger firms are in a better position to adapt to price differentiation measures in a variety of ways, or psychological factors may to a larger extent act as constraints for smaller companies than for larger ones. Sample sizes were too small for making a statistical investigation of this issue.

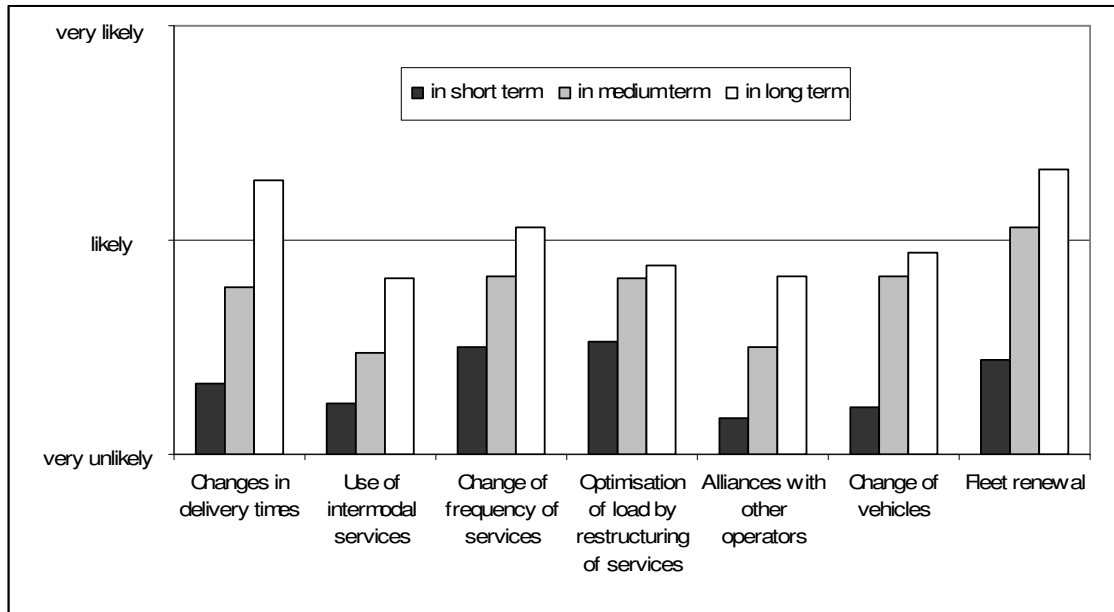


Figure 2: Stated likelihood of behavioural responses if pricing schemes would be applied on urban areas.

3. Survey 2: Interviews on interurban setting

3.1. Method

Questionnaire. The questionnaire for the second survey was almost identical with regard to the relevant items with the questionnaire used within study 1. Reference schemes were adapted to the characteristics of respondents. Participants were polled on the understandability of reference schemes, perceived effectiveness and engagement / motivation in prediction of tolls (Martino, 2008).

As in study 1, freight operators were asked about the likelihood of several behavioural adaptations if differentiated charges were be applied on a certain corridor, and in addition to this, on the whole European network. Respondents were asked to estimate the likelihood of their reactions in short term, medium term and long term. In addition to the items used in study 1, the questionnaire included re-routing to other motorways and respectively re-routing to express / parallel roads as possible behavioural responses. Further, this questionnaire distinguished the use of accompanied intermodal services (Rolling Motorway / Ro-Ro) from the use of non-accompanied intermodal services.

As in study 1, the last part also sought for information about perceived effectiveness, fairness and acceptability on differentiation elements. In addition to the differentiation elements presented in study 1, an item referring to differentiation based on geographical aspects (mountainous or sensitive area) was added.

Participants. The sample contained $n = 17$ participants. 30 questionnaires were sent out, a total of 17 were returned (9 by Polish operators, 8 by Italian operators). 9 out of 12 respondents stated that their annual turnover is larger than 500 k Euro, 5 participants refused the question about yearly turnover. Half the respondents operate mainly on international level; about 50% of operators are mainly active on national level.

3.2. Results

Differentiation elements according to emission, and respectively, to vehicle class (e.g. axels, weight) were more acceptable than other differentiation types. The acceptability of differentiation according to period of the year / week and according to geographical sensitive areas received the lowest ratings by the freight operators (see Figure 3). There were slight differences between the ratings referring to the interurban corridor and ratings referring to the network setting but these differences were not statistically significant.

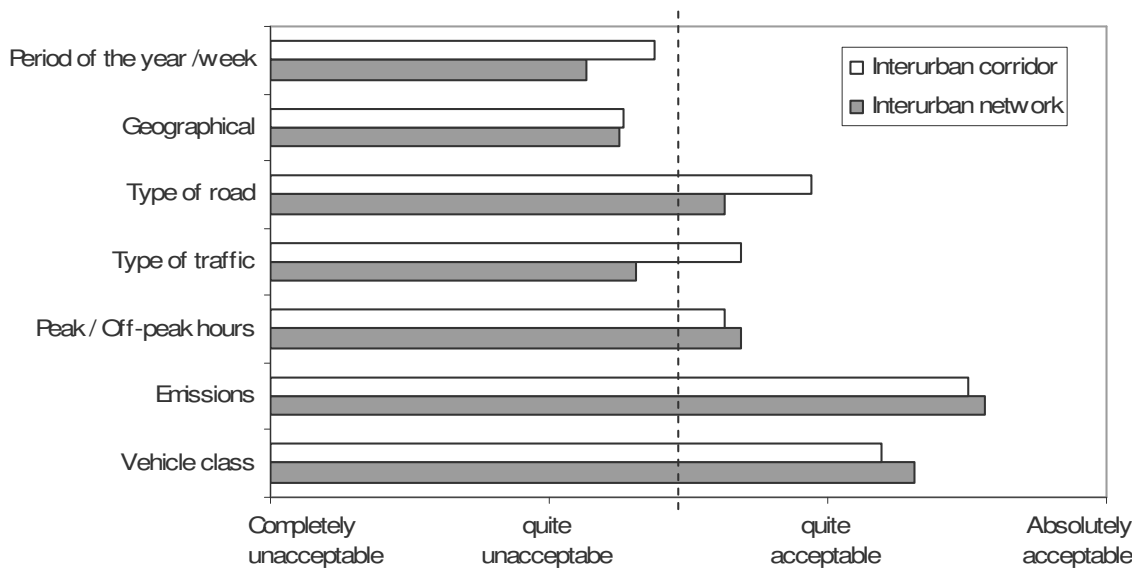


Figure 3: Acceptability towards differentiation types in interurban settings.

Correlation analyses further emphasized that stated acceptability of specified types of differentiation were strongly related to perceived fairness. This held true for statements referring to the corridor case as well as for statements referring to the EU road network. The fairer differentiation elements were assessed, the more these aspects have been accepted. Tests of correlations between acceptability and perceived effectiveness showed weaker associations. Average correlation coefficients were computed via Z – transformation: the correlation between acceptability and perceived fairness was $r = 0.80$ if the setting referred to an application of charging schemes on the whole EU road network. If the setting referred to an application of charging schemes on a single corridor, the correlation coefficient between acceptability and perceived fairness $r = .47$ was smaller but remained considerably. The average values for correlation coefficients

between perceived effectiveness of differentiation types and acceptability towards differentiation types were $r = 0.24$ for the EU road network and $r = 0.28$ for the application on an interurban corridor.

Concerning the stated likelihood of future responses, there were no significant differences between the ratings with respect to a certain corridor and the ratings with respect to the European road network. As an example for the interurban setting, Figure 4 provides an overview of respondents' statements on behavioural adaptation strategies if charges would be applied on the EU network. Like results in study 1 already indicated – and not surprisingly, the most apparent effect on the likelihood of behavioural changes seemed to have the time horizon. Regarding a short time perspective, behavioural responses to charging schemes were rather unlikely whereas the likelihood increased with an increasing time horizon across all behavioural categories. However, these increases in the likelihood seemed to be different for certain behavioural categories. While “Alliances with other operators” was (relatively) rated as the most probable strategy referring to a short time perspective, in medium and in long terms “Fleet renewal” became the most probable behavioural adaptation strategy. Re-routing, changes in delivery times and optimisation of load by restructuring also became more probably over the time than the use of intermodal services or making alliances with other operators respectively. Obviously, behavioural strategies in adapting to charging schemes will change over time.

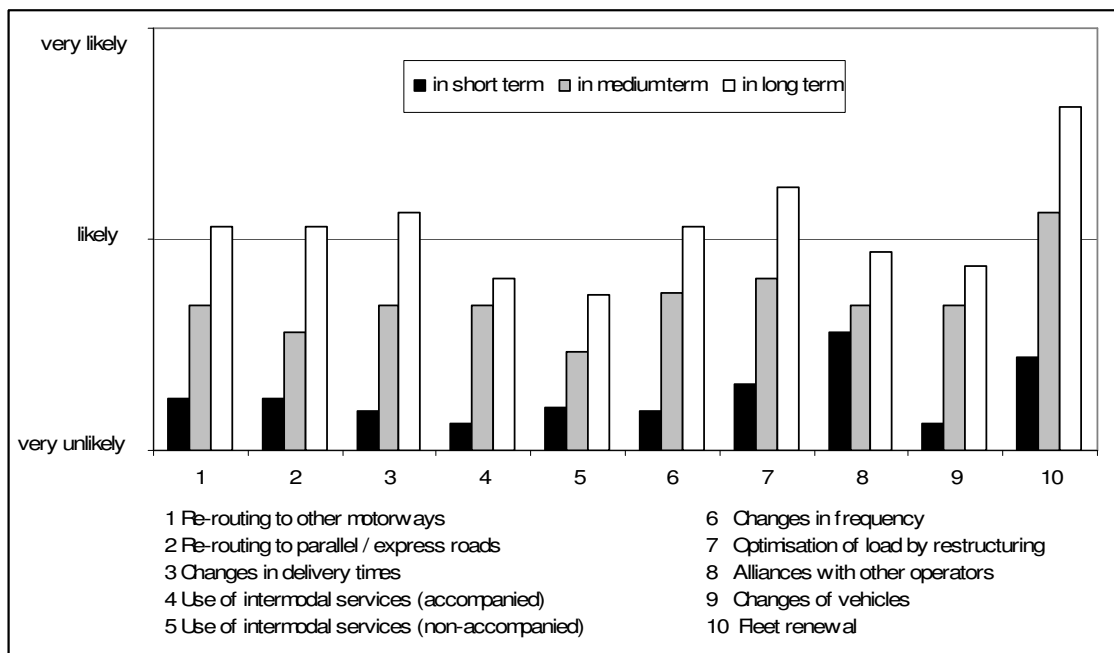


Figure 4: Likelihood of future behavioural responses if charging scheme would be applied on the EU network.

4. Further analyses

Datasets of both surveys were merged together into a joint dataset. The purpose for this procedure was to get more generalisable valid results for freight operators and to get

a more reasonable sample size for interference statistical analyses. Furthermore a joint dataset provides the possibility to compare responses between the urban and interurban setting. Since the statements within study 2 considering behavioural strategies and attitudinal variables do not differ in respect to the reference areas (interurban corridor vs. EU road network), for the joint data analyses only statements referring to the EU network have been used.

Comparisons between the urban and the interurban setting show differences in the acceptability of differentiation elements. So, differentiation according to the vehicle class (axels / weight) and differentiation according to emissions were rated significantly more acceptable if the respondents were exposed to an interurban setting than to an urban setting (see Table 1).

Table 1: Differences in acceptability statements between urban and interurban setting.

<i>Differentiation element</i>	<i>Setting</i>	<i>Mean</i>	<i>Std. Deviation</i>	<i>Std. Error Mean</i>	<i>Signif.</i>
Vehicle class (axels / weight)	Urban	2,78	,647	,152	.011
	Interurban	3,31	,479	,120	
Emissions (Euro standards)	Urban	3,22	,428	,101	.043
	Interurban	3,56	,512	,128	
Peak / Off peak hours	Urban	2,47	1,179	,286	.555
	Interurban	2,69	,873	,218	
Type of traffic (crossing /internal)	Urban	2,65	1,169	,284	.375
	Interurban	2,31	,946	,237	
Type of road (motorways /express /local)	Urban	2,94	,873	,206	.256
	Interurban	2,63	,719	,180	
Period of the year /week /day	Urban	2,56	,984	,232	.159
	Interurban	2,13	,719	,180	

Differences between the urban and the interurban setting also have been found with respect to the likelihood of certain future behavioural adaptation strategies. Considering the likelihood of short term responses, in the urban setting participants tended to rate “Changes in frequency” and “Optimisation of load by restructuring” more probable than participants in the interurban setting. On the contrary, respondents in the interurban setting rated it more probable to make alliances with other operators than respondents within the urban setting. This difference was significant at 5% significance level (Figure 5).

Prediction of Stated Likelihood of Behavioural Changes. Future behavioural responses to reference pricing schemes have been obtained in order of short term, medium term and long term responses separately. As descriptive results from study 1 and study 2 show, behavioural changes in the short term were rather unlikely, whereas the likelihood of behavioural changes increased with enlarged time horizon. Moreover, fleet renewal seemed to be the most probable response in the long term as well as in the medium term. For the short time perspective, not only fleet renewal but also changes in frequency of consignments / departures showed slightly higher values of stated likelihood compared to other responses.

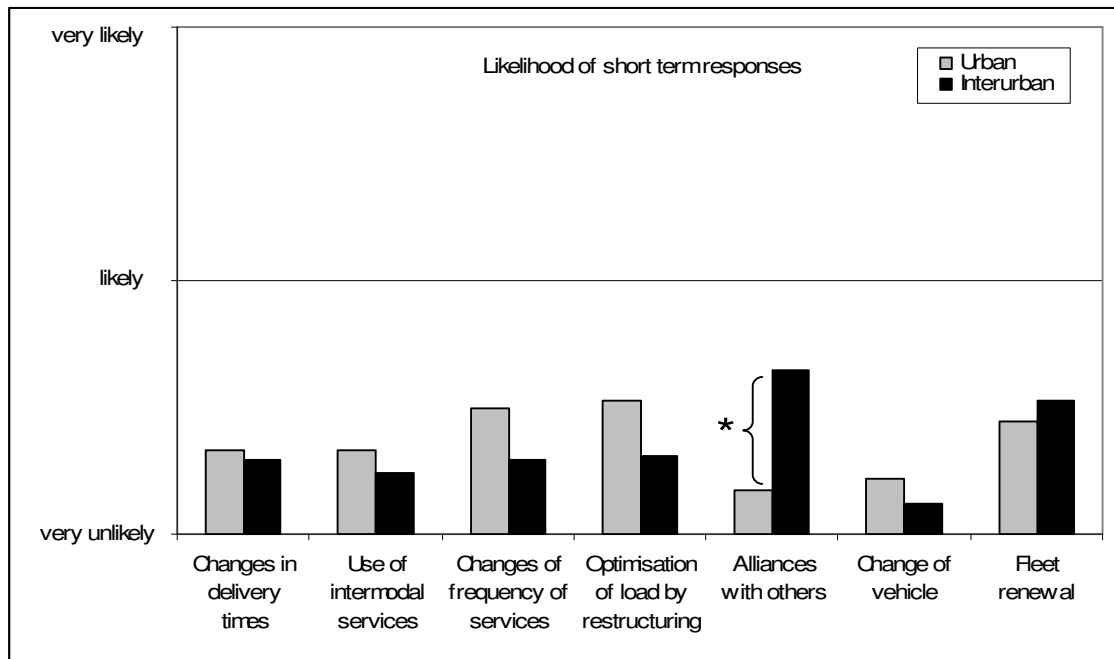


Figure 5: Differences in behavioural strategies as response to charging schemes between urban and interurban setting.

Based on the complete data set (study 1 and 2), three indices by means of average values of all used items for short term, medium term and long term responses have been computed serving as comparable indicators of the behavioural responses' likelihood. So, we produced three indices which provide approximations of the likelihood of future behavioural changes (LBC): LBC short term, LBC medium term, LBC long term. These indices were used in the following regression analyses as dependent variables.

Potential factors have been tested simultaneously regarding their impacts on prediction of likelihood of behavioural change indicators by stepwise regression analyses. Unfortunately, items considering acceptability had not been similarly obtained within both studies. As described above, both surveys however obtained acceptability toward several differentiation aspects similarly. An approximation of a global value of acceptability towards differentiated toll charges has been computed by means of an average value of these items. So, this acceptability indicator has served rather as an approximation of a more general attitude toward differentiated charges than an attitude toward a specific charging scheme.

In sum, theoretically relevant variables were included in a start regression model in an explorative way. After that, the number of predictors was stepwise reduced by criteria of non-significant changes in total explained variances. The start regression model included the following predictors:

- Global acceptability towards differentiated toll charges
- Understandability of reference scheme
- Engagement / motivation to deal with reference scheme
- Perceived effectiveness of reference scheme.

A regression model to predict LBC short term provided unsatisfactory results (Table 2). This result has suggested that the likelihood of short term response was not

predictable by independent variables included in the regression equation. None of the predictors showed a beta-weight at significant level. Based on this result, it has to be noted that operators' perceptions respectively opinions about a differentiated pricing scheme did not affect their (stated) likelihood of behavioural changes in the short term.

Table 2: Regression coefficients Prediction of Likelihood of Short Term Responses (LBC short term).

<i>Start model</i>	<i>Standardised coefficients</i>	<i>T</i>	<i>Significance</i>
(constant term)		6.578	.000
Acceptance	.259	1.384	.178
Understandability	.154	.704	.488
Engagement	-.134	-.624	.538
Effectiveness	.153	.804	.429

Results of regression analysis of LBC medium term showed a significant multiple correlation coefficient between obtained values and values predicted by all independent variables together (start model, $R = 0.618$, $p = 0.012$, see Table 4). The explained variance of this model (adjusted R^2) was 0.287: suggesting that about 29% of the variance in stated likelihood of behavioural changes was explainable by variances of the predictor variables. Moreover, the stepwise reduction of predictors did not change the value of explained variances significantly. In terms of tested variables this means that the likelihood was solely predictable by operators' index of acceptability towards differentiated toll charges. The coefficient for perceived effectiveness achieved significance only at the 12.5% level, but was the second most important factor (Table 3).

Table 3: Regression coefficients Prediction of Likelihood of Medium Term Responses (LBC medium term).

<i>Start model</i>	<i>Standardised coefficients</i>	<i>T</i>	<i>Significance</i>
(constant term)		3.883	.001
Acceptance	.523	3.363	.002
Understandability	.239	1.317	.199
Engagement	-.230	-1.285	.210
Effectiveness	.251	1.586	.125

Table 4: Summary of Regression Models: Prediction of Medium Term Responses.

<i>Model</i>	<i>R</i>	<i>Adjusted R²</i>	<i>Changes in F</i>	<i>Changes in significance of F</i>
Start model (a)	.618*	.287		
2 (b)	.585**	.269	1.650	.210
3 (c)	.573**	.280	.583	.451
4 (d)	.536**	.262	1.721	.200

Notes: a) Predictors: Acceptance, Understandability, Engagement, Perceived Effectiveness

b) Predictors: Acceptance, Understandability, Perceived Effectiveness;

c) Predictors: Acceptance, Perceived Effectiveness;

d) Predictor: Acceptance

Regression analysis of LBC long term also showed significant multiple correlation coefficient between obtained and predicted values of behavioural changes' likelihood (Table 6). Compared with the results above, the fit of regression equation was even stronger: correlation coefficient $R = 0.674$ and adjusted explained variance by all predictors together (start model) in index LBC long term was $R^2 = 0.371$. Stepwise reduction of predictors by above named criteria suggested that again mainly acceptability contributed essentially to the prediction of the behavioural change index. Changes in explained variances were not significant by reduction of predictors - except the variable acceptability. So, this finding was very similar to the result of regression analysis concerning medium term responses. Again, perceived effectiveness was the second best explanatory variable, but the coefficient achieved significance only at the 10% level (Table 5).

Table 5: Regression coefficients: Prediction of Likelihood of Long Term Responses (LBC long term).

<i>Start model</i>	<i>Standardised coefficients</i>	<i>T</i>	<i>Significance</i>
(constant term)		2.047	.051
Acceptance	.580	3.971	.001
Understandability	.212	1.243	.225
Engagement	-.256	-1.520	.141
Effectiveness	.255	1.714	.098

Table 6: Summary of Regression Models Prediction of Long Term Responses.

<i>Model</i>	<i>R</i>	<i>Adjusted R²</i>	<i>Changes in F</i>	<i>Changes in significance of F</i>
Start model (a)	.674**	.371		
2(b)	.650**	.358	1.544	.225
3(c)	.633**	.357	1.048	.315
4(d)	.597**	.334	2.054	.163

Notes: a) Predictors: Acceptance, Understandability, Engagement, Perceived Effectiveness

b) Predictors: Acceptance, Understandability, Perceived Effectiveness;

c) Predictors: Acceptance, Perceived Effectiveness;

d) Predictor: Acceptance

5. Discussion

The present paper considers freight operators' opinions and perceptions of road pricing charges as well as their views on selected elements of differentiation. Results show that a global index of acceptability of differentiation elements is particularly strongly correlated with the likelihood of future behavioural changes in medium terms as well as in long terms. These findings indicate that positive attitudes towards differentiated prices are also in the freight sector relevant for prospective success and effectiveness of pricing measures. Perceived effectiveness was the second most important motivational factor for all three time horizons, even if the estimated effect on the likelihood of behavioural change was only close to being significant, given the relatively small sample size. This gives some support to the hypothesis that a belief in

the effectiveness of price differentiation measures, in terms of providing more efficient transport operation, is important for behavioural changes to happen.

Further, variables investigating aspects of direct handling with toll charges by operators (e.g. understandability, engagement to deal with schemes) do not considerably contribute to the prediction of stated likelihood of behavioural changes. That might suggest that the understandability of charging schemes respectively the engagement to deal with them is less important for freight operators than for individual car users or transport passengers. A further fact supports this assumption: a vast majority of respondents' states that they have special staff calculating and evaluating road toll expenditures. So, cognitive burden by differentiated pricing schemes seems not to be a major issue for freight companies. It seems to be identified as a necessary separate task - allocated in companies' structures separately. Moreover, differences in likelihood of behavioural responses between several time horizons imply that effects of differentiated pricing in the freight operator sector affect behaviour more in the long run than in short term. This is comparable with the typical finding that long-term elasticities are usually higher than short-term elasticities (e.g. Nijkamp & Pepping, 1998).

Additional findings show that the attitudes of the surveyed freight companies towards various elements of differentiation differ. E.g., differentiation according to emission or vehicle class seems to be more acceptable than any other differentiation element. Differentiation in terms of geographic (e.g. mountainous or sensitive areas) or time aspects (period of year / week / day) are rather less acceptable to road freight operators. It is interesting to note that differentiation elements which relate to changes at vehicle side are rated as more acceptable than differentiation elements which refer to concrete behavioural changes. One possible explanation might be that freight operators perceive more control to respond towards vehicle based price differentiation than to a price differentiation which relates to changes in the operation of HGV. Comparison of certain future responses hints also in this direction: so, fleet renewal is seen as the most likely response to reference schemes in medium terms as well in long terms.

Due to the correlative design of the survey, further studies are needed to examine casual relationships between motivational factors and behavioural responses towards differentiated charging schemes. It might be possible that acceptability affects behavioural responses in sense of a higher willingness to deal with charges and thus behavioural adaptation will become more likely. On the other hand it might be also plausible that certain kinds of behavioural adaptation strategies are perceived as more realisable and therefore certain charging schemes corresponding to realisable adaptation strategies are more accepted. Finally, it is probable that both variables interact.

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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.

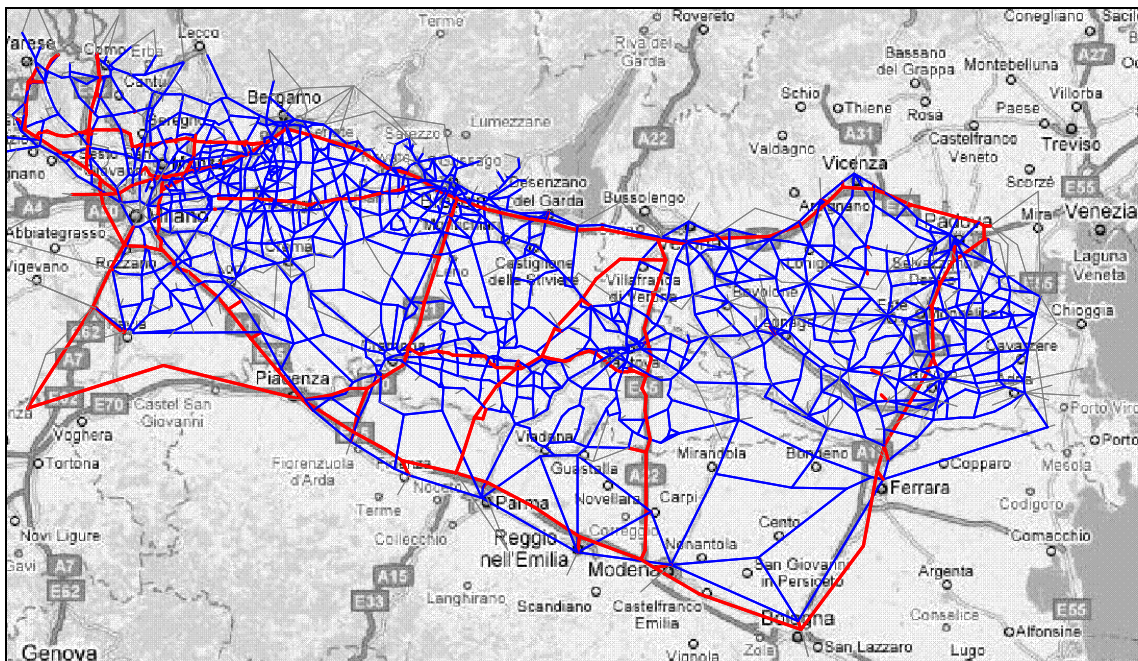


Figure 1: The Padana Region Motorway Model Network.

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.

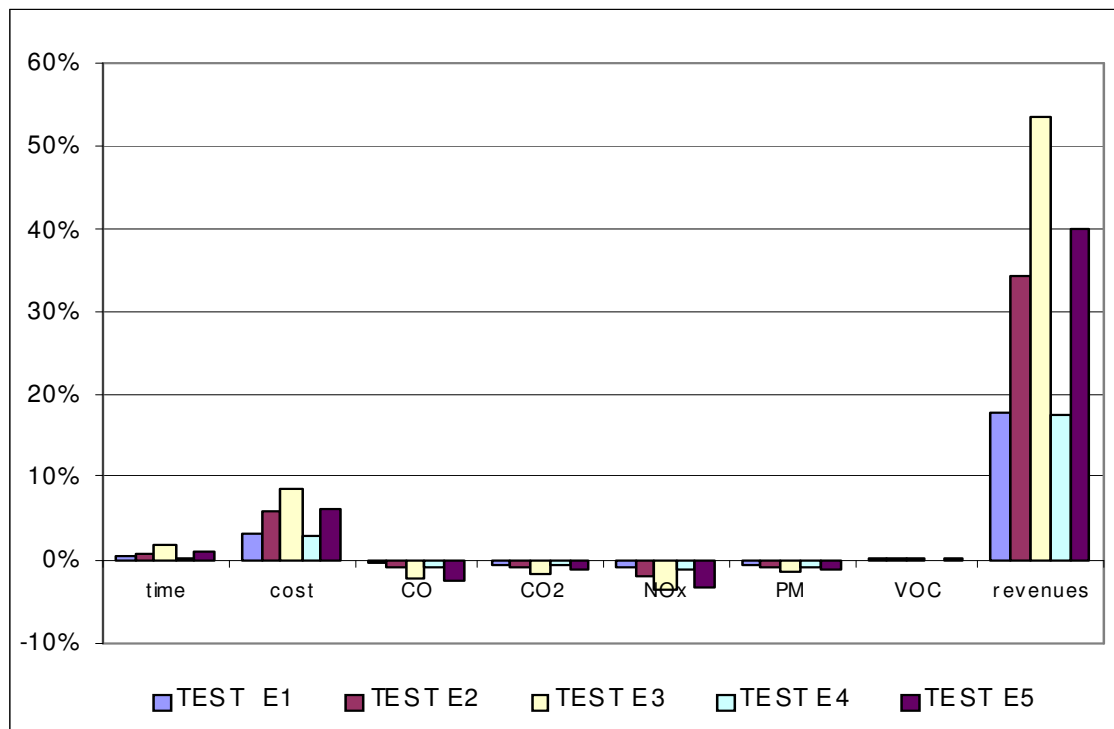


Figure 2: Summary Results of the E-Scenarios in the Brenner Corridor Model: Differentiation According to Emissions Level.

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*).

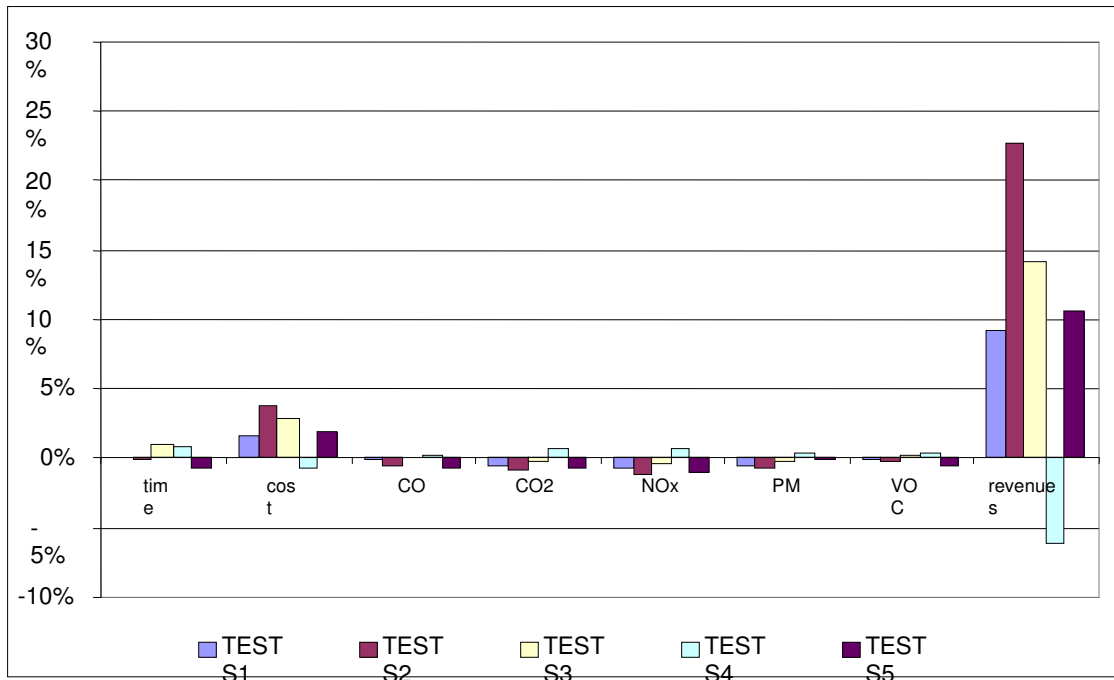


Figure 3: Summary Results of the S-Scenarios in the Brenner Corridor Model: Differentiation According to Vehicle Size.

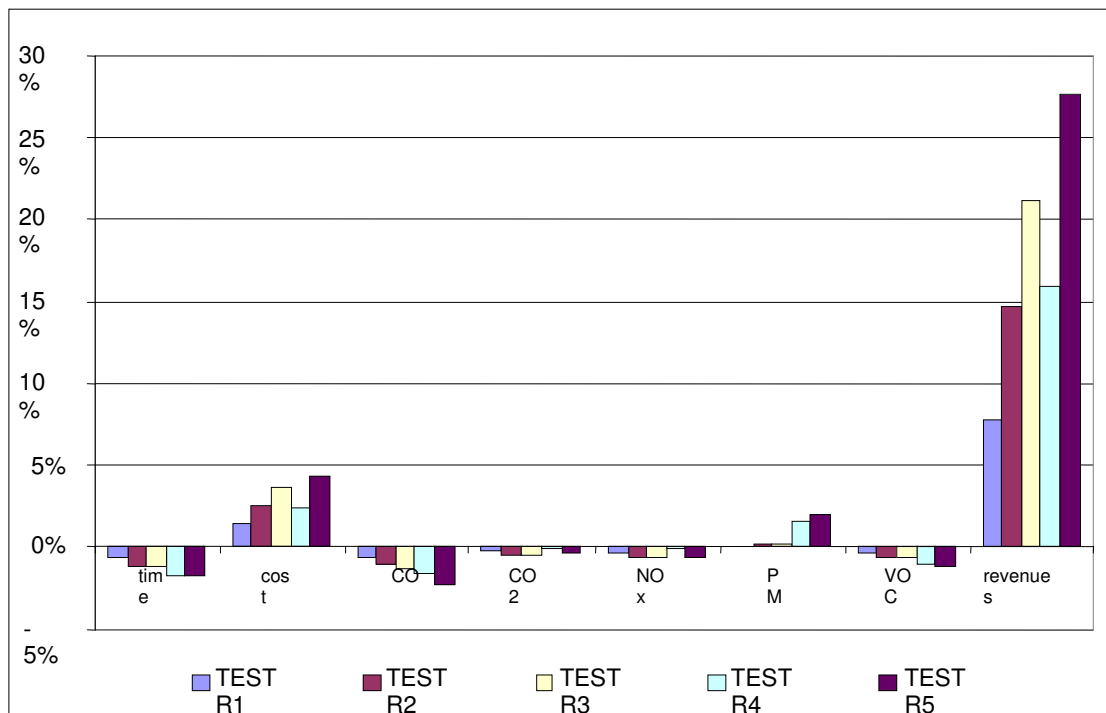


Figure 4: Summary Results of the R-Scenarios in the Brenner Corridor Model: Differentiation According to Road Type.

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.

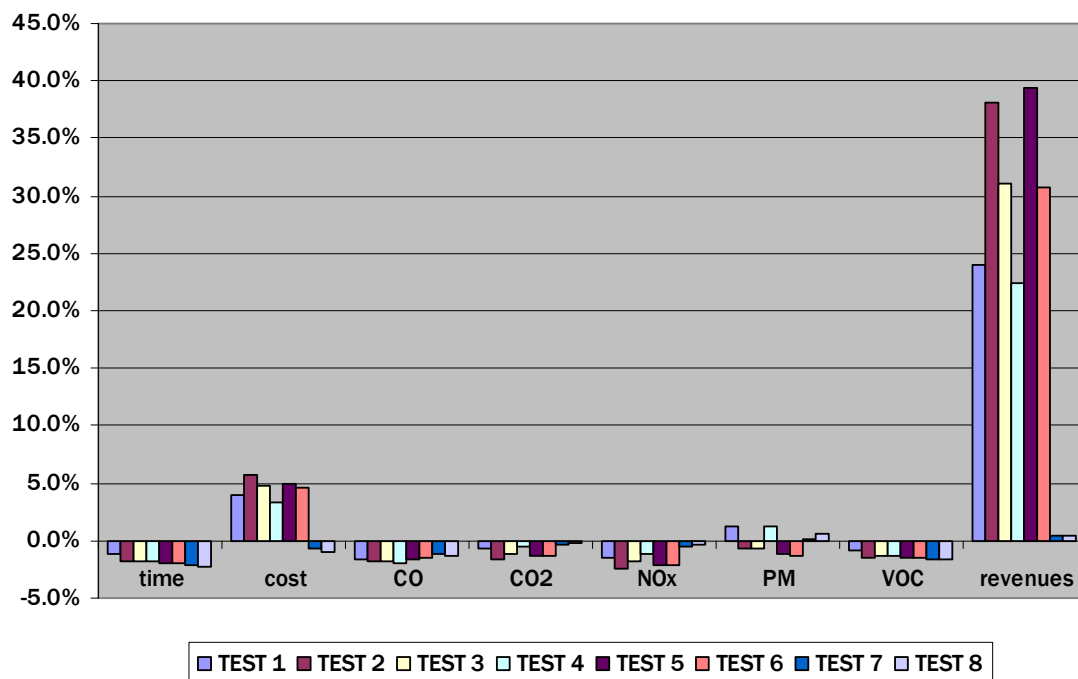


Figure 5: Summary Results of the Mixed Scenarios in the Brenner Corridor model.

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.

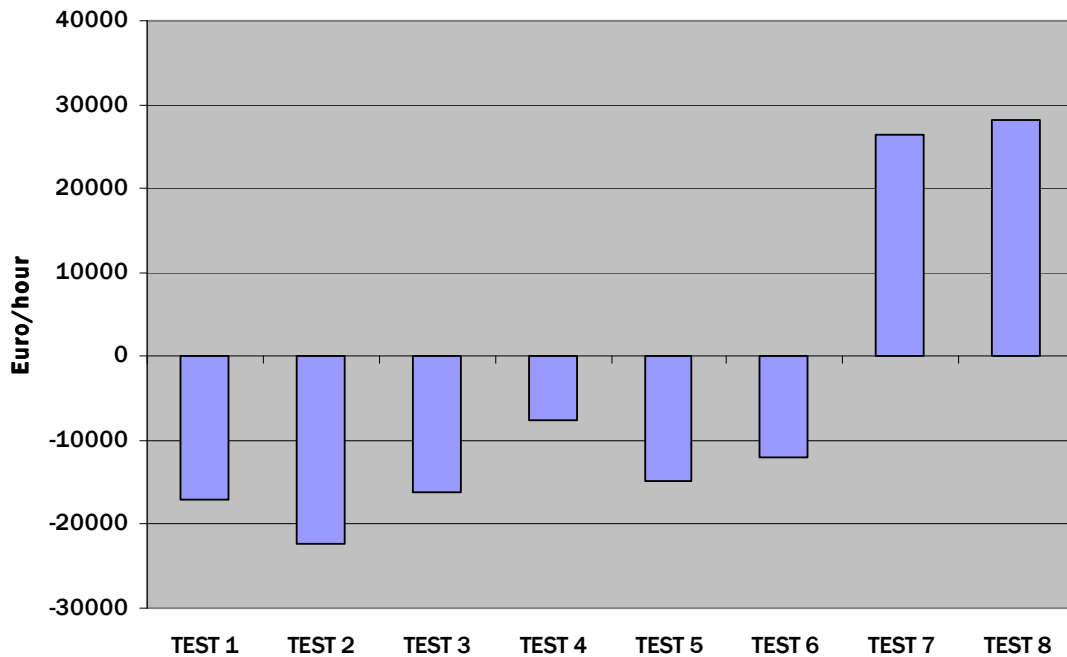


Figure 6: Net Economic Benefit of Final Scenarios in the Brenner Corridor model (1000Euros per year).

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.

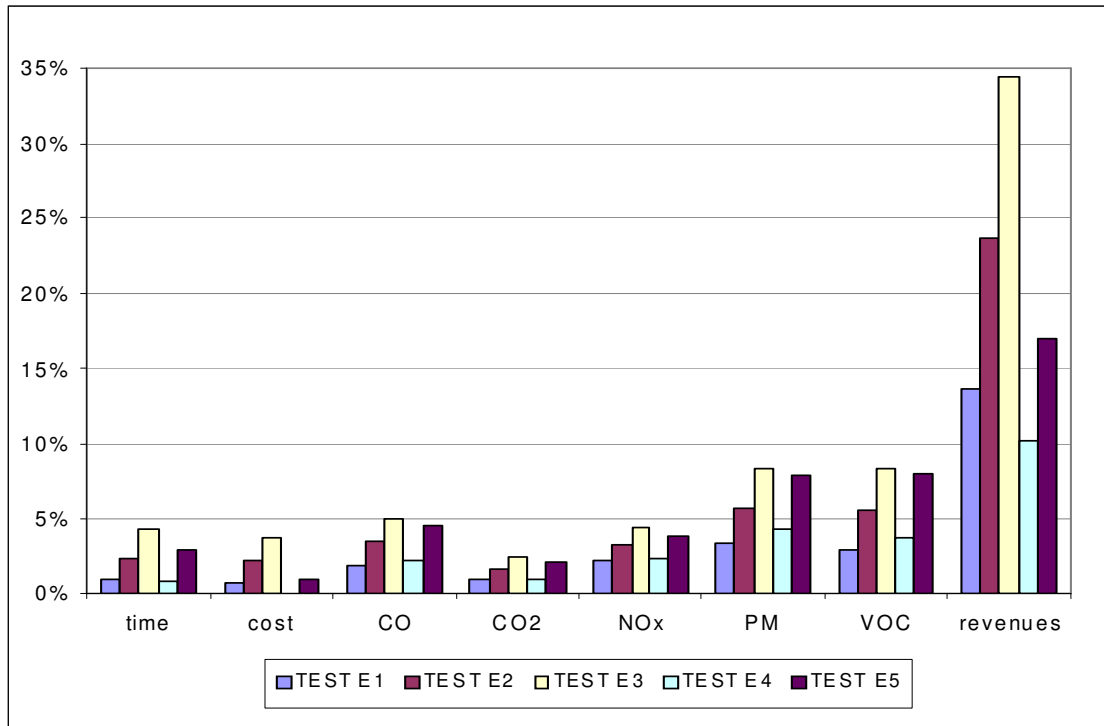


Figure 7: Summary Results of the E-Scenarios in the Padana Region Model: Differentiation According to Emissions Level.

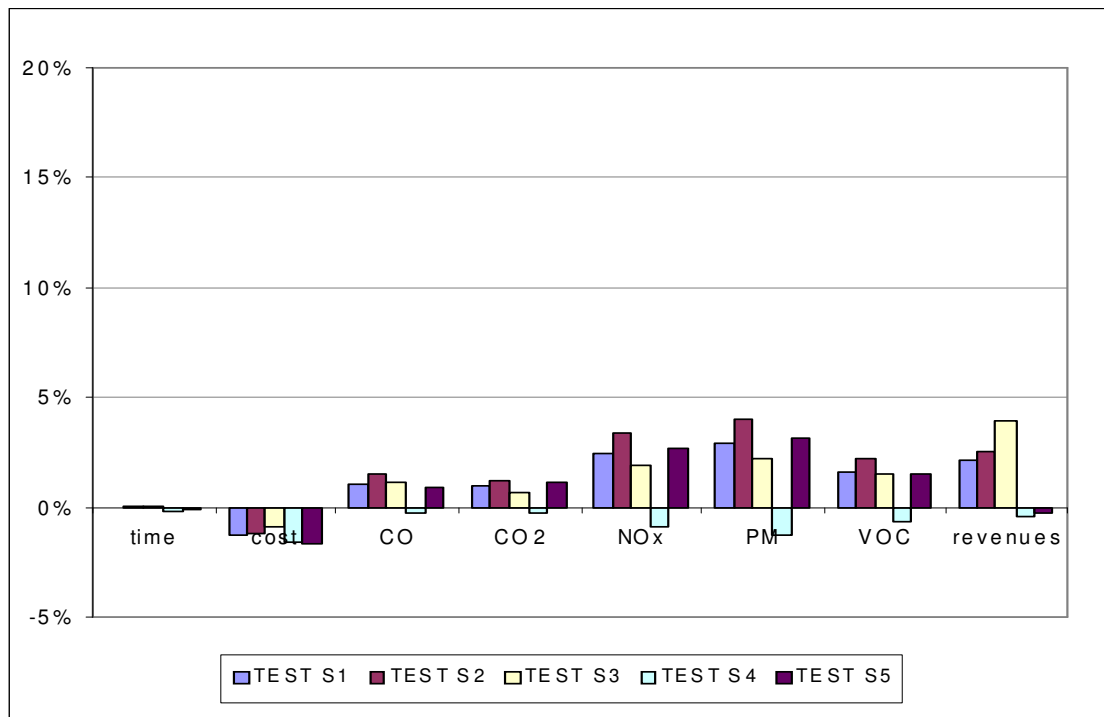


Figure 8: Summary Results of the S-Scenarios in the Padana Region Model: Differentiation According to Vehicle Size.

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.

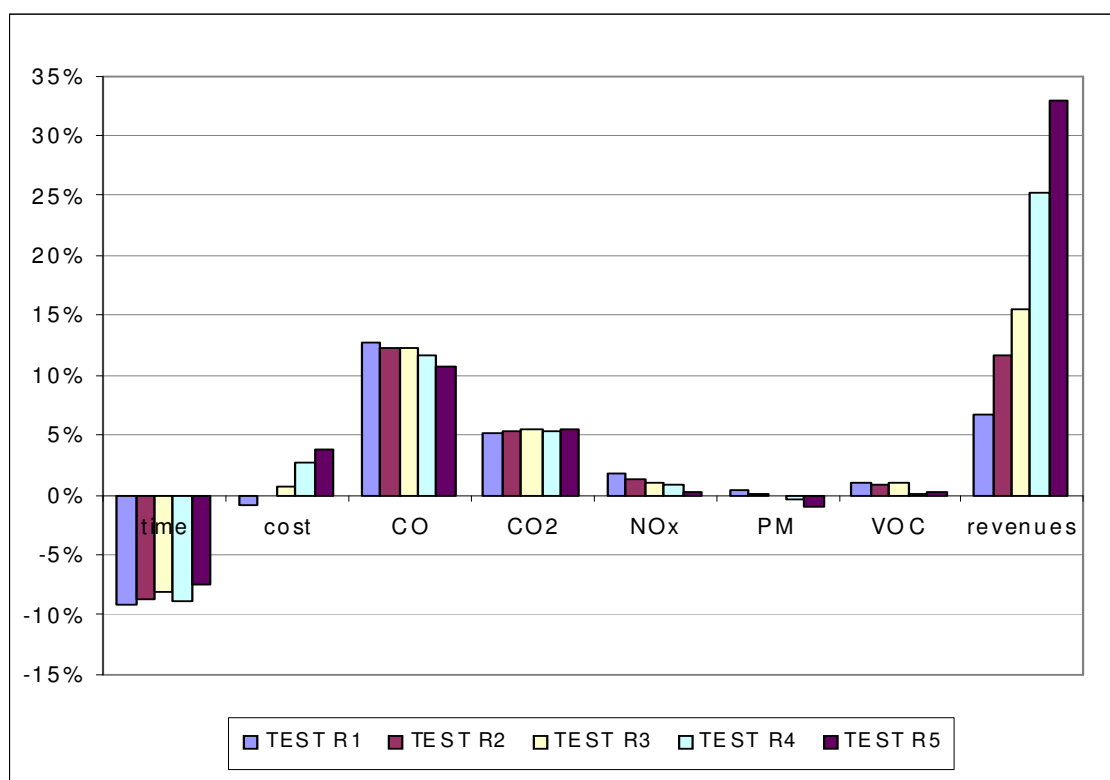


Figure 9: Summary Results of the R-Scenarios in the Padana Region Model: Differentiation According to Road Type.

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.

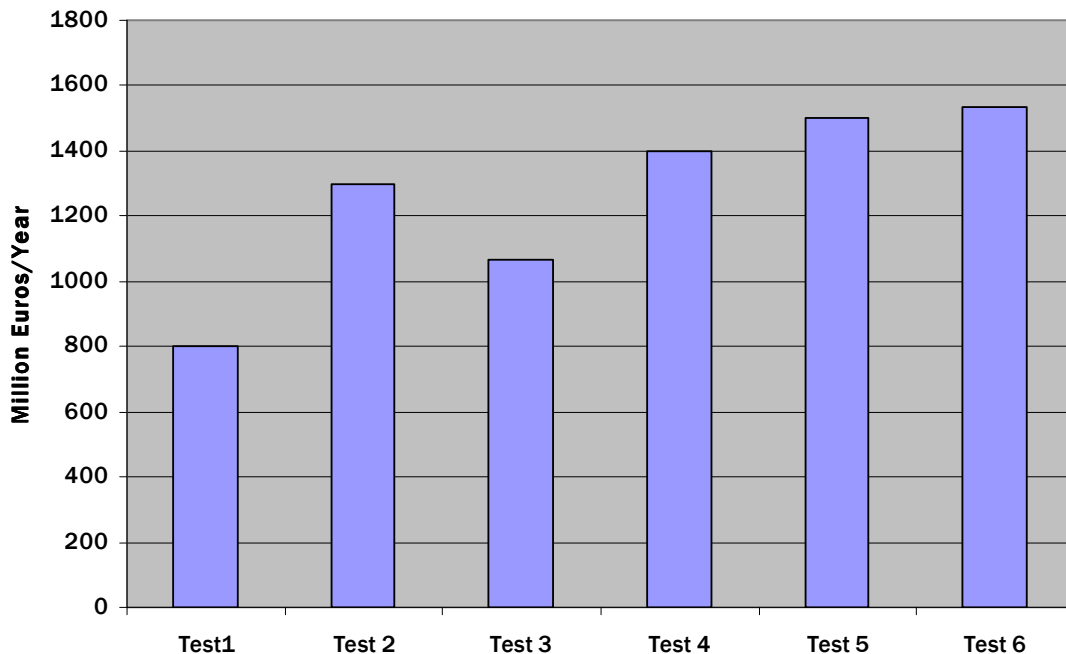


Figure 10: Net Economic Benefit of Final Scenarios in the Padana Region model (Million Euros per year).

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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Co-introduction of charges on urban roads and motorways in metropolitan areas: a model-based investigation

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Abstract

This paper explores the relationship between charges on motorways and on other types of road. It draws on a model-based study of different pricing scenarios which was conducted within an EU-funded investigation of differentiated infrastructure charges (the DIFFERENT project). The scenarios covered strategies ranging from full charging on all roads irrespective of category, on motorways only, on motorway access roads, on urban roads only, and at cordons. A number of different charge levels were tested. The test results suggested that positive impacts and revenues are maximised by applying charges to each link which reflect the contribution to externalities made by the marginal user of that link - irrespective of whether it is a motorway link or an urban link. However, when implementation costs are taken into account, the best performing scheme was a cordon charge combined with a per-km charge for use of motorways outside the cordon. Fixed per-km charges on motorways or on urban roads are much less effective than charges which are differentiated to reflect congestion on individual links. The introduction of charges only on motorways produces little benefit and causes unwanted diversion to urban roads, and although the introduction of a charge designed to protect the level of service enjoyed by strategic motorway traffic succeeds in achieving that goal, it yields little revenue and has little overall impact on delay or other externalities. The paper highlights the practical implications of these results and notes that, although it is likely to be easier to gain political support for introducing charges on motorways than on other types of road, the benefits from so doing are generally lower than can be obtained by introducing charges on congested urban roads.

Keywords: Road pricing; Model; Motorway; Metropolitan; Differentiation.

1. Introduction

1.1. Background and scope

Tolls are commonly applied on motorways. They are generally designed to yield a revenue stream to offset the costs of the original construction or ongoing maintenance

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and, perhaps, to generate funds to support future expansion in capacity. Most tolled motorways serve long/medium distance traffic but many pass close to centres of population and there are an increasing number of tolled motorways in urban areas – Melbourne’s City Link and Toronto’s Highway 407 being prominent examples. Charges are less commonly levied on users of general purpose urban roads but schemes in London and Stockholm exemplify increased interest in this policy option and, as demonstrated in Singapore, the introduction of charges in the city centre, on urban expressways and on major arterials offers a powerful tool with which to manage demand throughout the network. The objectives of charges on urban roads generally differ from those of motorway tolls in that they include an explicit goal of reducing demand and thus alleviating congestion – although the generation of revenue may still be an important aspect.

Motorways and urban roads have different functions and generally serve different types of traffic. However, when motorways pass through, or near, metropolitan areas these distinctions may become blurred and it becomes impossible to optimise the performance of one type of road without considering its interaction with the other. The introduction of charges on one category of road is, of course, likely to have impacts on the usage of other nearby roads. This may be a result of diversion (e.g. drivers choosing to use uncharged routes in preference to charged ones) or of changes in trip patterns (e.g. as when introduction of charges in one part of the network suppresses trips and thereby relieves congestion across the whole network).

It is a well-known principle of transport economics that maximum efficiency is not achievable in a transport network in which some links cannot be tolled¹. In such situations, the best result is achieved, not by introducing marginal social cost prices on those links which can be tolled, but by setting tolls which take account of the effect on un-priced capacity (Lévy-Lambert, 1968; Marchand, 1968). The welfare gains from this kind of pricing are lower than those achievable when all links can be charged but are better than those achieved simply by optimising only for those links which can be priced (e.g. Liu and McDonald, 1998).

Since it is usually much easier, politically, administratively and technically, to introduce tolls on motorways than to introduce charges on urban roads, more consideration has been given to the effect that introduction of motorway tolls might have on urban roads than vice versa. Recognition of the possibility of diversion of traffic from motorways onto adjacent roads has long been recognised by policy analysts (e.g. MVA, 1993) and has generally been seen as a potential problem. Although some analysts have suggested that any unwanted diversion might be prevented by local traffic management measures, others have concluded that it would be safer simply to avoid introducing charges on motorways near urban areas. (Atkins (2006), acting as consultants for the Greater Bristol Transportation Study, decided to exclude urban motorway charges from their list of potentially useful charging structures on just such grounds.) This approach, pragmatically justified though it may be, clearly leaves important questions unanswered.

This investigation seeks to examine the relationship, within metropolitan areas, between charges on motorways and on other types of road, to explore the case for a coordinated approach to setting tolls on motorways and other roads and to consider the constraints which might make this difficult to achieve. The paper presents the results of

¹ This is one example of the difference between first best and second best pricing.

some previous modelling exercises before presenting some new modelling work in which the performance of different charging schemes is examined. Conclusions are then drawn on the interaction between charges on motorways and on other roads in urban areas and recommendations are put forward on the basis of these results and in the light of practical constraints and considerations which impinge on the design of road pricing schemes.

1.2. The results of previous modelling exercises

A number of studies have used models to examine scenarios for the introduction of charges on motorways and other roads in urban/metropolitan areas. The following paragraphs summarise some relevant results.

Motorway Charging in West Yorkshire

Mauchan and Bonsall (1995) used a fixed matrix SATURN assignment model to assess the effect of different forms of motorway toll on traffic diversion to the non-motorway network in West Yorkshire. The study area was about 45 kms by 45 kms, had a population of about 2.2 million concentrated in 5 urban agglomerations and, at that time, included about 90 kms of motorway much of which passed quite close to the urban areas. Four charging regimes were tested: (i) a simple per-km charge on all motorways; (ii) a flat rate charge, irrespective of distance travelled, for any traffic using the motorway system; (iii) a per-km charge on traffic using the “strategic” motorways; and (iv) a flat rate charge on traffic using the “strategic” motorways. The flat rate regimes were designed to dissuade traffic from using the motorways to travel short distances while the “strategic motorway” charge regimes were designed to exempt local traffic.

Tolls were assumed to be imposed on all traffic throughout the day and night with no distinction between different types of vehicle or between peak and off-peak times. Sensitivity analyses were conducted to gauge the sensitivity of results to the level of charges (per km charges were tested in the range of Eurocents 3 to 12 per km, whilst flat rate charges were tested in the range of cents 15 to 30 per trip).

The key findings of the study were:

- that the introduction of charges on the motorways caused traffic flows to increase significantly on the main non-motorway roads, especially in the off-peak period;
- that, with charges in place, peak period congestion increased on the minor non-motorway roads (via a knock-on effect whereby motorway traffic moved onto the major non-motorway roads and in turn displaced traffic from these roads onto the more minor ones);
- that the distance-based charge diverted more traffic than did flat rate charges yielding the same overall revenue (the per distance charges typically caused increases of up to 25% in the flow on the major non-motorway roads - five to ten times as much as was caused by the flat charges - because the motorway routes tend to be longer and were thus less attractive when charges were based on distance travelled);

- that tolls introduced on only the “strategic” motorways caused 25% less diversion to non-motorway roads than tolls levied for all motorways – even though the tolls were set to produce a similar overall revenue;
- that traffic was diverted away from ‘feeder’ motorways even when they themselves were not tolled; and
- that diversion of traffic away from motorways caused increases in overall travel time and overall mileage in the network.

The authors concluded that the introduction of tolls on motorway in or near urban areas could have significant deleterious effect on the urban network, if tolls were not simultaneously introduced on those urban roads. Their broader conclusion was that differentiation by type of traffic (long-distance vs. short distance) and by type of motorway (strategic vs. general purpose) can be used to control the impacts on the surrounding network.

The South and West Yorkshire Multi-Modal Study (SWYMMS)

The South and West Yorkshire Multi-Modal Study (SWYMMS) (MVA (2002), although not focussing exclusively on road charging, considered a number of strategies for road charging and is relevant to the current paper because the study area includes motorways running close to major conurbations. The investigations, reviewed by Coombe (2004) in the context of the UK Department for Transport’s Road Pricing Feasibility Study (DfT, 2004a), included charges at cordons around the centres of the three major cities; charges at cordons around the main urban areas; charges for travelling within urban areas; a per km charge for using any part of the motorway network²; and various combinations of these.

The performance of these schemes was predicted, for the year 2020, by a strategic scale multi-modal model which, although employing a spatially aggregate representation of the network, included a disaggregate representation of traveller type and trip purpose and allowed trip frequency, destination, mode and time of day to vary in response to changes in the generalised cost of travel. The model produced estimates of equilibrium flows, journey times and costs, and of revenues. An aggregate measure of total time and money benefits was also calculated.

The results suggested that the simultaneous introduction of charges in urban areas and on the motorways would yield very significant revenues, very significant reductions in journey times, particularly during peak periods, and significant overall benefits to road users. The introduction of charges on all roads in urban roads – with no charge being imposed on motorways – produced somewhat lower, but still significant, revenues and benefits (the imposition of charges at cordons around the urban areas also yielded significant revenues and user benefits but charges at cordons around the city centres generated only modest revenues, caused increased journey times and led to net disbenefits to car drivers and goods vehicle traffic). The introduction of charges on the motorways – with no charges for use of urban roads - yielded reasonable revenues but resulted in some increases in car journey times (presumably because some traffic diverts from motorways onto more congested routes) and produced only modest overall benefits. Interestingly, the SWYMMS model predicted that the introduction of charges

² Defined for the purposes of the investigation to include the strategic A1 trunk road.

in urban areas would result in *reduced* flow on the motorway network (whether or not it too was charged) – indicating that, taking motorways as a whole, the general reduction in trips caused by urban charging would have more impact than any local diversion of trips onto motorways.

These results indicate that, in areas where motorways pass close to urban areas and serve local as well as strategic traffic, the combination of urban congestion charges (at a high rate per km) with motorway charges (at a lower rate per km) appears to perform better than charges introduced only on the motorways or only on the urban roads. However, the SWYMMS study also noted that there were circumstances in which the introduction of charges on motorways might be justified even in the absence of charges on urban roads. For example, the authors of the study suggested that, where motorway capacity has been increased, the introduction of motorway charges could be used to dissuade additional traffic and so help to “lock in” the benefits of the capacity increase³.

2. New modelling work

2.1. The model

The new modelling work sought to go beyond the studies outlined above by exploring a wider range of scenarios for the co-introduction of charges on motorways and other roads in metropolitan areas. It sought to improve on the work conducted by Mauchan and Bonsall (1995) by allowing for the effect that the introduction of charges might have on total trip numbers and to include a more realistic representation of the network than had been attempted in the SWYMMS work (MVA, 2002).

The new work used a user-equilibrium traffic assignment model, with a single user class and an elastic trip matrix. The assignment model used BPR-type link performance functions and employed the Frank-Wolfe method to iterate through to an equilibrium solution. The demand function used to modify the trip matrix is of the power law type, with a constant elasticity e such that the demand function is:

$$\frac{Q}{Q_0} = \left(\frac{C}{C_0} \right)^{-e}$$

where Q_0 and C_0 are the demand and travel cost for an OD pair in the “no charges” scheme; and Q and C are the equilibrium demand and travel cost in any other scheme (i.e. when tolls are applied).

An iterative process is applied to adjust the demand, starting from the base demands of Q_0 until convergence is obtained (that is, the demands applied are in balance with the travel costs, according to the demand function above). Good convergence (to within 0.1% of each OD’s demand) was found to be obtained in around six or seven of these outer loops.

³ The economic case for using charges to “lock in” the benefits of new capacity presupposes that the increase in capacity is insufficient to eliminate congestion from the network. It differs from the case, frequently made, that tolls should be imposed to raise revenue pay for a previous increase in capacity.

The network and trip matrix used for the modelling were chosen to be broadly representative of a medium sized metropolitan area and are loosely based on the city of Edinburgh. The full network diagram, shown in Figure 1, consists of 175 (mainly) two-way links (= 344 one-way links) and represents a total road length of 490 km - of which 143 km is of motorway or near-motorway standard, including a short section of urban motorway near the central area. The motorways, which include major approach routes to the city from the north, west and east, and a southern route passing to the south of the city centre, run parallel with other, non-motorway routes, in places.

The study area covers an area approximately 30 km by 20 km and is made up of 25 zones connected to the network via 52 centroid connectors. The total demand (representing the morning peak) consists of approximately 110,000 movements in the base case, spread over 550 OD pairs. The study area is divided, for the purposes of analysis, into two regions. Region A comprises that part of the network that is inside the dotted line in Figure 1, consisting of most of the urban area, extending out to the circumferential motorway, and containing 14 of the 25 zones, the trips from which comprise 62% of the morning peak trip origins and 77% of the trip destinations. Region B covers the remainder of the region (outside the dotted line) and contains the remaining 11 zones.

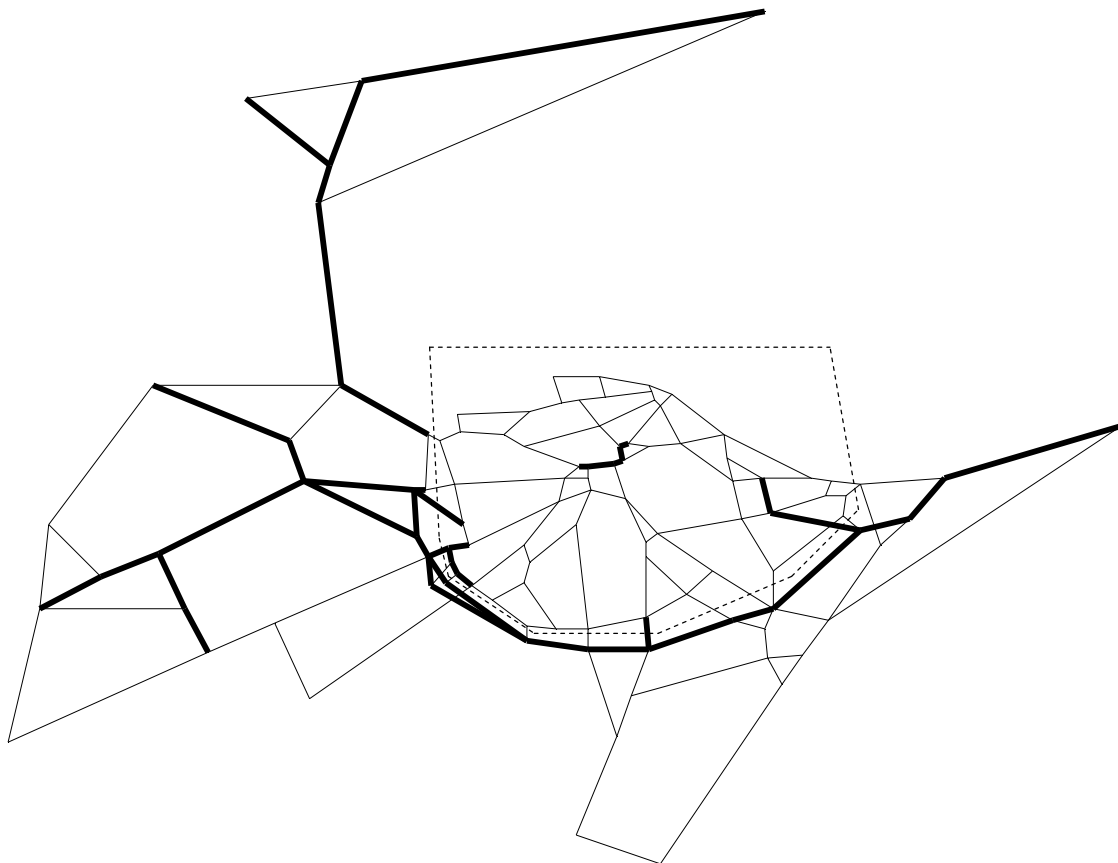


Figure 1: Diagram showing the modelled network (with motorway links shown in bold).

The network and trip matrix were originally developed for a study of road charging in Edinburgh (Sumalee et al, 2005) and were subsequently used in a study of the effect that differentiation of road charges might have on overall scheme performance

(Bonsall et al, 2007). More recently they, together with the model described above, were used by Maher (2008) to explore a methodology by which the performances of different road user charging schemes might be fairly compared and displayed.

2.2. The tests

Eight scenarios were specified which, between them, cover a number of different ways in which charges might be introduced on motorways and other roads in a metropolitan area. (Note that in what follows, for simplicity of terminology, all links of motorway or near-motorway standard are referred to here as “motorways”, and all other links are referred to simply as “urban” links):

1. “*First best*”; optimal tolls applied on each link in the network without specific regard to whether it is an urban road or a motorway link (optimal tolls being those which reflect the contribution to delay and externalities by the marginal vehicle on each link). Under this scenario the (flow-weighted) average toll charged on urban roads is 39.9 cents per km while that on motorways is 16.2 cents per km.
2. “*Best urban*”; the “optimal” tolls defined in scenario 1 are applied to urban roads only (leaving motorways un-tolled). Note that the tolls on each urban link are the same as in Scenario 1; they were not re-calculated to be optimal for a situation in which motorways are not tolled.
3. “*Constant urban*”; a constant (39.9 cents) per km toll was charged on every urban link (leaving motorways un-tolled). The 39.9 cents value being the flow-weighted average of the rates charged on urban roads under scenario 1 (and therefore also under scenario 2). This scenario was designed to test how much of Scenario 2’s benefit would be lost by applying a simplified, but comparable, charging regime.
4. “*Best motorway*”; the optimal tolls defined in scenario 1 are applied to motorway links only (leaving urban roads un-tolled). Note that the tolls on each motorway link are the same as in Scenario 1; they were not re-calculated to be optimal for a situation in which urban roads are not tolled.
5. “*Constant motorway*”; a constant (16.2 cents) per km toll was charged on every motorway link (leaving urban roads un-tolled). The 16.2 cents value being the flow-weighted average of the rates charged on motorways under scenarios 1 (and therefore also under scenario 4). This scenario was designed to test how much of Scenario 4’s benefit would be lost by applying a simplified, but comparable, charging regime.
6. “*Cordon only*”; a €15 charge to cross an inbound cordon. The cordon surrounds the main built-up area just inside the circumferential motorway (following the dotted line in Figure 1, and separating Regions A and B) but intersects some motorway spurs and the traffic on these spurs has to pay the cordon charge. The charge was chosen, after inspection of the performance of a number of different values, as one likely to achieve significant reduction in delay per trip without suppressing total trip numbers by more than 10%.
7. “*Cordon & motorway*”; the cordon defined in scenario 6 plus a 10 cents per km charge for using motorways outside the cordon. The 10 cents charge was chosen, after inspection of the performance of a number of different values, as one likely to yield a revenue approaching that of the “first best scenario”.

8. “Access charge”; a €3 charge was levied on all trips accessing the motorway network. The same charge applied irrespective of the distance travelled (unless the driver left the motorway and then rejoined it – in which case he would pay a second access charge). The justification for such a structure was that it would dissuade local traffic from using the motorways and preserve it for strategic traffic – for whom the one-off charge would be quite modest. Charges of this kind are sometimes referred to in policy debates as a means of “protecting” strategic traffic. The charge level for this scenario was selected after testing a range of values – the €3 charge being the one which minimised congestion (and total externalities).

2.3. Evaluation of results

The effect of introducing charges was measured using a variety of statistics which, between them, attempt to reflect the impact on demand, congestion and other externalities, the revenue generated, and an indicator of overall benefit. The impacts on demand are measured in terms of vehicle trips, vehicle kilometres and vehicle hours travelled – with an indication of the demand in different parts of the network and of average trip length and duration. Congestion and other elasticities are expressed in money values (using a resource value of time of € 0.1413 per person minute⁴ for delay and € 0.03219 and 0.03278 per vehicle kilometre⁵ on principal roads, and other roads respectively). An average car occupancy of 1.2 is assumed. Total revenue is a useful measure but net revenues are more revealing because they reflect the fact that the scheme implementation and operating costs are likely to be different for different scenarios. The scenario costs have been estimated following the principles set out in the UK’s Road Pricing Feasibility Study (DfT, 2004b)⁶. It is assumed that scenarios

⁴ Based on the assumption that our peak period matrix is 50% commuters, 10% workers and 40% other and using the UK department for Transport’s recommended resource values of time of £4.17, £22.11 and £3.68 for these three purposes respectively (see DfT, 2007).

⁵ Based on estimates by Sansom et al (2001) for small and large cars in outer metropolitan areas in peak periods (and assuming that our fleet consists of equal proportions of small and large cars). The main component (about 77%) of this cost is attributable to accident costs with smaller amounts for local air pollution (about 15%), climate change (about 6%), noise (about 1%) and infrastructure wear and tear (less than 1%).

⁶ Costs for scenarios 1, 2 & 3 were taken from the upper estimate for DfT’s scenario 7b (wide area schemes with mandatory OBUs) reduced to reflect the fact that the population in this study area is about 3.6% of that for which the DfT study produced its estimates. Two estimates were made for the costs for all other scenarios. The first was based on the estimate for DfT’s scenario 5a (motorway and trunk schemes with mandatory OBUs) deflated to reflect the fact that, whereas the DfT scheme required 117 charging points, our scenarios 4, 5 and 8 require 15, our scenario 6 requires 17, and our scenario 7 requires 32. The second estimate was based on the lower estimate for DfT’s scenario 7b (lower because the GNSS for motorways and cordons need not be so accurate as for general urban roads) reduced, as above to reflect the relevant population. Interestingly, using these figures, all scenarios were found to cost less using GNSS technology than DSRC technology.

All costs assume that the scheme we are considering is one of several similar schemes in the country and thus can share some fixed costs. The costs have been inflated to allow for optimism bias and, strictly speaking, relate to 24hr schemes (some reduction in costs might be expected for peak-hour-only schemes but, given that the cost profiles are dominated by fixed costs, the reduction might not be great). The DfT report quotes total costs over 20 years; these have been converted into daily costs simply by dividing by 20x250.

1, 2 & 3 require GNSS onboard units whereas all other scenarios, because the charges are imposed at a limited number of locations, can be implemented via DSRC units.

The indicator of overall benefit is simply defined for each scenario as the reduction in delay and other externalities minus the costs of scheme operation (i.e. [base delay and other externalities] – [scenario delay and other externalities costs] - [scenario operation costs]). It thus treats revenue as a transfer payment and takes no account of loss of consumer surplus, loss of tax revenues, long term impacts on land use and the economy, etc. The implications of excluding these aspects are discussed in Section 3.1 below but, meanwhile, this naïve definition of benefit has the advantage of simplicity.

A comprehensive evaluation of each scenario would need to use a more sophisticated indicator of economic benefit and would need to consider such aspects as well as the practical and political feasibility of the proposed charging regime. Although these aspects were not covered in the modelling work reported in this paper, they are addressed in Section 3 below.

2.4. The results

Results for the 8 scenarios specified in Section 2.3 are summarised in Table 1.

It appears that the greatest reduction in vehicle trips occurs under the “first best” scenario, that applying charges only to urban links has slightly less impact than the first best scenario, and that applying them only to motorways has relatively little impact. Constant charges have virtually the same impact on trip numbers as link-specific charges.

The picture for vehicle kilometres is similar, with the first best scenario again seeing the greatest reduction and the effect of urban-only charges being again greater than that of motorway-only charges. The cordon charge, with or without the accompanying motorway charge, has a greater effect on vehicle kilometres than do any of the other second best charges – even though they have less impact on overall trip numbers (this is presumably because many trips are unaffected by the cordon but those that are, are severely affected).

The constant urban charge has more impact than the per-link urban charge (presumably because, with a constant charge, long journeys are penalised even though they are not congested).

Unsurprisingly, introduction of tolls solely on motorways causes a diversion of trips to the urban roads and vice versa. The constant motorway charge diverts more traffic to urban roads than does the best motorway charges (again this is presumably because, with a constant charge, long journeys are penalised even though they are not congested). Interestingly, the cordon has no impact on the balance between urban and motorway traffic volumes. The motorway access charge leaves a significant proportion of vehicle kilometres on the motorway – its main impact being to divert short distance trips from the motorway onto the urban network.

Turning now to the impact on delay, it appears that the greatest reduction is achieved under the “first best” scenario, followed in turn by the cordon & motorway charge, the cordon-only charge, the best motorway charge and the best urban charge. The constant charges on motorways and on urban roads do not perform at all well in terms of their impact on delay - with the constant urban charge performing worst of all (presumably because the charges are not related to congestion and cause very inefficient routing by people attempting to minimise the distance they travel). The motorway access charge

does not manage to reduce congestion very much (any reduction in congestion on the motorways is counterbalanced by increased congestion on the urban roads).

The greatest reduction in externalities other than delay is achieved under the “first best” scenario and the least under the scenarios which have charges only on motorways. The cordon scheme, particularly if combined with a motorway charge, performs almost as well as the first best scenario. Charges on motorways only, or on urban roads only, do not perform at all well - particularly when constant charges per km are applied.

Table 1: Results of Scenarios.

Measure	Base		Scenario							
	1	2	3	4	5	6	7	8		
	No tolls	First best	Best urban	Constant urban	Best motorway	Constant motorway	Cordon	Cordon & motorway	Access charge	
Total vehicle trips ('000 per day)	110	93	97	96	105	104	100	98	104	
Vehs crossing notional cordon [†] ('000 per day)	38	32	35	35	34	33	21	21	32	
Total veh km ('000 per day)	1798	1531	1657	1608	1677	1674	1594	1531	1720	
Percentage veh km on motorways	59	64	69	72	47	34	59	40	50	
Veh km ('000 per day) on motorways	1059	895	1143	1153	780	567	940	612	852	
Veh km ('000 per day) on urban roads	738	636	514	457	897	1107	654	919	868	
Percentage veh km in Region A	33	32	30	30	36	35	33	35	34	
Veh km ('000 per day) in Region A	588	497	494	475	601	592	529	536	581	
Veh km ('000 per day) in Region B	1210	1034	1163	1133	1076	1082	1065	995	1139	
Total veh hr ('000 per day)	56	39	49	53	50	55	46	45	54	
Percentage veh hr on motorways	42	91	57	55	58	42	74	72	34	
Average trip length (km)	16	17	17	17	16	16	16	16	17	
Average trip duration (min)	31	25	31	33	29	32	28	28	31	
Total cost of delay (k€ per day)	356	216	310	355	293	338	273	257	331	
Total other externality cost (k€ per day)	58	50	54	52	55	55	52	50	56	
Reduction in externalities relative to base ^{††}	0	148	50	7	66	21	89	107	27	
Rank (in terms of externality reduction)		1	5	8	4	7	3	2	6	
Total revenue from tolls (k€ per day)	0	378	210	182	141	92	317	369	96	
Assumed cost of scheme (k€ per day)	0	699	699	699	552	552	552	552	552	
Net benefit relative to base (k€ per day) ^{†††}		-551	-649	-692	-486	-531	-463	-445	-525	
Rank (in terms of net benefit)		6	7	8	3	5	2	1	4	

Notes: [†] between regions A and B (the dotted line in Figure 1); ^{††} [base externalities (incl delay) – scenario externalities (incl delay)]; ^{†††} [base externalities (incl delay) – scenario externalities (incl delay)] - [assumed operating cost].

The revenues from the first best scenario are greater than from any other scenario but those from a cordon scheme, particularly if combined with a motorway charge (i.e. schemes 6 and 7) are also very substantial. Revenues from charges on urban roads exceed those from charges on motorways or on access links and are higher from schemes in which charges vary from link to link (in line with first best charges) than from those for which average charges are applied for a class of links.

When allowance is made for costs of scheme operation, no scheme produces sufficient benefit to cover its costs. This result is not as alarming as it may seem at first sight because the schemes represented here are limited to the peak period (the potential additional revenue from charges at other times of day would be many times greater than the increased costs of operation – particularly in the urban areas). When the cheaper implementation costs of scenarios 4-8 are allowed for, they all outperform the first-best all-links scheme.

The conclusions which we draw from these results are that:

- positive impacts and revenues are higher for schemes which include charges on motorways and on urban roads than for schemes which include charges only on one type of road;
- positive impacts and revenues are highest when link charges reflect the externalities associated with the marginal user of that link - irrespective of whether it is a motorway link or an urban link;
- fixed per-km charges on motorways or on urban roads have much less positive impact than charges which are differentiated to reflect conditions (most notably congestion) on individual links (fixed per km charges on urban roads (only) are particularly ineffective because they cause people to use congested – albeit short – routes);
- the introduction of charges on motorways, but not on urban roads, produces little benefit and causes unwanted diversion to urban roads;
- the introduction of a charge designed to protect the level of service available to strategic motorway traffic succeeds in achieving that goal, but yields little revenue and, because it diverts traffic onto the urban network, has a modest overall impact on delay and other externalities;
- net benefits are reduced by implementation costs and, since these costs are highest for schemes which involve charges on all urban links (and thus require the most sophisticated GNSS equipment), the overall performance of such schemes is depressed relative to that of cheaper schemes – particularly those based on cordons and/or motorway charges; and
- the best performing scheme when implementation costs are taken into account is a cordon charge enhanced by adding a per-km charge for use of motorways outside the cordon.

3. Discussion

3.1. Limitations of our approach

Model simplifications

Any model is a simplification of reality and the simplifications open the door to potential criticism. The model described in Section 2.1 can be criticised in various respects but perhaps most crucially for its use of a single user class and a single time period because it is known that the welfare gains from tolls are underestimated if allowance is not made for heterogeneity of travellers (Verhoef and Small, 2004) or for the dynamics of departure time adjustments (Braid, 1996; De Palma and Lindsey, 2000).

If the model had included more than one class of driver with different values of time (VoT) it could have captured the benefit which high VoT drivers might derive from reduced congestion on links which, due to the imposition of high charges, low VoT drivers were seeking to avoid. A shift of high VoT drivers onto high cost links, and of low VoT drivers onto slower or longer routes, would clearly have implications for equity and the distribution of benefits. More importantly, given our focus on the relative performance of the different charging scenarios, its impact on the overall performance of the network might be different in different scenarios. The effect will depend crucially on factors such as the relative sizes of the different user classes and on whether their trip patterns differ systematically in terms of their use of motorways and of links with different degrees of congestion. On balance, one might expect that the inclusion of different user classes with different VoTs would increase the benefits to be gained from motorway tolling more than those to be gained from urban charging⁷, but this assumption needs to be tested.

If the model had included a dynamic representation of departure time adjustments, it would have been possible to explore the effect of introducing different levels of charge at different times of day and thus to investigate a much wider range of scenarios for the co-introduction of changes on motorways and on urban roads. To the extent that urban areas tend to have more off-peak congestion than motorways, one might expect that extension of the analyses to include off-peak periods would add more to the justification for urban charges than to that for motorway tolls⁸. However, this assumption needs to be tested because a realistic, dynamic, representation of departure time adjustment would show that some of the traffic seeking to avoid a peak charge would shift to the preceding period and thus contribute to the build up of the peak – and the seriousness of this phenomenon would depend on how the trip departure profile of users of motorways differs from that of users of urban links.

If the model had included a representation of mode choice (rather than simply using a constant elasticity to adjust the trip matrix in response to any change in the generalised costs of car travel), it would have allowed for the fact that there are generally more modal alternatives in urban areas. It would thus have allowed charges on urban links to

⁷ Since all journeys start and end on “urban” links, no group could be priced-off the urban links and so, of the two types of link, it is clear that motorways are the only candidate to become the high-price-high-speed links which high VoT drivers would be prepared to pay for.

⁸ Off-peak charges would help to offset the costs of operating the charging system.

have more impact on demand than those on motorways. The economic case for charges on urban links would therefore have been enhanced.

Definition of benefit

The indicator of benefit included in Table 1 makes no allowance for loss of consumer surplus caused by trip suppression, for loss of fuel tax revenue, or for any long term impacts on land use and the economy, and makes no assumptions about the uses to which the revenue might be put.

Inclusion of an allowance for loss of consumer surplus would reduce the attractiveness of scenarios 1, 2, and 3 relative to 4, 5, and 8 (1, 2 and 3 having greater reductions in trip making than 4, 5 and 8) but would probably have no significant effect on the overall rankings. Inclusion of an allowance for loss of fuel tax revenue⁹ would reduce the attractiveness of scenarios 1 and 7 relative to scenario 8 (1 and 7 being the ones with greatest reductions in trip kilometres and scenario 8 being that with the least reduction) but, again, would not be expected to alter the rankings (e.g. the fuel tax accruing from scenario 7 might be about 19 k€ per day less than in scenario 8 and would leave scenario 7 well ahead of scenario 8 in terms of benefit).

Table 1 reports any reduction in vehicle trip numbers but, in the absence of any disaggregation of the elasticity parameter we are not in a position to indicate what proportion of the “missing” trips can be assumed to have moved into other time periods, or on to other modes, or to have ceased to occur. City authorities are likely to be concerned that any trip suppression might harm the local economy. A full economic appraisal of a charging scheme would clearly need to know the extent of time shift, mode shift and trip suppression, because they have very different implications for the overall benefit (for example; diversion of trips to public transport may have implications for subsidies and producer surplus, while trip suppression will affect consumer surplus and the performance of the local economy). Work by Bonsall et al (2007) suggested that the loss of consumer surplus associated with suppressed trips could significantly erode the overall benefit of road user charging.

It is difficult to speculate on the effect of including long term impacts on land use and the economy because the impacts would depend crucially on how the revenues were spent but, on balance one might imagine the long term benefit to be greatest for those schemes which show the greatest revenues and benefits in the short term.

Our indicator of benefit includes an allowance for changes in environmental externalities but they are assumed to be simply proportional to the vehicle kilometres on specified types of road. In practice they will vary with traffic composition and speed.

The indicator of net benefit seeks to allow for the costs of scheme operation but, although the costs are based on an authoritative report, they remain speculative and any error could affect the relative levels of net benefit calculated for each scenario.

Net effect?

The net effect of the simplifications in the model and the limitations of the benefit measure discussed above are difficult to estimate without more detailed analysis but, on

⁹ Note that revenue from fuel tax, like that from charges, is a transfer and only affects net benefit if trips are suppressed or if it is assumed that returns from expenditure of the revenue are lower (or higher) than those that would be achieved by the individual motorist.

balance, it seems likely that the model used for this work has under-represented the true performance of the urban charging regimes relative to that of the motorway charging regimes.

3.2. Practical considerations

A number of studies have explored the performance of networks in which certain classes of link are left un-tolled or in which different objectives are being used to set the tolls on different classes of link (for example, if different authorities or toll-concessionaires have control over different parts of a network). Although most of this work has been based on simple networks with a very small number of links, on generalised representations of networks or without any explicit network representation (e.g. Verhoef et al, 1996; De Palma and Lindsey, 2000; Verhoef, 2002; Proost and Sen, 2006; Ubbels and Verhoef, 2008), it is possible to draw a conclusion which is relevant to metropolitan networks. Namely, that, while social welfare is likely to be maximised by having charges set by one government agency responsible for the entire network, competition between government agencies attempting to maximise the welfare of their separate constituencies is likely to yield less welfare than that might come from a monopolistic profit optimiser or from effective competition between profit optimisers. An example of competition between toll operators having a potentially adverse effect on overall societal goals can be seen in the Paris region where concessionaires offer return tickets and regular user discounts (marketed as “*Liber-t Weekend*” and “*Activ-t*”) which may increase overall demand not only on the concessionaire’s motorway, but also on the roads leading to and from that motorway (for a fuller description of the incentives offered by toll concessionaires in the Paris region, see Section 10.3.1 of Bielefeldt et al, 2008).

Theoretical modelling clearly suggests that one cannot expect to maximise welfare unless charges can be implemented on all links in a network. However, it is in practice easier, technically, politically and administratively, to impose tolls on motorways than on general purpose roads. It is technically easier because physical limitations on access and egress allow use of cheaper charging technologies and more effective enforcement. It is politically easier because the public are more accepting of charges on high quality, “special”, roads (particularly if they are new) the use of which is discretionary, than on general purpose roads which they cannot avoid using. It is administratively easier because motorway administrators, unlike local highway authorities, generally have no specific responsibility to riparian owners and can concentrate exclusively on transport objectives.

It is quite common for the administration of motorways in a conurbation to be separated from that of other roads in the area. In such cases it is likely that the owners, managers and/or franchisees of the different networks will have different objectives. Typically, the motorway manager will want to maximise revenue (initially to cover the costs of the infrastructure and subsequently to generate profit) or maintain strategic connections, while the urban roads manager will want to manage congestion and/or promote the local economy. It should also be noted that charging schemes on different types of road might be best implemented using different technologies; for example, the technology required to implement a simple motorway toll is likely to be much cheaper than that required for a scheme covering urban roads. These different objectives and

requirements will often lead different scheme sponsors to favour charging regimes and technologies which might be incompatible with those favoured by other sponsors.

It is perhaps interesting to note that the most prominent example of successful co-introduction of charges on urban roads and nearby expressways is found in Singapore - a country famed for the strength of its central planning. Singapore's original charging scheme was limited to the city centre but was extended to include the expressways and, when this caused some diversion onto arterial roads and charges were introduced on these roads too (though at lower levels). The current system, as described by Santos (2005), uses a common technology (stored-value smart cards from which charges are deducted at charge points) combined with a charge regime in which charges vary by location, type of vehicle and time of day. Charge levels are reviewed every three months with the goal of maintaining average speeds on expressways and arterials within a target range. The differentiation by location allows charges to be set to reflect the different roles of different roads and appears to give the authorities the ability to manage demand throughout the urban network (including the expressways) in pursuance of their overall objective - to optimise the use and performance of the overall network.

Although it may be theoretically desirable to co-ordinate the introduction of charges on all classes of road, it is very common to find motorways and other roads under the control of different agencies and for these agencies to have different objectives. However, this need not mean that they cannot cooperate on technical and design issues. For example, in Trondheim, a single agency has been formed to administer tolls on roads owned by different authorities, a single unified toll structure has been devised and a single pass can be used to pay tolls on any of the roads (see chapter 2 of Bielefeldt et al, 2008).

Although institutional barriers may exist (e.g. if different authorities, with different powers and objectives, are responsible for the different types of road), the scale of potential benefits may be sufficient spur to seek to overcome them. A coordinated approach which treats the overall network as a single entity will have greater chance of achieving agreed prioritisation of objectives, and only by adopting a coordinated approach is it likely to be possible to achieve complicated, multi-faceted, objectives such as regional development or social equity.

An issue which was not captured in the theoretical work referred to above is the fact that competition among profit-oriented concessionaires may result in schemes which may cause some confusion among motorists. For example, competition among concessionaires in the Paris region (as described in Section 10.3.1 of Bielefeldt et al, 2008) has resulted in adjacent schemes adopting different definitions of the peak period and different classifications of vehicles. Any scheme characterised by highly differentiated charges and/or a non-intuitive relationship between the charges on urban roads and motorways might not be easily understood by road users. This could be a significant problem if it prevented people from understanding the intended price signal (because their behaviour would not reflect the signal) or if it led them to put pressure on the political authorities to abandon the scheme.

Failure to coordinate details such as start and finish times, vehicle classifications and exemptions might create perverse incentives and so generate unwanted responses (e.g. if, in order to maximise revenue, the motorway authority started the morning peak surcharge period earlier than that on urban roads, early morning traffic might switch to the urban roads - exacerbating the build up of the urban peak; or if, given the objective of reducing production of greenhouse gasses, motorway charges were based on engine

emissions, the most polluting vehicles would be the most likely to switch to the urban roads - with unwanted implications for urban air quality).

4 Conclusions

4.1. Policy implications

The degree of interaction between urban roads and adjacent motorways will naturally depend on the location and frequency of motorway access and egress points, the density of the urban network and the degree of spare capacity on parallel links in each network. Obviously, the greater the degree of interaction the more important it is to consider the potential cross-impacts.

Previous modelling work, reinforced by the new work described in this paper, has shown that charges imposed on one category of roads in a typical metropolitan network can have profound consequences for traffic on other categories of road in that network. Considerable problems are likely to occur if charges on urban roads are designed without regard to their potential impact on any adjacent motorways or if charges on motorways passing through metropolitan areas are designed without regard to their potential impact on the roads in those areas or on the local economy.

Some diversion of traffic from one network to the other is an inevitable consequence of introducing charges. Although some diversion may be desirable in order to achieve a better match of demand to capacity or to prioritise particular types of traffic, excessive diversion can cause serious problems. Diversion of traffic from motorways to other roads can be particularly serious, because it leads to increased accident risk and environmental externalities.

Where motorways and other roads come under different political or administrative jurisdictions, it is particularly important to ensure effective coordination and cooperation. Cooperation on technical and procedural issues, and over detailed definitional points such as start and finish times, vehicle classifications and exemptions, is desirable even if the two road authorities have different objectives. In the absence of such cooperation the resulting complexity will tend to increase costs for system operators and end users and may cause particular resentment among the latter.

Although it has not been proven by detailed modelling, it appears unlikely that a scheme designed to maintain free-flow on the motorways or maximise revenue for the motorway manager would simultaneously minimise congestion and other externalities within the urban area. It follows that, in order to maximise overall benefits, a degree of prioritisation or compromise is required.

It seems likely that net benefit to society and the economy might be maximised by combining a charge on the urban roads with charges designed to provide a high level of service for traffic using motorways and other strategic links. The urban charge might be levied on traffic crossing specified cordons or using roads within a specified area, while the strategic-link-protection charge might involve specific charges for using motorway access or egress links or dynamic charges just sufficient to preserve free flow conditions.

Although benefits are likely to be obtained by introducing a charge regime which draws no distinction between motorways and other roads, that does not mean that all

roads should carry the same charge; different roads have different characteristics and roles and an optimal design may imply charges which tend to be higher on one type of road than on another – but this is an output of the design process not an input to it.

Although it is likely to be easier to gain political support for introducing charges on motorways than on other types of road, the benefits from so doing are generally lower than can be obtained by introducing charges on congested urban roads. It seems clear that the un-coordinated introduction of charges on motorways and other types of road in metropolitan areas could seriously compromise the efficiency of the overall network and the effectiveness of such charges that are introduced. The most serious problems are likely to occur if charges are imposed on only one type of road (with the other type left free at point of use) but problems can also occur when both types are charged if the charges are not co-ordinated.

4.2. The need for further work

We identify a need for more detailed modelling – particularly to include a representation of different user classes with different values of time and elasticities, a representation of the complex consequences of any re-timing of trips from the peak into adjacent periods (including the impact on the build-up and decay of congestion), and a fuller representation of mode choice. It is recognised that the first two issues, in particular, are not amenable to a simple solution.

We identify a need for more detailed evaluation and would advocate an approach involving sensitivity analysis to allow for uncertainties in costs and benefits. The treatment of some impacts – notably loss of fuel tax revenue and of consumer surplus – are controversial and so should be separately identified in any evaluation. Impacts on employment, retail activity, property rents, economic output or efficiency are difficult to predict but could be based on an assessment of the effect that the scheme is likely to have on the costs of doing business in the city or region and of changes in the perceived attractiveness of the area. This requires a calculation of changes in the transport costs (including any expected congestion relief) experienced by commuters, shoppers, and suppliers, of changes in local environmental conditions, and of changes in business sentiment – with the latter two being particularly difficult to quantify.

The potential social impacts of a road charging scheme are a matter of particular concern to government and require thought to be given to the incidence of costs and benefits among the affected population. Our suggested use of a model incorporating different classes of user is consistent with this aim.

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Impacts and incentives of differentiated rail infrastructure charges in Europe - focus on freight

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Abstract

One of the key objectives of rail infrastructure charges has been stated as being to promote the efficient use of the infrastructure. Much effort has been put into the derivation of charging regimes by infrastructure managers and regulators throughout Europe, and a mix of differing regimes have been put in place. However, relatively little work has been undertaken to examine the impacts and incentivisation effects that these charging regimes produce. This paper gives consideration to relevant theory in this area, what one might expect - from first principles - and then reports on a number of interviews and case studies undertaken to explore these impacts and incentives. Finally, it discusses a number of methodological issues surrounding this area of research, and proposes further lines of enquiry that might reasonably be pursued.

Keywords: Railways; Infrastructure charging; European Policy; Competitiveness; Impacts; Freight; Differentiated.

1. Introduction

Charging in the rail sector has, over recent years, made a number of moves towards greater efficiency and this has tended to lead to a greater degree of differentiation in the charges. A number of countries sought, as part of the reform of their national railway industries, to develop and implement systems of rail infrastructure charging that approximate to marginal cost pricing and, since adoption of Directive 2001/14 which requires rail infrastructure charges to be based on marginal cost, the majority of member states have now done the same. However, the ways in which Member States are basing

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their systems on marginal cost principles differ from one country to the next and a diversity of approaches has developed.

Previous research in this area has tended to focus on the design of infrastructure charging regimes which, in principle, promote efficient use of the infrastructure, efficient investment or which enable a particular degree of cost recovery. This has then led on to a substantial body of research into the measurement of costs, in particular of marginal cost (Wheat and Smith, 2008; Nash et al, 2008 etc)).

There has been relatively little research in the area of how train operators react to the charges they face. There is, for example, no previous research to estimate infrastructure charge elasticities and no research into how train operators perceive and interpret different charging structures; i.e. whether they can interpret highly differentiated, complex regimes or whether there may be a necessity to keep things simple. A further apparent gap in the research on rail infrastructure charges relates to the issue of how operators pass on their costs to end-users – that is, passengers and freight forwarders - and how different infrastructure charging regimes impact on charges to end users.

There is, nevertheless, some evidence that train operator reactions to infrastructure charges are important. A key factor motivating the revisions to rail infrastructure charges in Britain in 2001 was the view that the initial system of infrastructure charges gave the wrong incentives to train operators and led to greater congestion on the network. User reactions were also a key factor in Germany, where the infrastructure charging system has undergone reforms largely motivated out of concerns about competitive incentives and user reactions amongst train operators.

One can postulate that rail infrastructure charges might have two principal effects on train operators. Firstly, they might affect their behaviour, in terms of their use of the infrastructure and the way they operate their services. That is, a train operator's decision as to whether to offer a rail service and how to offer that service – when, where and with what rolling stock, staffing levels etc – is likely to be affected by the charges that they will incur in doing so. If there is a differentiated charging system featuring relatively high infrastructure charges in peak times (as was proposed in Britain) or on highly utilized lines (as is the case in Germany and Austria), that may serve as a disincentive to an operator considering the introduction of a new or additional peak service. Correspondingly, relatively low charges at night, for example, or on less utilized lines are likely to serve as a stimulus to new or additional services. Secondly, rail infrastructure charges could be expected to affect the charges that train operators make to their customers, be they passengers or freight forwarders. In fact, there may be a feedback mechanism, whereby the charges that train operators are able to make to their customers has an impact on the rail infrastructure charges as well. For example, if a train operator is faced with a high infrastructure charge for operating a particular service but thinks that passengers place a high value on that service, they might decide to operate the service on the basis of being able to cover the cost of the infrastructure charges through charging high passenger fares. Indeed, the reason behind the high infrastructure charge for that service may actually be a factor of the value that train operators believe that their customers place on the relevant rail services.

There are likely to be differences between reactions and impacts within the passenger as compared with the freight market. Freight is, in European rail systems, often a marginal activity, which is fitted around the passenger services. Freight may be more flexible, at least for some flows, in that the time windows it operates in are less constrained than for passengers. Furthermore, freight tends to be, and it would appear to

increasingly be, more international in its nature than passenger services. This then leads to the necessity for operators to interpret several, sometimes very different, systems of infrastructure charging as they pass through two or more countries.

The diversity of infrastructure charging regimes that exist throughout Europe is, in one sense, a good opportunity to undertake comparative research in this area. That is, Europe provides a real world laboratory, in which the attributes and impacts of one system can be compared and analysed in relation to one or more others. However, it is not only infrastructure charging regimes that differ across different countries; differences in respect of subsidy to the industry, regulation of the industry, market entry and competition serve to cloud the issue somewhat. Hence, there is a rich set of situations to draw on for research purposes, but with this comes a set of varying contexts that need to be controlled for somehow.

Our aim was to develop a better understanding of the ways, in principle and in actuality, in which users react to differentiated charges in the rail sector. At a relatively early stage in the work, it became clear that relatively little quantitative data would be available to us, and so our method naturally turned toward being based on a mix of reviews and case studies, drawn from those Member States that have been most active in the areas of rail charging. In this paper we begin by reviewing the few items of previous research on this topic, before then summarising the outcomes of a round of stakeholder interviews and the results of a set of four case studies. We then give consideration to methodological issues that might affect further research in this area, and close with our conclusions.

2. Literature Review

There is relatively little literature relating to the impacts of charging in the rail sector in terms of rail infrastructure charges. We pick out here three notable studies relating, in one form or another, to rail infrastructure charges.

Firstly, the Leeds Freight Transport (LEFT) model is used for multimodal freight demand modelling in the UK (Johnson, Whiteing and Fowkes, 2007). The model tests a range of individual policies for the UK. In order to form the 'best case strategies' for road and rail, the policies are bundled into two groups to form a Pro-rail strategy and a Pro-road strategy, which are tested against a Do-nothing strategy. The results are explained in terms of the impacts for 2016.

The impacts of the policy of doubling rail track access charges (part of the pro-road strategy) for rail freight operators, on road and rail modes are illustrated in the table below.

Table 1 shows that with the doubling of rail track access charges, rail tonnes fall by 2.03% and even further by 4.71% in tonne kms in comparison to the Do-nothing scenario. The length of haul falls by 2.73% in comparison to the Do-nothing scenario. As expected, the impact on road is in the opposite direction with increases in tonnes and tonne-kms and the length of haul in comparison to the Do-nothing, but the increases are rather modest. Interestingly, introduction of marginal social cost pricing on roads, part of the pro-rail strategy, increases rail-tonne kms by 18% (reducing road by 11%).

Table 1: Impact of Doubling Rail Track Access Charges by Mode for 2016.

<i>Mode</i>		
Rail	Tonnes (millions)	196.9
	Change from do nothing (%)	-2.03
	Tonne kms (billions)	28
	Change from do nothing (%)	-4.71
	Length of Haul	141.9
	Change from do nothing (%)	-2.73
Road	Tonnes (millions)	1935.2
	Change from do nothing (%)	0.14
	Tonne kms (billions)	170.3
	Change from do nothing (%)	0.7
	Length of Haul	87.8
	Change from do nothing (%)	0.56
Total	Tonnes (millions)	2132.1
	Change from do nothing (%)	-0.07
	Tonne kms (billions)	198.3
	Change from do nothing (%)	-0.1
	Length of Haul	92.8
	Change from do nothing (%)	-0.03

Source: adapted from Johnson, Whiteing and Fowkes, 2007.

It must be noted that several other multimodal models do exist for testing transport policies and scenarios, such as the MODEV model in France. But these models usually do not include a specific representation of infrastructure charges. The impact of infrastructure charges can be taken into account only indirectly, generally through the impact it is supposed to have on final rail prices.

Secondly, Preston, Holvad and Raje (2002) contrast infrastructure costs and charges in Britain and Sweden during the late 1990s. Although rail infrastructure costs appear similar on a track km basis in both countries, they highlight that British charges per train km were almost eight times those of Sweden. Table 2 shows the similarities in cost figures (particularly in terms of cost per track mile) and Table 3 shows the differences in infrastructure charge values. The basis of the charging regimes in Britain and Sweden are different. With charges in Britain being set on the basis of full cost recovery and charges in Sweden being based on short-run marginal cost.

Table 2: Comparison of Railtrack and Banverket's Infrastructure Wear and Tear Costs – 1998.

	<i>Infrastructure Wear and Tear Cost £m</i>	<i>Cost per Route Mile (£)</i>	<i>Cost per Track Mile (£)</i>	<i>Cost per Train Mile (£)</i>	<i>Cost per Traffic Unit (£)</i>
Railtrack	2290	217000	108000	7.95	0.051
Banverket	874	129000	113000	6.71	0.033

Source: Preston, Holvad and Raje, 2002.

Table 3: Swedish and British Rail Infrastructure Charges Compared (1999/2000 prices £ per train km).

<i>Sweden</i>	<i>1990</i>	<i>0.882</i>	<i>Great Britain</i>	<i>1994/5</i>	<i>6.032</i>
	<i>2000</i>	<i>0.646</i>		<i>1999/2000</i>	<i>5.039</i>

Sources: Nash, 1997, Prognos, A.G., 2000.

Assumes increases in RPI 1990/91 to 1999/2000 are 27.8% (<http://www.netaccountants.com/rpi.html>).

Assumes that €1=£0.646 Oct 1999 (<http://www.ecb.int/pub/pdf/mb199912en.pdf>).

Preston et al (2002) noted that on track competition in the passenger rail market is currently limited, but postulated that were such competition to be permitted on a wider scale, the extent would be influenced by the level of track access charges. To explore this, they used a simulation model - PRAISE - to assess the impact of on-track competition in both Britain and Sweden.

They found that, for a main line intercity route in Britain, competition would be largely of a cream-skimming nature, with the new entrant concentrating its services during the peak periods of the day. Evaluation of this competition found that, although it was profitable for the new entrant, it would not improve welfare overall. Furthermore, head-on and fares competition did not appear to be profitable where infrastructure charges are based on full cost recovery, with the possible exceptions of some route and product competition. By contrast, for Route S1 in Sweden, it was found that on-track competition would lead to large service increases and significant fare reductions, and that this would represent a welfare improvement on the current situation; however, it would force a parallel route, currently commercial, into requiring subsidy. They went on to observe that, in Sweden, a greater proportion of the passenger rail network can be operated commercially because infrastructure charges are much lower than in Great Britain. Hence, there is greater scope for commercial on-track competition in Sweden than in Britain.

Table 4: Estimated Impact of an Increase in Track Access Charges on Rail Freight Traffic (tonnage in 2014).

Commodity	Growth by 2014 (%)	Impact of a track access charge increase (%)	
		+20%	+50%
Maritime Containers	50	-6.4	-15.2
ESI coal	-9	-0.4	-1.1
Other coal	0	-0.7	-1.6
Metals	12	-1.9	-6.3
Iron Ore	-5	0	0
Construction	46	-10.5	-17.7
Automotive	100	-3.2	-8.5
Petroleum and chemicals	4	-1.8	-5.9
Waste	15	-0.1	-0.2
Domestic intermodal	215	-5.4	-13.5
Spent nuclear fuel	0	0	0
Mail/premium logistics	n/a	-2.3	-5.8
Channel Tunnel	261	-2.1	-5
Total	20	-3.9	-7.9

Source: ORR 2006, page 6 (i.e. table above)

Finally, the British Office of Rail Regulation (ORR) commissioned MDS Transmodal to assess the impact of an increase in track access charges on freight traffic (ORR, 2006). This work formed part of their work to review British charges, and was designed to investigate the impacts of including a mark-up on infrastructure charges for freight so as to recover the costs of freight-only lines. MDS used the GB Freight model along with models for intermodal and coal traffic, and their results are summarised in Table 4.

3. Stakeholder Interviews

A next step in our methodology involved a round of 25 interviews with industry stakeholders, undertaken in early 2007. Rail infrastructure managers, regulators and train operators (both passenger and freight) from six countries – Austria, Britain, France, Germany, Italy and Sweden – were interviewed using a common semi-structured interview framework. Full details of the interviews are reported in Matthews et al (2007); here we provide a summary of the key findings to emerge.

One early finding was that, whilst infrastructure charges are a potential influence on train operator behaviour, other cost elements for train operators (staffing costs, train operating costs etc) and demand elements (demand reactivity to price levels, to quality of service, willingness to pay, etc) would also be expected to be important influences on the market. Furthermore, the rail market is also likely to be affected by a host of contextual factors, including the competitive and regulatory framework (monopoly or oligopoly, type of regulation) and levels of car ownership and economic growth.

Secondly, whilst we were able to gather information about infrastructure charge categories and levels for the selected case study countries, we very often encountered a lack of even the basic information about precise infrastructure charge quantities (i.e. train-paths, or train-km) bought for each category. Many of the other elements are viewed by train operators as being commercially sensitive; even the price levels are often not precisely observable, due to yield management techniques introduced in preparation for competition in the rail market.

Hence, it was concluded that a systematic analysis of the impact of infrastructure charge differentiation seems an extremely difficult prospect at this point. Disentangling the impact of charges from the impacts of all of the other significant influences on the rail market, amidst a diversity of charging regimes and contexts, with a limited supply of detailed data, would appear to be highly problematic.

The rail market is comprised of many different sub-markets, and there are potentially different scales of impacts in different sub-markets. In actuality, it appears to be the case that, in many situations, operators have relatively limited scope to adapt their supply policy and their tariffs in response to infrastructure charges. For instance, where services are franchised, e.g. as is the case with regional passenger services in Germany or France, and with nearly all passenger services in Britain, services are quite closely defined by the terms of those franchises. Hence, there is limited scope for operator response to infrastructure charges during the life of the franchise. However, charges may serve to influence the terms of franchises, either through franchising authorities examining the implications of the charges for the services they wish to specify or through the terms of the franchise bids submitted by competing operators. This

mechanism for response, being contained within the planning process, is very difficult indeed to tap into.

In some situations, there may be no reaction at all on the part of train operators, due to mechanisms of compensation being in place. For instance, again where services are franchised it is common (and reasonable) for the terms of that franchise to require operators to be compensated by the franchising authority for any changes in infrastructure charges during the course of the franchise. Again, it may be possible to tap into the impacts as they relate to the franchising authority, but this would again be expected to be problematic.

Nevertheless, whilst reactions may be difficult to analyse and, in certain situations, relatively limited in scale, our interviews did uncover which sorts of parameters have been affected. Main reactions observed were in relation to:

- Design and choice of rolling stock;
- Suppression of unnecessary path reservations when reservation charges were introduced in France.

There was some interesting discussion of the share of train operating costs comprised of infrastructure charge-payments, and we have come to the view that the scale and form of reaction to infrastructure charges is likely to depend crucially on these cost shares. The cost shares for the use of infrastructure vary markedly across the interviewees in different countries. In general, the share of infrastructure charge costs as a proportion of train operating costs was reported to range between 10% and 30%. However, in Sweden the cost share was estimated at approximately 5%, whilst in Germany some operators estimated it to be as high as 60%.

Almost all participants indicated elasticities greater than one. There are reasons to doubt whether elasticity in all cases is greater than one, since the interviewed persons represent at the same time the interests of their industry, and therefore it is natural that interviewed persons in such cases tend to exaggerate.

Interestingly, on a number of occasions, operators reported that current degrees of differentiation were actually insufficient to elicit a reaction. For example, participants in Austria and Germany expressed the view that charge differentiation for highly utilized lines seems, due to the higher operating costs of the lower charged tracks, to miss its goals. Apparently there would be more recognizable effects if there was a higher degree of differentiation. Furthermore, many operators reported that they would be ready to accept higher charges in exchange for better quality of service.

In all of our sets of interviews, freight operators indicated a greater degree of sensitivity to infrastructure charges than did passenger operators. In general rail freight tends to be privately operated, is confronted with severe competition from the road, has experienced more open access competition and receives less government financial support, than do passenger services, and together these factors may explain this apparent greater degree of sensitivity. In Britain, for example, there has been significant growth in the rail freight market since infrastructure charges for freight operators were revised – incorporating a marked reduction in their level – in 2001. The extent to which this growth is as a result of this revision is, however, not clear as other changes in the market have occurred simultaneously; nevertheless, it potentially offers an interesting line of further enquiry.

An initial hypothesis was that one of the impacts of differentiated infrastructure charges would be on prices charged to end-users – passengers and freight forwarders. In some cases, e.g. where services are franchised and infrastructure charges change during the course of the franchise, it seems clear that any such impact on prices to end-users is minimal or non-existent. Beyond this, it would seem that there would be some impact, but that this impact would be heavily influenced by the degree of external competition – be that from other rail operators or from other transport modes - in the end-user market. In general, the greater the degree of external competition the smaller the likely impact of infrastructure charges on prices to end-users. Indeed, the level of external competition often appears to be more important in determining end-user prices than infrastructure charges.

Finally, it became clear that the data situation with respect to user reactions to differentiation of track access charges in rail is very problematic. Certainly, the charges themselves are public (although in freight some are the subject of private contracts) but the necessary data to analyse the reactions of the train operators with respect to output quantity (e.g. train kilometres), prices, costs and adjustment of production processes (choice of path or of type of rolling stock etc.) are extremely unsatisfactory or none existent.

4. Case studies

Having found that freight operators indicated a greater degree of sensitivity to infrastructure charges than did passenger operators, we concentrated much of our subsequent attention on the freight market. As referred to above, rail freight tends to be privately operated, is confronted with severe competition from the road, has experienced more open access competition and receives less government financial support, than do passenger services, and together these factors may explain this apparent greater degree of sensitivity.

We undertook four case studies focused on rail freight. Three case studies analysed changes in the rail freight market in order to make informed observations regarding potential linkages between changes in the infrastructure charging regimes and changes in rail freight traffic; one focused on Britain, one on France and the third on Eurotunnel. The fourth case study undertook aggregate modelling, applying the LEFT model to the British rail freight market, to test a number of charging scenarios for their impacts. Additional case studies, focused on passenger services, were also undertaken, details of which are reported in Matthews et al (2008).

4.1. Observations of Reactions in the British Freight Market

Up to the point of British rail privatisation which commenced in 1993, the demand for rail freight had been on a 40-year downward trend. However, having reached a low-point in 1995, demand has grown over the subsequent 10 years for which we have data. There has been an increase in rail freight over the last ten years from 15 billion tkm moved in 1996 to 22 billion tkm in 2006. In terms of the total growth in freight across all four modes illustrated, there has been an increase of 189% from 1953 to 2005.

Privatisation established a series of privately-owned open access rail freight operators, required to pay Track Access Charges to the infrastructure manager for the use of the network. During this period there have been 2 sets of infrastructure charges in place for freight operators. The first framework of charges for freight train operators was put in place in 1995. This framework remained in place until 2001, when the first Periodic Review of Track Access Charges recommended substantial changes be made.

The first charging framework, introduced in 1995, was a negotiated two-part tariff, based on the value to each user of using the infrastructure, subject to the constraints of covering avoidable costs and avoiding discrimination between operators competing in the same sector. A charge ‘floor’ and a charge ‘ceiling’ were established. The floor was based on the avoidable costs, whilst the ceiling was based on standalone costs, I.E. those costs that ‘... would be incurred by a notionally efficient competitor providing a dedicated network for the service(s) in question.’ (ORR, 1997, cited in Stittle, 2004). In fact, the two-part tariff comprised a large fixed component and a relatively small variable component. The average track access charge under that framework payable by freight operators was estimated as being approximately £6.23 per thousand gross tonne miles (kgtm), whilst Railtrack's freight-specific costs were of £5.53 (CFIT, 2001).

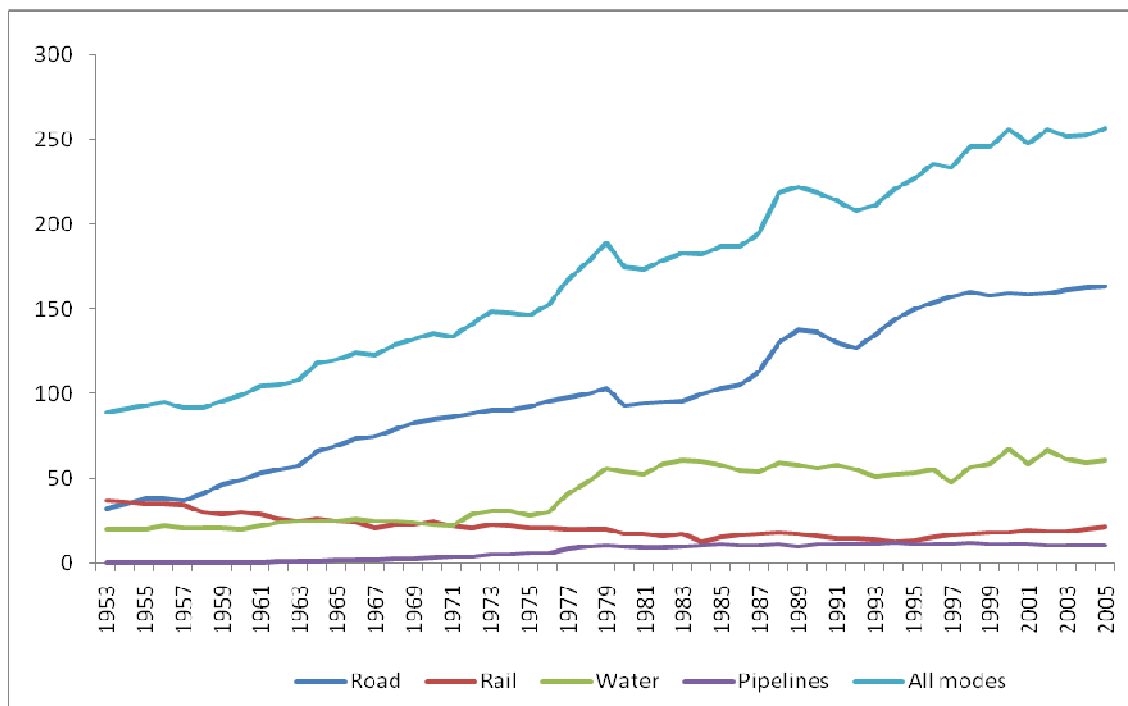


Figure 1: Domestic Freight Transport Moved (Billion Tkm) by Mode 1953-2005.

Source: Transport Statistics Great Britain 2007.

By 2001, gross tonne mileage had increased by more than 35% and additional growth was anticipated. Indeed, the government had set out an ambitious strategy for increasing demand for rail freight, with a target of achieving 80% growth over the period 1998/99-2010 and, with this in mind, a number of new operators were considering entering the market. Concurrently, rail freight was thought to be facing increased competitive pressures from road and other modes. For example, decisions to allow the operation of 44 tonne lorries and to stabilise vehicle/fuel duty were considered to be giving road haulage a significant competitive advantage. Furthermore, the periodic review of access

charges for franchised passenger train services had the effect of changing the balance of incentives between rail passenger and freight services on the network.

These changes in rail freight market conditions led the Regulator to conclude that it was appropriate to undertake a review of the freight charges. Crucially, a better understanding of cost causation had developed, meaning that there was a stronger body of evidence on which to base a new set of charges.

Prior to the outcome of the Periodic Review of Track Access Charges in 2001, an independent government advisory body, the Commission for Integrated Transport (CFIT) established a Rail Freight Working Group to consider track access charges. CFIT believed that rail infrastructure charges for freight services were “a significant factor for the further expansion of the domestic freight market”. In particular, their view was that the high costs of track access were serving to hold back rail freight operators from diversifying into non-bulk traffic. They commissioned research to analyse how rail freight operators could set about achieving the Government’s target of growing the rail freight market by 80% by 2010, with particular attention given to the influence of the amount paid for track access.

This work identified infrastructure charges as one of seven key issues associated with growing the rail freight market and estimated the level of track access charges which would need to apply, under various scenarios, to deliver the Government's 80% growth target. Under a central scenario, which assumed relatively small improvements in rail service efficiency, and continued decline in road haulage journey times (and efficiency), they estimated that an average track access charge of £3.50 per kgkm would deliver approximately 80% growth by 2010. This implied almost a halving of the then average track access charge. Under a "worst case" scenario, assuming no improvement in rail service efficiency or journey times over road haulage, they estimated that an average track access charge of £1.50 per kgkm would be required to deliver the same volume of growth by 2010.

The outcome of the 2001 Periodic Review represented a fundamental shift away from a negotiation-based approach to a published set of charges, the stated aim of which was to reflect the variable costs to the infrastructure manager of freight operations. The intention was that this would reduce transaction costs, improve operators’ ability to plan their businesses and create a more level playing field for new and potential freight operators.

A fundamental change involved the Regulator no longer requiring that freight operators be expected to pay either fixed freight costs or the infrastructure manager’s costs which are common between freight and passenger operations for use of the existing network. The charges comprised three components:

- Usage charges – designed to reflect infrastructure wear and tear costs directly attributable to particular services;
- Traction electricity charges – designed to relate directly to the amount of electricity consumed by any particular vehicle; and
- Capacity charges – designed to broadly reflect the congestion costs associated with increases in capacity utilization.

The effect of these changes was that, on average, the charges that freight operators paid to the infrastructure manager were halved. The resulting shortfall in revenue to the infrastructure manager from freight operations, which was estimated as being £500

million over a 5 year period, was to be funded by the government (via the Strategic Rail Authority). In addition, performance regime arrangements were put in place to provide both freight operators and the infrastructure manager with an incentive to reduce the delay which they impose on users of the network.

Interestingly, the outcome of the Periodic Review was very close to the charges associated with the 'central scenario' examined in the work for CFIT. It is, therefore, revealing to examine the growth in the demand for rail freight and how that compares with that projected in the CFIT work.

The trends in commodities moved by rail over 1998-99 to 2006-07 are illustrated in Table 5. It shows that, across all commodities, there has been a growth of 28%. Within this, it is notable that coal traffic has almost doubled and construction traffic has increased by a significant 29%.

Table 5: National Railways Freight - Freight Moved by Commodity 1998-99 to 2006-07 (Billion Tonne-Kilometres).

	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07
Coal	4.5	4.8	4.8	6.2	5.7	5.8	6.7	8.3	8.8
Metals	2.1	2.2	2.1	2.4	2.7	2.4	2.6	2.2	2.1
Construction	2.1	2.0	2.4	2.8	2.5	2.7	2.9	2.9	2.7
Oil and petroleum	1.6	1.5	1.4	1.2	1.2	1.2	1.2	1.2	1.5
Other traffic	7.1	7.6	7.4	6.7	6.6	6.8	7.0	7.1	7.0
All traffic	17.3	18.2	18.1	19.4	18.5	18.9	20.4	21.7	22.1

Source: Transport Statistics Great Britain 2007.

Table 6 illustrates the trends in rail freight lifted for coal, other traffic excluding coal, and of all traffic over the period 1998-99 to 2006-07. It shows a decline over the first part of the period, followed by an increase, resulting in an overall growth over the period of 6%. Linking this to the numbers presented in Table 5, this indicates that rail freight growth has been associated more with an increase in the distance freight is moved than the actual quantity of freight being moved. In terms of coal, despite the increase in tkm in 1998-99 to 2000-01, there has been a decline in tonnes lifted. Despite the 29% increase in coal tkm in 2001-02, tonnes lifted only rose by 12% in that same year. In the years that followed, changes in coal tkm were also characterised with changes in tonnes lifted in the same direction. However as coal tkm rose from 8.3 to 8.8 billion from 2005-06 to 2006-07, tonnes lifted decreased slightly from 48.9 to 48.8 million over that same period. In terms of all rail freight traffic lifted over the last decade, the lowest point was in 2002-03 where only 87 million tonnes were lifted.

Table 6: National Railways Freight - Freight Lifted by Commodity 1998-99 to 2006-07 (Million Tonnes).

	1998-99	1999-00	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07
Coal	45.3	35.9	35.3	39.5	34.0	35.2	44.0	48.9	48.8
Other traffic	56.8	60.6	60.3	54.5	53.0	53.7	57.1	58.7	59.6
All traffic	102.1	96.5	95.6	93.9	87.0	88.9	101.1	107.6	108.4

Source: Transport Statistics Great Britain 2007

Thus, whilst charges were essentially halved in 2001, growth in rail freight demand is not proceeding in line with the 80% government target (as the CFIT projections estimated that it would). Having grown by an impressive 4.8 billion tonne-kilometres between 1998-99 and 2006-07, it would have to grow by a further 9 billion tonne-kilometres over the next 3 years in order to achieve this target. This then begs the question of how the assumptions of the CFIT 'Central scenario' compare with what has actually occurred since 2001. Certainly a number of unforeseen events have taken place over the period, including the closure of a major steel works (reducing demand for both coal and steel traffic), the switching of postal services from rail to road and the essential break down of the Strategic Rail Authority's freight strategy. However, it is tempting to conclude that perhaps the CFIT work over-stated the importance of the role of infrastructure charges in stimulating rail freight demand.

Nevertheless, there has been considerable growth in rail freight over recent years and infrastructure charges are likely to be partly responsible for this. Indeed, commentators have tended to site six factors as explaining the growth since 1995, as follows:

- Increased road congestion;
- Increased costs for road freight arising out of the fuel duty escalator and, more recently, the Working Time directive;
- An increase in coal imports;
- Improved quality of service for rail freight;
- Investment in rail freight facilities;
- Infrastructure charge changes.

In terms of the types of commodities transported, there has been strong growth in some sectors. This has been most notable in relation to coal, which rail is inherently better-suited to carrying. The movement of coal and coke currently dominates rail freight, and 87% of coal and coke were carried by rail in 2006 (MDS GB Freight report 2006). However, it is thought that, for coal, transport accounts for only approximately 5% of the price of delivered coal, so the market is thought to be relatively insensitive to changes in the costs of transport. Hence, the actual growth in coal tonnes lifted was probably not related to the regime of infrastructure charges, but more concerned with changes in the detail of the power-generation market. The charge reductions may have enabled length of haul for coal and other traffic to increase at relatively little expense. Length of haul for coal traffic, for example, increased by 15% between 2001-02 and 2006-07. However, on inspection, this seems to simply be the continuation of a trend that commenced prior to 2001. The average length of haul was 120kms in 1980 and had risen to 206kms by 2004 (MDS GB Freight report 2006).

There has also been quite strong growth in construction traffic. In contrast to coal, the construction market is thought to be very price sensitive, with transport accounting for as much as 50% of the price of delivered materials. Hence, it is likely that charge reductions would stimulate growth in construction traffic. However, construction traffic since 2001 has fallen, then risen and, most recently, fallen again to a point slightly lower than that in 2001. It must be concluded that if charges are having an impact on this market, some other factor is clearly having an offsetting impact.

Rail freight growth actually started in 1995, and we do not observe a major change in the trend around the time of the reductions in infrastructure charges introduced in 2001. Prior to 2001, the structure of charges was such that there was a large fixed charge

which, once paid, provided an incentive to operate as much as possible. Post 2001 the structure no longer provided this incentive but it did allow for increased competitiveness, but the level was such that it enabled the rail freight market to remain buoyant. It is thought that, initially, charge-reductions were only passed on to clients in a limited way – so part of the reduction was enjoyed by the operators as windfall gains. Then, once contracts with clients were renegotiated, the reduction in charges were past on as reductions in charges to clients. Furthermore, differentiation by vehicle-type is thought to have focused the industry on track-friendly bogies.

As the rail freight industry has become more competitive and cost-conscious, it is rational that operators will pay more attention to what they are being charged for access to the infrastructure. It is suggested that this will have alerted operators to possible arguments for reduction of charges. Such arguments may have an effect on the overall charge level, as the rail freight industry has a strong incentive to make robust representations to the charge-setting authorities. They might also relate to incentives for operators to reduce impact of rail freight on the network, e.g. by operating less-damaging rolling stock, by requiring fewer slots to operate a particular service etc.

4.2. Observations of Reactions in the French Freight Market

Infrastructure charges in France were first implemented in 1997, at which time the French infrastructure manager, Réseau Ferré de France (RFF), had just been set up. The network was divided into track categories and the charging components were established as follows:

- DA - a fixed access right;
- DR - a path reservation fee;
- DC - a charge for train circulation; and
- Additional charges, such as for the use of electrical supply equipment and access to marshalling yards.

RFF was not then able to make a precise bill to SNCF, the only rail operator on the French network up to 2005, so the charging regime comprised a global package based on traffic, up to 2002. Hence, no freight or passenger trains had any marginal infrastructure charge to pay until 2002. Therefore, whereas the evolution of the total charges paid may be observed from 1997, the evolutions of unit price levels have to be made on the basis of 2002 or later years.

There have been several changes to charging structure and levels over the period. The level of charges was increased extensively in 1999, but this increase was chiefly focused on passenger traffic, with only a 2% increase in freight charges. Freight traffic decreased slightly (-1%) in 1999, then increased by 6% in 2000 before decreasing again in 2001 by some 9%.

From 2002 on, the structure of charges is stable and gives marginal charge levels' signals to the operator(s). Yearly arrêtés from the Ministry of Transport set the charging regime for one year and, generally, charge levels are known at least one year in advance. Given this level of pre-announcement, we assume that demand can adapt more or less to these evolutions with no important delay, allowing us to compare directly yearly traffic and tariffs. Additional charges such as those applying for the use of marshalling yards are not covered by these arrêtés.

The arrêté setting the 2002 charging regime defined the track categories, as set out in Table 7.

Table 7: RFF Track Categories.

Track category	Subclasses	Length	Designation
Urban and suburban lines	High level of traffic	287 km	A
	Medium level of traffic	985 km	B
Main interurban lines	High level of traffic	7,209 km	C
	High level of traffic and max. speed 220 km/h		C*
	Medium level of traffic	5,840 km	D
	Medium level of traffic and max. speed 220 km/h		D*
Other lines		12,738 km	E
High-speed lines	High level of traffic	718 km	N1
	Medium level of traffic	457 km	N2
	Mediterranean HSL, medium level of traffic		N2*
	Low level of traffic	321 km	N3
	Mediterranean HSL, low level of traffic		N3*
	East-European line	300	N4

Note: the length per track category actually changes slightly from year to year.

Key aspects of the charging regime introduced in 2002 are as follows:

- DA is zero for D and E track categories. It is 365.88 €/path-km used per month for A & B, and 3.05 € for C track category.
- DR is composed of a reservation fee (DRS) and a 0.6 coefficient (coefficient K) for freight trains (this means that freight trains get a 40% rebate on path reservation fee in return for lower quality paths – quality of passenger trains being consistently favoured). The levels of this charging component are set out in Table 8.

Table 8: DRS Tariffs for Conventional Track Categories in 2002 (€/Path-Km).

	A	B	C	D & E
Off-peak hours	1.52	0.61	0	0
Normal hours	4.88	1.22	0.8	0
Peak hours	14.3	2.44	0.8	0

DC is set lower for freight trains than for passenger trains (0.23 €/train-km vs. 0.79), whilst a fee for power transport (RCTE) is created. Like the use of electrical supply equipment (RCE) and the use of marshalling yards, etc., it is an optional service. Rail freight traffic remained stable.

In 2003 DA was increased slightly for track categories A and B, but a coefficient M was created for differentiating this access fee, for A, B and N track categories, varying with the number of reserved paths and the duration of the agreement for those paths, as set out in Table 9. Total DA paid decreased (86 M euros i.e. 4.7% of total charges vs. 95 M euros and 5.2% in 2002).

Table 9: M Coefficient for Access Fee DA.

Coefficient M	Number of booked paths in A, B, N			
Per category	1-10	11-100	101-1000	>1000
Purchase agreement < 5 years	0.03	0.225	1.5	1.5
Purchase agreement > 5 years	0.02	0.15	1	1

Furthermore, coefficient K was divided into 2 categories: K=1 for train paths > 300 km with an average speed > 70 km/h (meaning no rebate for these “rapid” trains, that correspond roughly to “high value” freight such as containerised traffic), and K=0.6 for all other freight trains. In addition, all DRS and DC tariffs increase by 2 %.

Freight traffic decreased by 6.4%, but it is understood that this was mainly due to a long strike during the spring. SNCF freight branch’s losses reached 450 M€. A 3-year restructuring plan, the Plan Fret 2006, is implemented. It aims at focussing on heavy-haul, profitable services, and defines a new strategy based on customer approach and a better quality of service. SNCF forecast that they would obtain financial balance in 2006 and expected the traffic to decrease under 35 billion tkm.

Then in 2004, DA’s structure was modified by an arrêté, in readiness for the imminent arrival of new rail operators. For each path, DA became the product of the length of each network section used and a fee per path km. This new structure applied from 2006 on. Also, DRS of less expensive categories increased slightly. Zero terms were suppressed except for E off-peak hour category, but their level was still low (D= 0.01 to 0.05 €/path-km and E= 0,005 €/path-km). On the contrary, the increase was important for C category: + 60 % in normal hours (0.13 €/path-km), and multiplied by 15 in peak hours – still, the level remains quite low (1.25 €/path-km). A and B remain quite stable. In addition, DC freight increases by 3 %.

Freight traffic remained more or less stable (increased by 1 % in tonnes but decreased 1% in tkm). The Plan Fret seemed to achieve its 2004 target results, but traffic doesn’t fall under 40 billion tkm. The marshalling yards/ freight courtyards system was revised. Quality of service and productivity indicators showed a little improvement despite the increase of energy costs and important reorganisations in the industry. Some shippers report that SNCF’s freight tariffs doubled, or even were multiplied fourfold without prior consultation. All these evolutions of SNCF’s services and prices have in 2005 an overwhelming impact compared to the marginal impact of infrastructure charge evolution.

In 2005, conventional track categories (A to E) are not much affected by 2005 DRS rises, except for C which DRS gets almost quadrupled (x 3,7) for off-peak hours and tripled for normal hours (0.38 €/path-km for both tariffs). DC freight increases slightly but remains about 1/3 of DC passenger.

Freight traffic decreased by 12%, but it is understood that this was largely due to Plan Fret’s rationalisation. After a long controversy, the European Commission approved the 800 M€ State aid for SNCF freight branch reorganization.

The modifications of DA structure’s that were introduced in 2006 means that it is not possible to define its change in level from previous years. Although DA’s share in total charges is very small (around 4%), this modification was necessary in order to allow the development of new entrants’ traffic in a non-discriminative way –the package term would obviously have favoured SNCF. DA for conventional track categories was 0.015 €/ path-km, except for D and E, which were zero. In addition, DRS increased by 4 % in

B off-peak hours (0.65 €/path-km). C off-peak and normal hour tariffs were aligned on this tariff (+70 %). Furthermore, DC freight increased by 15 %.

Freight traffic remained stable. However, Plan Fret's objectives, even after downward revision, were not achieved, and the freight branch ended the year with 260 M€ losses. Shippers pointed out a downfall in quality –especially punctuality on the second half of the year. CNC, the main rail-road container operator owned by SNCF, was restructured and focused its activity on maritime containers, abandoning most other market segments.

In 2007 DRS' main increase was concentrated on A off-peak hours (19 %) and C peak hours (20 %). In addition, DC Freight increased by 33 % (0.4 €/train-km). The freight branch launched a second reorganization plan in the August, focussing on single wagon traffic. This traffic is to be handled through 3 main "hubs" –Villeneuve-saint-Georges (Paris), Sibelin (Lyons), Woippy (Metz)- and 31 regional yards, 262 courtyards (mainly located in Centre and Poitou-Charentes regions) being closed to single wagon traffic. Since this new organization was to be implemented within only 3-months following the announcement, shippers were forced to use emergency alternatives and local governments were alarmed. Strangely enough, the announcement was made while the Government organised the great debates of "Grenelle de l'Environnement", that planned for non-road transport modes a +25% market share increase. Besides this, the strikes following the special working regimes reform in France, that highly concerned SNCF's workers, brought on an estimated 80 M€ loss to freight branch. Recently, since high deficits continued and quality objectives were only partially met, SNCF issued another restructuring plan, including 1 billion Euros investment and a reorganization of its freight activities.

Thus, there have been a number of modifications to infrastructure charges in France over the past decade, as well as some industrial upheaval arising out of reorganisation and new competition. Identifying clear and distinct impacts of these factors on the demand for rail freight would always be difficult, but the lack of data from the two main sources, SNCF and RFF, has been a major problem. Had it been possible to get the figures of quantities bought by rail operators for each type of tariff, we could have realistically sought to extract some kind of statistical link between tariffs and quantities bought. However, as it is, all that is possible is to draw some broad indications.

In drawing any conclusions, we should recall that low-value freight traffic cannot bear high prices and is not very sensitive to transit time; therefore it is more likely to use low quality paths and thus less expensive track categories, especially D and E. Still, two of the three main marshalling yards -Villeneuve-Saint-Georges (Paris) and Sibelin (Lyons) - are located on category A sections, so that a notable part of freight traffic cannot avoid running on the most expensive track category. Except for a few postal TGVs, freight trains cannot run on high-speed (N) lines, even though this issue is under study for future high speed lines. Freight trains are also more likely to use off-peak paths during the night.

As a whole, the increase of infrastructure charges for freight is important (see Table 10) but less apparent than for passenger traffic. RFF's global revenue for freight showed a 5 % increase from 1997 to 2004 with a 29% decrease in traffic (in tkm). The most important evolutions are those of track category C, coefficient K applied to reservation fee DRS, and circulation fee DC. The access fee DA decreased and remained stable at a low level since its new 2006 variable structure for all conventional (non-N) categories.

DRS increased mainly for track category C: A increased by 11% from 2002 to 2009, B increased by 28 % and C was multiplied by 15. D and E tracks began to pay a reservation fee in 2004. E tracks remained stable up to 2009 and D increased by 3%. DRS increased mainly in 2005, for C tracks only.

Peak hour tariff remained around 1.9 times the normal hours tariff from 2002 to 2009. But off-peak hour's coefficient increased from 0.27 to 0.42 during the same period, concerning more specifically freight trains. Indeed, the level of time differentiation has decreased during this period.

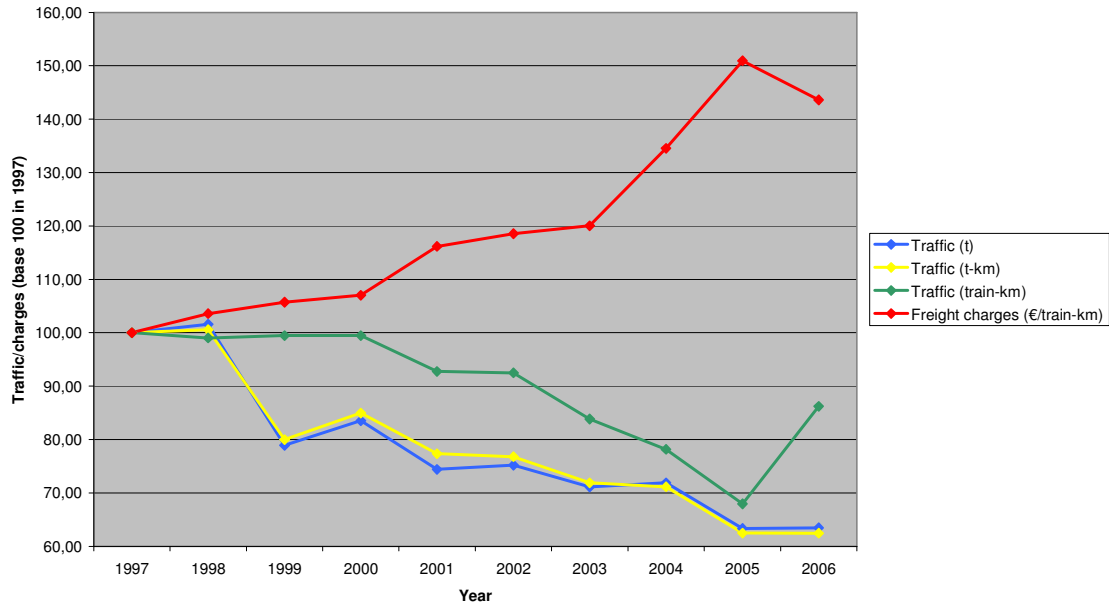


Figure 2: Freight Infrastructure Charges and Traffic Indicators from 1997 to 2006 (Base: 100).

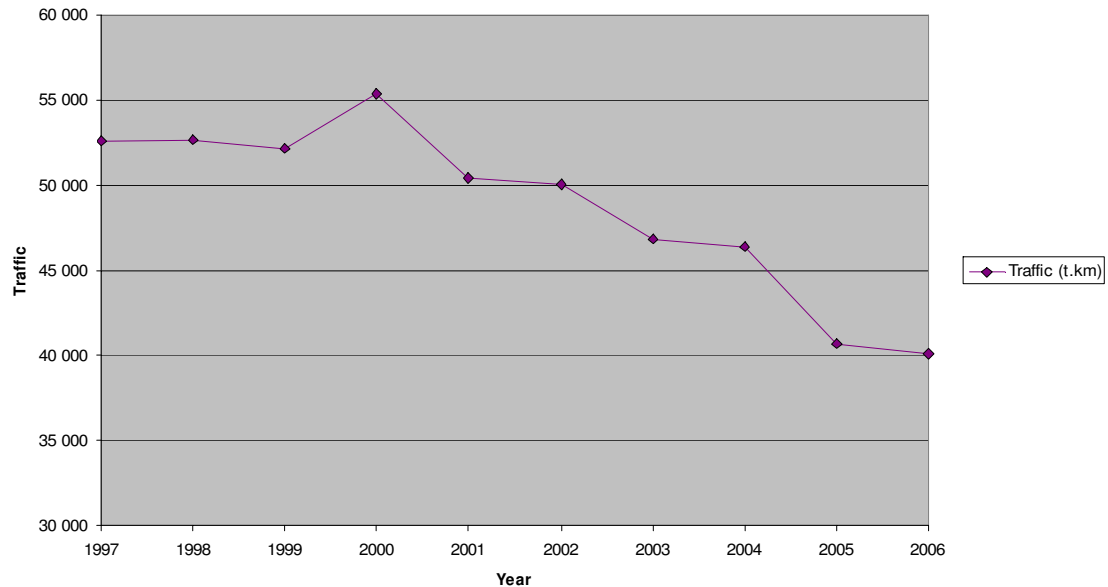


Figure 3: Freight Traffic (Mt-km) from 1997 to 2006.

Coefficient K has been modified in order to introduce a willingness to pay criterion, introducing a differentiation between “rapid” (high value) freight traffic and other

freight. DC for freight doubled between 2002 and 2009. While freight infrastructure charges went up as described, freight traffic went on a downward trend from the end of the 1990's (see Figure 2, Figure 3 and Table 10). These evolutions may seem, at first sight, to be closely related.

Table 10: Charges per Freight Train-Km from 1997 to 2005.

	Total Freight Charges (M€)	Freight Traffic (M train-km)	Charges per train-km (€)
1997	155	155,6	1,00
1998	159	154,1	1,03
1999	163	154,8	1,05
2000	165	154,7	1,07
2001	167	144,3	1,16
2002	170	143,9	1,18
2003	156	130,4	1,20
2004	163	121,6	1,34
2005	159	105,7	1,50

Nevertheless, the linkage between charges and traffic remains unclear and probably low; it would be certainly misleading to see tariff evolution as the main reason for freight traffic decreases; expert views and interviews of operators tend to think that the impact of tariffs is rather low. First, the main effect of tariff evolution, that occurred when reservation fees were effectively implemented, was the suppression of "facultative" paths that were unused, thus this effect does not appear in traffic figures. Second, even though it increased globally, the charge level still represents a low share in operators' costs, especially for SNCF (around 8%), whereas the evolution of traffic showed important shocks that seem to be much more related to the changes in SNCF's freight strategy. Indeed, reorganization plans, railway strikes, the liberalization of fret services and economic globalisation have extensively confused the price signal and impacted the traffic at a much higher degree than could do the relatively small signal of infrastructure charge.

However, set now at higher levels, and in a more stable environment, infrastructure charges may play a stronger role in the future. At least, the steady increases, observed also in 2009 tariffs, may have an impact on operator's purchase strategy –choice of day period, train speed, routes. Unfortunately, we couldn't have any access to wagon loading rates, or to the relative use of off-peak periods, or to the distribution of train speed.

RFF considers that freight operators have enough willingness to pay for long-haul, high-speed traffic, which is generally the most profitable. Nevertheless, French operators are doubtful about RFF's ability to improve the quality of its freight path offer. Discussions have been led on 2010-2015 infrastructure charges tariffs; this resulted in new increases, so as to obtain a better cost coverage ratio for RFF in exchange for improved infrastructure quality for freight trains. The problem is that a good deal of freight traffic could simply not pay for the tariff increase and would then disappear. Therefore, a public contribution will, for several years, compensate the operators for the tariff increase. This contribution will, however, decrease progressively and then disappear, since it is expected that operators' productivity gains, obtained both

by their own efforts and by the improvement of RFF's freight paths, will make it possible to progressively increase the tariff effectively paid by the operators.

As a conclusion, it has not been possible to show a precise impact of the increase and differentiation in RFF's freight tariffs. The lack of data from the two main sources, SNCF and RFF, was a major problem. Very important events on the operators' side and on the demand's side had a major effect, and data available was not precise enough to get effects sorted out. Nevertheless, it is highly plausible that RFF tariffs' evolution accompanied the other changes in the same direction, possibly accentuating the decreasing trends in traffic levels.

4.3. Freight through Eurotunnel

Eurotunnel provides an interesting case, as rail freight through the tunnel has performed somewhat disappointingly over a number of years and the charges faced by freight operators have consistently been cited as a potential cause of this poor performance. After 14 years of service, the channel tunnel is far from operating at the level of capacity requested by the reports giving support to the tunnel alternative for a cross-channel fixed link. Having originally had a design capacity of approximately 10 million tonnes, freight traffic grew during the first 3 years of operation to three million tonnes in 1997. However, it then stagnated until 2000, before declining to just over one million tonnes in 2007.

Table 11 and Table 12 draw similar pictures for tunnel freight forecasts: a total traffic of about 30 million tonnes around 1993 and a total market share of about 35% for the tunnel, corresponding to about 10 Mt, with better market shares for rail wagons than for Le Shuttle.

Table 11: Historical Forecast for Freight: Total Cross-Channel vs. Channel Tunnel (Million Tonnes).

<i>Freight forecasts</i>		<i>1969</i>	<i>1971</i>	<i>1980</i>	<i>1985</i>	<i>1990</i>	<i>2000</i>
MoT (1963)	Via tunnel	2,6	2,9	4,0	4,5	-	-
C & L (1973)	Total demand	-	5,7	13,1	-	25,3	-
	Via tunnel	-	-	5,4	-	11,3	-
CTAG (1975)	Total demand	-	5,7	12,9	-	20,2	-
	Via tunnel	-	-	5,3	-	7,8	-
DoT (1982)	Total demand	-	-	15,9	-	27,3	37,2
	Via tunnel	-	-	-	-	8,6	11,1

Source: Chevroulet et al, 2007; Anguera, 2006.

Table 12: CTG-FM Unitised Freight Forecasts –Total Demand & Market Share (Million Tonnes).

	<i>Cross-Channel</i>	<i>Tunnel freight</i>	<i>Market share</i>	<i>Tunnel freight</i>
	<i>1993</i>	<i>1993</i>	<i>1993</i>	<i>2003</i>
Roll-on/roll-off freight	24,2	6,0	25	7,5
Containers and rail wagon	7,9	4,0	52	6,8
Total	32,1	10,0	31	14,3

Source: Chevroulet et al, 2007 ; Anguera, 2006.

However, actual traffic was much different, as shown in Table 13 and Table 14. The total freight tonnage was underestimated by most of the forecasts, and the traffic of

through rail services remains very low compared to forecast and to freight shuttle. Freight shuttle service, in absolute terms, increased quite steadily ahead of what was forecast through to 2007. Nevertheless, forecasts for freight Shuttle's market share appeared to be not far from what occurred.

Table 13: Actual Channel Tunnel Freight Tonnes (Million Tonnes).

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Le Shuttle Freight	0,8	5,1	6,7	3,3	9,2	10,9	14,7	15,6	15,6	16,7
Through rail services	-	1,3	2,4	2,9	3,1	2,9	2,9	2,4	1,5	1,7
Total tunnel freight	0,8	6,4	9,1	6,2	12,3	13,8	17,7	18,8	17,1	18,4

Source: Chevroulet et al., 2007; Anguera, 2006.

Table 14: Actual Channel Tunnel Freight Tonnage (Million Tonnes).

	2004	2005	2006	2007
Le Shuttle Freight	16,6	17	16,9	18,4
Through rail services	1,9	1,6	1,6	1,2
Total tunnel freight	18,5	18,6	18,5	19,6

Table 15: Cross-Channel Unitised Freight 1994-2003 (Million Tonnes).

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Channel tunnel	0,8	6,4	9,1	6,2	12,3	13,8	17,7	18,8	17,1	18,4
Port of Dover	15,1	14,0	13,9	20,8	19,8	21,7	21,0	23,0	24,1	23,2
Total cross-channel	15,9	20,4	23,0	27,1	32,1	35,5	38,7	41,1	41,2	41,6

Source: Chevroulet et al., 2007; Anguera, 2006.

Eurotunnel's only forecast that proved to be more or less correct is the freight Shuttle's market share. This traffic obeys mainly to road logics, for which existing methods, data and tools were more appropriate for doing forecasts. A hypothesis we can make is that by the time forecasts were made, the methods and tools used were built using these road logics, inducing no anticipation of strong competitive reaction (a shipping line is very mobile, unlike roads; prices are not often a competitive tool in the road sector) and modelling the competitive situation as a network composed of minor (high cost) "road links" for the ferries, compared to a new (low cost) motorway for the Tunnel. Another hypothesis is that Eurotunnel had more incentive and tools to reach its forecasts of roll-on roll-off than of through trains. This last point leads us to the issue of infrastructure charges.

The situation of infrastructure charges for using Eurotunnel is a complex one, having involved 3 major components. Prior to the opening of the tunnel, a fifty-year agreement was formed between Eurotunnel and the two then state railways, British Rail and SNCF, that each be allocated half of the tunnel's capacity in return for the payment of infrastructure charges. In addition, the two railways agreed to pay a Minimum Usage Charge each year for using the tunnel, irrespective of how many trains actually used it. Thirdly, the two railways agreed to pay a fixed annual contribution to Eurotunnel's operating costs, amounting to approximately £6.5 m each.

The infrastructure charges were initially levied on a per tonne basis, based on a guide price of £10 per tonne and an overall volume of 10m tonnes. To that was added fixed

charges for Eurotunnel and for essential facilities at either end of the tunnel, each of which should have added another £1 per tonne. In reality though, those fixed charges were divided by the number of trains, and, since there were not many trains, this ended up resulting in very high charges. The per tonne charges were differentiated between bulk and non-bulk traffic, though – apparently somewhat counter-intuitively – the charge for non-bulk was three times that for bulk traffic.

On rail privatisation in Britain, freight operations through the tunnel were sold to EWS, but it was agreed that government retain the responsibility for paying the infrastructure charges, the Minimum Usage Charge and the operating cost contribution through until November 2006. As of 2006, the agreement was that the Minimum Usage Charge would cease and the payment of infrastructure charges and the operating cost contribution would transfer to EWS. Subsequently, EWS have agreed with the government that the operating cost contribution continue to be paid by the government, leaving EWS to pay the remaining infrastructure charges. On the French side, SNCF has, throughout the past 14 years, been responsible for all 3 charging components.

Following the cessation of the Minimum Usage charge and continued decline in rail freight traffic through the tunnel, discussion between the key stakeholders led to another set of revised charges being announced in autumn 2007. This set of charges, set out below, was issued as part of Eurotunnel's strategy for 'relaunching' Open Access cross-Channel rail freight. The charges are focused around a central average charge of 4.5k Euro (£3k) per train, irrespective of train-load. This central charge represents a significant reduction compared to the 2007 average charge of 8k Euro (£5,3k). Furthermore, the charges are differentiated according to speed and time of day. The central charge is based on a train passing through the tunnel at a speed of 120kph during a period of medium traffic density; lower charges are applicable for higher speeds and/or periods of lower traffic density, and vice-versa. Most intermodal/non-bulk traffic tends to travel at 120kph, whilst bulk traffic has tended to travel at slower speeds. At the same time, additional measures have been introduced to provide operators guarantees of equitable and efficient open access to the essential facilities at either end of the tunnel.

These new charges, and the relaunch strategy, appear to be having clear impacts on rail freight traffic. Firstly, EWS report that they have increased the speed of their bulk traffic so as to take advantage of the lower charge for this. This has been somewhat fortuitous, as the change occurred at a time when they happened to have the rolling stock available to enable this. Secondly, EWS have announced the commencement of two regular Channel Tunnel services. Thirdly, though on a more negative note, Freight Europe UK have announced withdrawal of services apparently in response to the new charges. Freight Europe UK have been providing a less than train-load service between continental Europe and the UK which was, whilst charges were on a per-tonne basis, viable. However, with the switch to per-train charges, their payments have increased as they have begun having to pay for empty or part-empty trains. It may be that this is a temporary problem, as they rationalise their service and arrive at a new level of service, although it may also be the case that such a rationalised level of service may no longer be sufficiently attractive to customers and that they find their service having to be rationalised further.

Table 16: Eurotunnel Infrastructure Charges, 2007-08.

Train @ 120 km/h	Reservation fee per train single (£)	Access fee per train single (£)	Equivalent price per train single (based on 52 train single/year) (£)
Off-peak period	270	2430	2700
Intermediate period	300	2700	3000
Peak period	330	2970	3300

Train @ 100 km/h	Reservation fee per train single (£)	Access fee per train single (£)	Equivalent price per train single (based on 52 train single/year) (£)
Off-peak period	300	2700	3000

Maintenance periods	Reservation fee per train single (£)	Access fee per train single (£)	Equivalent price per train single (based on 52 train single/year) (£)
All trains @ 100 km/h	300	2700	3000

Source: Eurotunnel's Network Statement - 2008 Working Timetable.

The main problem of the forecasts, as compared with the actual traffic, seems to rely on the nature of the market Eurotunnel could try to grasp. The reaction of ferries proved to be quite effective at cutting Eurotunnel from a good part of its expected market, among other means by concentrating and reinforcing offers for origin-destination trips remote from the Channel. The decline in competitiveness relative to road transport, as a result of the impact of the fixed costs of frontier infrastructure (including security constraints) proved to be further constraints on channel Tunnel rail freight growth.

Hence, the original charges were devised with no reference to the market, and the monopoly and state aid aspects of the market rendered them irrelevant as signals to the market. Since the removal of state aid, opening up of the market and establishment of the new charging regime, traffic appears, on the whole, to be responding positively, though it is too soon to say whether this is a sustained turn-around.

4.4. Modelling Reactions in the British Rail Freight Market

The effect of changes in rail access charge regimes on rail and road traffic in Britain have been modelled using the Leeds Freight Transport Model (LEFT) (Johnson et al, 2007)). The LEFT model is essentially an aggregate mode split model for road and rail freight traffic in Britain, capable of forecasting changes in traffic for different commodities and modes following changes in transport costs. LEFT was initially constructed in 2002 and has been further developed over subsequent years, the current version being LEFT3. The model has no geography and uses Binary Logit models calibrated to existing data to perform mode split. Market size is determined using elasticities of tkm with respect to Generalised Cost and applying them with the mode

split element stripped out. Disaggregation within LEFT3 is by the following dimensions:

1. The base data is split over 7 commodity groups consistent with the categories provided in the Department for Transport's Continuing Survey of Road Goods Transport (CSRGT) data, reported in Transport Statistics Great Britain (TSGB) (DfT, annual):
 - a. Food, Drink and Agricultural Products;
 - b. Coal, Coke and related items;
 - c. Petroleum and Petroleum Products;
 - d. Metals and Ores;
 - e. Aggregates and Construction;
 - f. Chemicals and Fertilisers;
 - g. Other, including manufactures, miscellaneous, containerised, and international.
2. The base data by commodity is split over 9 distance bands, again consistent with those used by the CSRGT data. These are, 1-25 km, 25-50 km, 50-100 km, 100-150 km, 150-200 km, 200-300 km, 300-400 km, 400-500 km and Over 500 km. We have taken the midpoint of the 500+ distance band to be 550 km.
3. The base total market is split for each commodity and distance band according to whether traffic is favourable for rail operations, referred to as train-friendly (TF), or train-unfriendly (TU). For Bulks, TF traffic is that traffic we deem suitable for trainload movement from origin to destination. For Non-bulks (Food etc, and Miscellaneous), TF traffic is that to which we have assigned the need for collection and delivery (at most) at one end.

There are therefore $2*7*9 = 126$ cells in LEFT3. Traffic can switch mode or distance band, disappear altogether or new traffic can be generated. Just two modes were modelled - road and rail. The data used was collected from a variety of sources. For road, the primary source has been the Continuing Survey of Road Goods Transport, as reported in TSGB. For rail we have used unpublished data from the Strategic Rail Authority (SRA) with gaps being filled by our own best estimates. Base data relates to the period 1998-2000. All monetary amounts are in 2000 prices. A base for 2010 was obtained by projecting current trends forward.

We were interested in looking at the responsiveness of rail traffic to different access regimes and pricing structures. Our aim was to see if, and to what extent, rail can replace some road traffic given the appropriate incentives. We determined the following six scenarios/policy tests to examine:

- Removing current track access charges- the idea here is to create the best possible scenario for rail freight and see how much growth there could be in these conditions, with the aim of mode shift from road to rail on environmental grounds.
- Halving current track access charges; again here the aim is to stimulate mode shift, whilst still recovering some track access revenues.

- Doubling current track access charges; here we see how rail traffic responds to a doubling of access charges across the board, with the aim of raising revenue from rail access charges.
- Quadrupling current track access charges; as above but a larger increase.
- Introduce a structure of fixed and variable track access charges; punishing short distance rail traffic. This is approximated using distance bands, with doubled access charges for the shortest distance band, tapering down to current charges at the longest distance. The justification for this scenario is to remove some short distance rail traffic, for which rail may be not as well suited and for which there are fewer environmental benefits of mode shift
- A fixed and variable access charge stimulating long distance traffic. This is approximated by using differential charges over distance bands, with double access charges for the shortest distance, tapering down to ½ current charges at the longest distance. The justification here would be to stimulate a switch to rail from road only from that traffic for which rail is most suitable, namely long distance traffic, which will have a good environmental benefit and which is approximately revenue neutral.

Table 17 and Table 18 report the results for the 6 different scenarios compared to the 2010 Do Nothing. It can be seen that, in *Scenario 1 (Zero Access Charges)* Rail tonnes increase by 8.17 million (5.69%) and tkm increase by 2.13 billion (9.24%). Nearly half of the overall increased rail traffic is accounted for by an increase of 0.99 billion tkm in Ores & Metals. There is also a significant increase of 0.57 billion tkm in Others. The largest increases in rail's share of tkm are found in Chemicals (by 31.75%), Ores & Metals (by 21.6%) and Others (12.08%). The smallest absolute increases are in rail's Food, Drink & Agriculture and Petroleum tkm traffic. The smallest increases are in rail's share of tkm of Food, Drink & Agriculture, Petroleum and Coal & Coke.

In *Scenario 2 (Halved Access Charges)* Rail tonnes increase by 3.95 million (2.75%) and tkm by 1.02 billion (4.43%). The magnitude of the effect of this scenario is approximately a half that of scenario 1, which is as expected. The increase of 0.48 billion tkm in Ores & Metals accounts for nearly half of the overall increased rail traffic. There is also a significant increase in Others and Construction traffic. The largest increases in rail's share of tkm are found in Chemicals (by 15.36%), Ores & Metals (by 10.60%) and Others (5.85%). The smallest absolute increases are in rails' Food, Drink & Agriculture, Petroleum, Coal & Coke and Chemicals tkm traffic. The smallest increases are in rail's tkm share of Food, Drink & Agriculture, Petroleum and Coal & Coke.

In *Scenario 3 (Doubled Access Charges)*, Rail tonnes decrease by 7.16 million (4.99%) and tkm by 1.75 billion (7.59%) overall. The drop of 0.83 billion tkm in Ores & Metals accounts for nearly half of the overall lost rail traffic. There is also a significant drop of 0.50 billion tkm in Others. The largest percentage reductions in rail shares of tkm are in Chemicals (by 27.54%), Ores & Metals (by 18.17%) and Others (by 10.59%). The smallest absolute falls are in rails' Food, Drink & Agriculture, Petroleum and Coal & Coke tkm. The smallest effects on rail's share of tkm are in Food, Drink & Agriculture, Petroleum and Coal & Coke.

In *Scenario 4 (Quadrupled Access Charges)*, Rail tonnes decrease by 17.97 million (12.51%) and tkm by 4.29 (18.62%) overall. The drop of 1.88 billion tkm in Ores & Metals accounts for over one third of the overall lost rail traffic. There is also a

significant drop of 1.33 billion tkm in Others and 0.38 billion tkm in Construction. The largest reductions in rail's share of tkm are in Chemicals (67.27%), Ores & Metals (41.12%) and Others (28.3%). The smallest absolute falls in rails' Food, Drink & Agriculture and Petroleum tkm traffic. The smallest effects on rail's share of tkm are in Food, Drink & Agriculture, Petroleum and Coal & Coke.

In *Scenario 5 (Higher Short Distance Access Charges)* rail tonnes decrease by 4.28 million (2.98%), and tkm by 0.82 billion (3.54%). Compared to scenario 3, tonnes fall by proportionally more than tkm highlighting that the reduction in rail traffic is more concentrated in the shorter distances than in scenario 3. In absolute terms, the drop of 0.43 billion tkm in Ores & Metals accounts for more than half of the overall lost rail traffic. There is also a significant drop of 0.18 billion tkm in Others. The largest decreases in rail shares of tkm are in Chemicals (by 12.85%), Ores & Metals (by 9.41%) and Others (by 3.88%). The smallest absolute decreases in Food, Drink & Agriculture, Petroleum, Coal & Coke and Chemicals tkm traffic. The smallest decreases in rail's share of tkm are in Food, Drink & Agriculture, Coal & coke and Petroleum.

In *Scenario 6 (Higher Short Distance and Lower Long Distance Access Charges)*, rail tonnes decrease by 2.65 million (1.85%) and tkm decrease by 0.27 billion (1.16%), highlighting that much of the reduction in traffic is over the short distances. Interestingly there is little increase in Food, Drink & Agriculture tkm (0.06%) but decreases in all other commodities – very little of rail's traffic in this commodity is in the shorter distances. The largest absolute falls are found in Ores & Metals and Construction. The largest decreases in rail share of tkm are in Chemicals (by 5.15%), Ores & Metals (by 4.02%) and Construction (by 1.04%). The smallest reductions in rail's market share of tkm are found in Coal & Coke, Others and Petroleum.

Overall, changes in rail freight traffic are driven primarily by the shifts in Ores & Metals traffic, (as this accounts for 19.8% of Rail's overall tkm traffic), and also Others (accounting for 20.4%). Although Coal & Coke accounts for 22.3% of rail's tkm traffic, there is little movement in tkm as its market share stays relatively static due to the level of captivity and the favourability of rail over longer distances. There are relatively significant changes in Construction, which accounts for 17.1% of rail's tkm traffic. Whilst there are large shifts in the market shares of Chemicals, these represent very small absolute changes in tkm.

In summary, by using LEFT, we were able to explore the potential impacts of variations in infrastructure charging in isolation from any other changes that might impact on the rail freight market. We found that by removing access charges, rail tonne kms increase by 9%, reducing road traffic by almost 2 billion tkm, just 1%. This highlights an underlying lack of competitiveness of rail in key freight markets such as Food Drink and Agriculture and Construction, because of high captivity to road transport, given the short distances involved and the lack of suitable rail infrastructure. We examined the sensitivity of the rail market to levels of access charges and found that rail is slightly less sensitive to access charge increases than it is to equivalent decreases. If we introduce different structures of access charging over distance bands, approximating a fixed and variable charging regime, we show how we can incentivise rail traffic over the longer distances where rail is more competitive and environmentally more beneficial.

Table 17: Tonnes Lifted by Commodity for Different Scenarios in 2010.

Scenario	Mode	Tonnes lifted [millions]							
		Food, Drink, Ag	Coal & Coke	Petroleum	Ores & Metals	Construction	Chemicals	Others	TOTALS
Do nothing	Road	525.86	23.30	85.49	75.89	676.09	69.18	708.69	2164.50
	Rail	11.32	42.12	10.84	33.82	27.72	1.64	16.17	143.63
Scenario 1 Zero access charges	Road	525.83	23.20	85.38	73.19	675.88	68.77	708.34	2160.60
	% change from do nothing	-0.01	-0.42	-0.12	-3.57	-0.03	-0.60	-0.05	-0.18
	Rail	11.48	42.22	10.95	38.31	28.76	2.12	17.96	151.80
	% change from do nothing	1.41	0.24	0.99	13.29	3.74	29.57	11.06	5.69
Scenario 2 Halved Access Charges	Road	525.84	23.25	85.44	74.56	675.98	68.99	708.52	2162.58
	% change from do nothing	0.00	-0.22	-0.06	-1.76	-0.02	-0.29	-0.02	-0.09
	Rail	11.39	42.17	10.89	36.04	28.17	1.87	17.05	147.58
	% change from do nothing	0.65	0.12	0.44	6.56	1.63	14.21	5.39	2.75
Scenario 3 Doubled Access Charges	Road	525.89	23.43	85.56	78.32	676.33	69.53	709.00	2168.05
	% change from do nothing	0.01	0.55	0.08	3.19	0.04	0.50	0.04	0.16
	Rail	11.18	41.99	10.77	29.70	27.02	1.23	14.57	136.46
	% change from do nothing	-1.19	-0.30	-0.61	-12.19	-2.52	-24.93	-9.94	-4.99
Scenario 4 Quadrupled Access Charges	Road	525.97	23.69	85.65	81.75	676.96	70.01	709.53	2173.57
	% change from do nothing	0.02	1.69	0.19	7.72	0.13	1.20	0.12	0.42
	Rail	10.89	41.73	10.70	23.88	25.99	0.66	11.82	125.66
	% change from do nothing	-3.82	-0.93	-1.32	-29.39	-6.22	-59.94	-26.91	-12.51
Scenario 5 Higher Short Distance Access Charges	Road	525.88	23.37	85.54	77.46	676.24	69.37	708.84	2166.70
	% change from do nothing	0.00	0.32	0.06	2.07	0.02	0.27	0.02	0.10
	Rail	11.23	42.05	10.79	31.16	27.26	1.42	15.44	139.35
	% change from do nothing	-0.79	-0.18	-0.41	-7.85	-1.66	-13.46	-4.54	-2.98
Scenario 6 Higher Short/Lower Long Distance Charges	Road	525.88	23.35	85.52	76.98	676.20	69.29	708.75	2165.96
	% change from do nothing	0.00	0.20	0.04	1.43	0.02	0.15	0.01	0.07
	Rail	11.26	42.07	10.81	32.00	27.40	1.52	15.91	140.97
	% change from do nothing	-0.51	-0.11	-0.30	-5.38	-1.14	-7.41	-1.61	-1.85

Table 18: Tonne-Kilometres by Commodity for Different Scenarios in 2010.

Scenario	Mode	Tonne kms [Billions]							
		Food, Drink, Ag	Coal & Coke	Petroleum	Ores & Metals	Construction	Chemicals	Others	TOTALS
Do nothing	Road	63.33	2.31	8.29	8.53	35.91	8.84	73.09	200.30
	Rail	2.17	5.13	2.13	4.57	3.94	0.40	4.69	23.04
Scenario 1 Zero access charges	Road	63.29	2.30	8.26	7.59	35.68	8.71	72.55	198.39
	% change from do nothing	-0.06	-0.62	-0.27	-11.05	-0.62	-1.43	-0.74	-0.95
	Rail	2.21	5.24	2.17	5.56	4.19	0.53	5.26	25.17
	% change from do nothing	1.96	2.10	2.03	21.60	6.46	31.75	12.08	9.24
Scenario 2 Halved Access Charges	Road	63.32	2.31	8.28	8.07	35.81	8.78	72.83	199.38
	% change from do nothing	-0.03	-0.32	-0.12	-5.43	-0.26	-0.69	-0.36	-0.46
	Rail	2.19	5.18	2.15	5.06	4.05	0.46	4.97	24.06
	% change from do nothing	0.82	1.02	0.95	10.60	2.75	15.36	5.85	4.43
Scenario 3 Doubled Access Charges	Road	63.36	2.33	8.30	9.33	36.02	8.95	73.56	201.85
	% change from do nothing	0.04	0.61	0.18	9.42	0.32	1.24	0.65	0.78
	Rail	2.15	5.04	2.10	3.74	3.78	0.29	4.20	21.29
	% change from do nothing	-1.20	-1.85	-1.61	-18.17	-3.92	-27.54	-10.59	-7.59
Scenario 4 Quadrupled Access Charges	Road	63.40	2.36	8.32	10.34	36.19	9.11	74.35	204.07
	% change from do nothing	0.11	2.09	0.38	21.26	0.78	3.02	1.73	1.88
	Rail	2.10	4.87	2.04	2.69	3.55	0.13	3.36	18.75
	% change from do nothing	-3.41	-5.12	-4.13	-41.12	-9.76	-67.27	-28.30	-18.62
Scenario 5 Higher Short Distance Access Charges	Road	63.34	2.32	8.30	8.94	35.97	8.89	73.26	201.03
	% change from do nothing	0.02	0.40	0.11	4.84	0.19	0.58	0.23	0.36
	Rail	2.16	5.09	2.11	4.14	3.85	0.35	4.51	22.22
	% change from do nothing	-0.50	-0.72	-0.89	-9.41	-2.17	-12.85	-3.88	-3.54
Scenario 6 Higher Short/ Lower Long Distance Charges	Road	63.33	2.32	8.29	8.70	35.94	8.86	73.09	200.54
	% change from do nothing	0.00	0.29	0.07	2.01	0.09	0.23	0.00	0.12
	Rail	2.17	5.12	2.12	4.39	3.90	0.38	4.69	22.77
	% change from do nothing	0.06	-0.12	-0.50	-4.02	-1.04	-5.15	-0.15	-1.16

5. Conclusions

Infrastructure charges were introduced in Britain in 1995 and, when reviewed in 2001, were effectively halved for freight operators. Over the period, growth in freight traffic has been quite remarkable, in the order of 50% over 12 years. Within this, growth has been particularly notable in coal traffic, which rail is inherently better-suited to carrying, and in construction traffic which appears particularly price-sensitive. However, rail freight growth actually started in 1995, and we do not observe a major change in the trend around the time of the reductions in infrastructure charges introduced in 2001. Nevertheless, the structure of charges appear to be incentivising operators to reduce impact of rail freight on the network, e.g. by operating less-damaging rolling stock and by requiring fewer slots to operate a particular service. Further changes are soon to be implemented, involving greater differentiation and increased charging levels for freight-only lines. It will be interesting to monitor any observable impacts of these forthcoming changes.

Infrastructure charges in France were first implemented in 1997 and there have been several changes to charging structure and levels over the period. A differentiation between “rapid” (high value) freight traffic and other freight was introduced. The circulation charge for freight doubled between 2002 and 2009. While freight infrastructure charges went up as described, freight traffic went on a downward trend from the end of the 1990’s. These evolutions may seem, at first sight, to be closely related but the linkage between charges and traffic remains unclear and probably low. First, a notable effect occurred when reservation fees were implemented and led to the suppression of “facultative” paths that were unused. Second, even though it increased globally, the charge level still represents a low share in operators’ costs, especially for SNCF (around 8%), whereas the evolution of traffic showed important shocks that seem to be much more related to the changes in SNCF’s freight strategy. Indeed, reorganization plans, railway strikes, the liberalization of freight services and economic globalisation have extensively confused the price signal and impacted the traffic at a much higher degree than the relatively small signal of infrastructure charge could. However, set now at higher levels, and in a more stable environment, infrastructure charges may play a stronger role in the future.

Eurotunnel provides an interesting case, as rail freight through the tunnel has performed somewhat disappointingly over a number of years and the charges faced by freight operators have consistently been cited as a potential cause of this poor performance. Having originally had a design capacity of c10 million tonnes, freight traffic grew during the first 3 years of operation to three million tonnes in 1997. However, it then stagnated until 2000, before declining to just over one million tonnes in 2007. The original charges were devised in the midst of rail re-structuring in both Britain and France, with no actual reference to the market. Furthermore, the monopoly and state aid aspects of the market rendered them irrelevant as signals to the market. Following the cessation of the Minimum Usage charge in 2006 and continued decline in rail freight traffic through the tunnel, discussion between the key stakeholders led to another set of revised charges being announced in autumn 2007.

Since the removal of state aid, opening up of the market and establishment of the new charging regime, traffic appears, on the whole, to be responding positively, though it is too soon to say whether this is a sustained turn-around.

The effect of changes in rail access charge regimes on rail and road traffic in Britain have been modelled using the LEeds Freight Transport Model (LEFT) (Johnson, Whiteing and Fowkes (2007)). Six scenarios/policy tests examined the effects of:

- Removing current track access charges;
- Halving current track access charges;
- Doubling current track access charges;
- Quadrupling current track access charges;
- Introduce a structure of fixed and variable track access charges; punishing short distance rail traffic;
- A fixed and variable access charge stimulating long distance traffic.

By using LEFT, we have been able to explore the potential impacts of variations in infrastructure charging in isolation from any other changes that might impact on the rail freight market. We have found that by removing access charges, rail tonne-kilometres increase by 9%, reducing road traffic by almost 2 billion tkm, just 1%. This highlights an underlying lack of competitiveness of rail in key freight markets such as Food Drink and Agriculture and Construction, because of high captivity to road transport, given the short distances involved and the lack of suitable rail infrastructure. We have examined the sensitivity of the rail market to levels of access charges and found that rail is slightly less sensitive to access charge increases than it is to equivalent decreases. If we introduce different structures of access charging over distance bands, approximating a fixed and variable charging regime, we have shown how we can incentivise rail traffic over the longer distances where rail is more competitive and environmentally more beneficial.

Data availability issues have placed constraints on the level of analytical detail that we have been able to achieve. For further systematic analysis in this area, one might, ordinarily, seek to employ some form of econometric or statistical modelling exercise. However, for this, one would require detailed cost and demand statistics at the train operator level, and this would appear not to be available to us. Nevertheless, the case study research has helped to identify key trends and issues, whilst we have also been able to pursue some interesting modelling ideas. It is clear that modelling can help in identifying the cases where the final impact of infrastructure charges is rather low, and therefore in giving indications about the degree of desirability of infrastructure charge differentiation, given some minimal data requirements on the market segments concerned.

Besides data requirements, the research field of imperfect competition in rail markets seems to be quite important if we want to explore these important issues further and have a better understanding of what the final indirect impacts of infrastructure charging are, once interactions between competitors and demand converge to an equilibrium. Simulation models, such as those developed by Meunier and Quinet (see “Effect of imperfect competition on infrastructure charges” in this issue) appear to provide a promising line of further research in this area.

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Effect of imperfect competition on infrastructure charges

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Abstract

The text explores the optimal infrastructure charges of an unbundled activity where the infrastructure manager sells the use of the infrastructure to operators providing services to a downstream market made up of atomistic customers. This situation has been widely analysed under the assumption that the upstream market is competitive, but more rarely in the case of imperfect competition. Typical examples are the railways activity in Europe and air transport. Various market structures are considered, illustrated by situations encountered in the transport field: a single mode operated by a single operator, two operators competing within the same mode, and two modes competing in a Bertrand way. In each case, situations are analysed using analytic formulae with a simplified demand function and a simplified cost function, and performing simulations with sensible parameter values drawn from current average situations. The main result is that the analysed imperfections make a dramatic departure from the conventional Marginal Cost pricing doctrine. Conclusions are drawn regarding infrastructure charging policy.

Keywords: Imperfect competition; Transport infrastructure; Rail; High speed train; Marginal cost; pricing; Differentiation; Pricing behaviour; Market power; Lerner index.

1. Introduction

The liberalisation of public services has created a great interest in Infrastructure Charges (IC), especially in Europe with the reforms leading to the unbundling of infrastructure management and operations. In this framework, the general doctrine commonly addressed (Proost and alii (2004), Quinet (2005)) is the Short Run Marginal Cost Pricing (SRMC), where the IC is equal to the Short Term Infrastructure Marginal Cost.

Inside this framework, a growing interest arose about differentiation of Infrastructure Charges. Among the many situations explored by the research program “Different”, a

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particular one deserves interest and is the subject of this text: the imperfect competition in transport markets.

Strangely enough, while a lot of attention has been paid to the situations of perfect competition, little consideration has been given to situations of imperfect competition. What happens in that case? How should optimal infrastructure charges deviate from SRMC? How should they vary according to the degree of competition? What are the consequences of alternative IC levels on welfare, on the revenues of the operators and on the consumers' surplus? This contribution explores these questions, using as an example the case of the railways, in which an infrastructure manager (IM) sells the use of the infrastructure to operators. These operators act in an imperfectly competitive market and provide services to atomistic customers. The IM sets the IC that all rail operators have to pay.

The effects and consequences of alternative Infrastructure Charges (IC) can be assessed either through theoretical considerations based on economic analysis or through tests of real situations. In the framework of imperfect competition, the first approach gets rapidly limited due to the complexity of mathematical derivations. As a consequence, only a few very general and well-known results can be derived through such a method.

The second approach, the numerical test of real situations, allows to use the power of computer calculation and to test more varied and complicated situations. But it needs some numerical assumptions so as to simulate the behaviours of the actors of the game.

The text is organized as follows: section 2 presents the basics of optimal IC in a framework of imperfect competition. Section 3 develops the modelling principles. Section 4 presents the data used. Section 5 presents the simulations and their results, and section 6 concludes.

2. Optimal IC under imperfect competition

Transport markets and especially rail markets are characterized by imperfect competition¹: for long distance passenger traffic, there is in general just one rail operator (RO), the competition is intermodal, with air transport, and it often happens on each relation that there is just one or a few air competitors. For medium and short distance passenger traffic, there are in general just one or very few competing rail operators, and the main competition comes from road transport; road transport is regarded as being operated under pure competition conditions between road hauliers, having no strategic behaviour, and in the case where one RO is competing only with road transport, everything looks as if the RO were a monopoly. On-track competition is more frequent in freight transport, but here again, the competitors are just a few on each single relation.

In such a situation, the classical doctrine of marginal social cost pricing does not apply. The rigorous formulae giving the charge should be derived from a general equilibrium model (GEM) taking into account the real features of the economy.

¹ The following results are drawn from Quinet 2007 ("Effect of market structure on optimal pricing and cost recovery") and Meunier 2007 ("Sharing investment costs and negotiating railway infrastructure charges"), both communications to the Second International Conference on Funding Transportation Infrastructure Leuven, Belgium, September 20-21, 2007

Unfortunately the formulae are not easy to handle (see for instance Mayeres I., Proost S. (2001)).

Another less rigorous but more tractable procedure can be used, in the framework of partial analysis, and some strictly localised departures from the first best situation are allowed. This procedure is the one used in the well-known Ramsey formula, where a budget constraint of the operator is modelled, or where the distortion of taxes is captured through a cost of public funds. And the result is that in this case, at the social optimum, the Lerner index (percentage of increase of price - here, the IC - compared to the short run marginal cost) is inversely proportional to the price-elasticity of the demand². But this result holds only in case of perfect competition in the downstream market. Our aim is to follow this way in order to explore the consequences on the optimal charge level in cases of imperfect competition between transport operators, where cost of public fund and, possibly, externalities, are introduced. The procedure is similar to the modelling framework exposed in Suter and alii (2004) on the Molino model; still, it is much less sophisticated and does not take into account the phases of investment funding. Using a simpler process, it allows putting more attention to the transport market and to its imperfections. Let us present the analytical results in two particular cases (the derivations of the formulae are given in Appendix 3).

The first case will be a profit maximizer monopoly. Let us derive the algebraic formula for the optimal IC, using the following symbols and assumptions:

- The demand function of the down-stream market is a linear one:
- $Q = f(p) = \alpha p + \beta$, $\alpha < 0$ and $\beta > 0$
- where Q is the traffic and p is the price paid by the users to the rail operator (RO)
- The operating cost of the RO is assumed to be constant and equal to: c' per unit of traffic
- The operating cost of the infrastructure manager (IM) is assumed to be constant per unit of traffic and equal to: b
- The IM sells the paths to the RO at a price: t per unit of traffic
- Then the cost per unit of traffic for the RO is constant and equal to: $c = c' + t$
- The RO generates an external cost of e per unit of traffic
- The Cost of Public Funds (or shadow variables of possible budget constraints) are $(\lambda - 1)$ for the IM and $(\lambda' - 1)$ for the RO

It is easy to show that the RO, aiming at maximising its profit: $Q(p - c' - t) = Q(p - c)$, chooses the price p such as:

$$p = (c / 2) - (\beta / 2\alpha) = \frac{\alpha c - \beta}{2\alpha}$$

i.e.:

$$p(t) = \frac{t}{2} + \frac{\alpha c' - \beta}{2\alpha}$$

² In presence of externalities, this opinion is wrong as shown in Quinet, Touzery et Triebel (1982) and in Oum and Tretheway (1988), and as it will be recalled later

The Welfare is:

$$W(p) = SU(p) + \lambda PR_{IM}(p) + \lambda' PR_{RO}(p) - eQ(p)$$

where PR_{IM} and PR_{RO} are the profits of the IM and the RO, SU being the final users' surplus.

The optimal IC is the value of t which maximises $W(p)$.

Noting that $\partial SU / \partial p = -Q$, and replacing the other terms by their expressions, it turns out that:

$$t - b = \frac{\frac{Q_b}{\alpha} (1 - 2\lambda + 2\lambda') + e}{(2\lambda - \lambda' - \frac{1}{2})}$$

where Q_b is the traffic obtained when the IC is equal to the marginal infrastructure cost.

Let us present also the case of a duopoly, representing competition between air and rail. The demand functions are:

$$Q_r = \alpha p_r + \gamma p_m + q_r \quad \text{for rail traffic}$$

$$Q_m = \beta p_r + \gamma p_m + q_m \quad \text{for air traffic}$$

$$\alpha < 0 \quad \beta < 0 \quad \gamma > 0$$

The profit of the RO is:

$$PR_r = Q_r (p_r - c_r) = -\alpha (p_r - c_r)^2 = -\frac{1}{\alpha} Q_r^2$$

with the similar relation for the competitor m . The welfare is:

$$W = SU_r + SU_m + \lambda PR_{IM} + \lambda' PR_r + \lambda'' PR_m - e_r Q_r - e_m Q_m$$

We assume for simplicity that both operators are purely private: $\lambda' = \lambda'' = 1$

and that rail externalities are negligible when compared to air externalities: $e_r \approx 0$.

Maximisation then leads to:

$$t - b = \frac{Q_r^r \left(\frac{\partial p_r}{\partial c_r} + \lambda - 2 \right) + Q_m^m \frac{\partial p_m}{\partial c_r} + e_m \frac{\alpha \beta \gamma}{\gamma^2 - 4\alpha\beta}}{\alpha \left[\left(\frac{\partial p_r}{\partial c_r} - 1 \right) \left(\frac{\partial p_r}{\partial c_r} + 2(\lambda - 1) \right) \right] + \beta \left(\frac{\partial p_m}{\partial c_r} \right)^2}$$

These developments confirm that the optimal IC under imperfect competition is quite different from the classical $SRMC$ pricing principle. But, even in the simple cases analysed using linear demand functions, the algebraic formulae are complex and not

easy to interpret. This point is an argument for using numerical simulations in order to explore the properties of the IC in situations of imperfect competition.

3. The modelling framework of the simulations

Simulations could be made on a large scale, for instance at the country level. The overall model would use as entries the cost and demand functions for each route of each operator, the ICs to be tested on each route, as well as the structure of the competition (if any) between the operators; the outputs would be the prices and the traffics for each mode and various other outputs such as the profits of the firms or the welfare.

In practice, the implementation of this model is hampered by the lack of data: we have no good knowledge of the cost functions of the operators at the level of each route; the type of competition between the operators is not known precisely. The lack of data prevents us from achieving econometric calculations and induces us to use more simple and crude methods, restricting the ambitions of the modelling framework.

The method implemented here can be entitled “sensible simulation”, and presents the following features:

- It involves a simple network: one or a few origin-destinations, one or two modes serving these relations
- The agents are: the final consumers, the transport operators (one or two rail operators, zero or one operator using another mode) and the infrastructure manager. The rail operator(s) pay an IC to the infrastructure manager. The IC has no fixed part tariff nor quantity rebates, it just uses a fixed unit price
- The demand functions are either linear or logit
- Cost functions are linear
- The parameters of the cost and demand functions are not calibrated on a specific real situation, they are set up in order to reproduce typical situations that are determined in relation to the common knowledge of the specialists of the field.
- Other parameters may be introduced such as cost of public funds or externalities
- Operators are supposed to adopt a continuum of possible behaviours between two extreme ones: the marginal cost pricing corresponding to the behaviour of an operator aiming at maximizing the welfare and, at the other end of the spectrum, the profit maximizing behaviour. The operator's utility function is assumed to be some kind of linear average between these extreme utility functions. Alternatively, this type of utility function can be interpreted as the result of more or less tight price regulation from the transport regulator.
- A variety of competition situations are represented, including:
 - For rail: monopoly, duopoly
 - For the competing mode: perfect competition, monopoly
 - For the type of duopoly competition: Bertrand competition
 - In case of oligopoly, the services provided by the operators are deemed to be imperfect substitutes.

It turns out (see Appendix 1) that these various competition situations can be represented using a single formula for each operator, that generalizes the Ramsey-Boiteux formula:

$$(p-c)/p = -s/\varepsilon$$

where p is the price of the operator, c is its marginal operating cost, ε is the own price-elasticity of the operator and s is a parameter representative of the behaviour of the operator or of the strength of the price regulation as seen above. Values of s are varying from 0 (case of perfect competition or own-market welfare maximisation behaviour, or extremely tight price regulation) to 1 (case of profit maximizing monopoly, Bertrand competition with profit maximizing operators, or no price regulation). Parameter s may be interpreted as a measure of the market power effectively exerted by the operator.

The simulation process is the following one:

- A set of sensible and reasonable estimates of some parameters is fixed, aiming at representing current typical situations: prices and traffic levels, costs of the operators and of the infrastructure manager, price-elasticities (a single elasticity in the case of a monopoly, 4 elasticities in the case of a duopoly).
- From this data set, the parameters of the demand function and the parameter s are deduced,
- After this calibration phase, the optimization phase aims at finding the IC that maximises the welfare, taking into consideration possible costs of public funds and external costs.

Appendix 2 details the corresponding calculations. They have been achieved through Mathematica and Excel softwares.

4. The data

The most difficult data to obtain are data on costs, since much of them are covered by secrecy. Prices are also difficult to gather due to the increasing use of yield management, that leads to high discrimination of the demand and to differentiation and multiplication of prices. The data base is shown in the following table:

Table 1: Main Data Set.

	<i>Link</i>	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>E</i>	<i>F</i>
Market structure		Monopoly	Monopoly	Monopoly	Duopoly	Duopoly	Duopoly
Operator's prices	p1	43	43	52	48	59	50
	p2				62	102	85
Operator's costs	c1	16	13	16	19	24	16
	c2				55	80	65
Elasticities	E11	-0,9	-1	-0,9	-1,5	-1,2	-1,5
	E22				-1,7	-1,5	-1,5
	E12				0,8	2,3	2,5
	E21				1,5	1,5	1,5

	<i>Link</i>	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>E</i>	<i>F</i>
Traffics	Q1	0,31	0,26	0,33	0,31	0,24	0,17
	Q2				0,39	0,45	0,51
Infrastructure charges used as references	RIC	12,60	12,60	5,80	16,15	20,56	10,28
Infrastructure Cost	b	2,06	2,06	2,13	3,44	5,52	5,21
Environmental Costs	e1	1	2,25	1,75	3,5	4,5	4
	e2	4,4	9,9	7,7	15,4	19,8	17,6

Situations A to C are “monopoly-like” situations of competition between high speed train and motorways for diverse travel distances, so as to represent more or less tough competition conditions and market shares for rail. Situations D to F are situations where high speed train is competing with air transport, again for diverse travel distances so as to represent a range of competition situations and a variety of relative competitive advantages for rail.

5. The simulations

The modelled cases are, according to the available data, the following ones:

- A rail operator monopoly on a single origin-destination (O-D) link
- A rail operator competing with an operator from another mode, both in situation of monopoly within their mode on a single O-D link
- A rail duopoly on a single O-D link, with two hypotheses for the infrastructure charges: either a single infrastructure charge, or a differentiated infrastructure charge (the two competitors do not have the same IC then).

Simulations provide several results. Some of them are confirmation of already well-known results. Other ones pertain to the sensitivity of the results to calibration parameters such as the shape of the demand function or costs and prices. A last series gives indications about how interesting it would be to introduce some differentiation.

In the following sub-sections, we selected some simulations so as to illustrate the specific points that came out from each simulation theme. The following tables will show only one or a few simulation situations taken from situations A to F, since the other ones would not give much more additional information, and so as to keep tables relatively simple and easy to read. We did not precise for each table the whole set of parameter values that were used, since they were too numerous, but the key parameters that change from table to table are highlighted.

5.1. Consequences of Marginal Cost pricing in some cases of imperfect competition

First, as clearly shown by the theoretical formulae given above, as long as there is no tax distortion, i.e. the CPF (Cost of Public Funds) parameter is 1, the optimal IC are

low, and may be lower than the marginal infrastructure costs, in case of monopoly at least. Optimal ICs are even in some cases negative³, which means that the rail service should be subsidized. This result is classical: in order to avoid the monopolistic distortion of prices vis-à-vis costs and to induce the monopoly to fix its price at the level of the marginal cost, it is necessary to decrease the prices of its inputs, and the single input on which the IM can act is the IC. This point is exemplified for instance in the case of monopoly, as shown by table 2:

Table 2: Comparison of optimal IC and marginal infrastructure cost in the case of a monopoly.

<i>Link</i>	<i>Costs of Public Funds</i>		<i>Optimal Infrastructure Charge</i>	<i>Marginal Infrastructure Cost</i>
	IM	RO	0IC	b
C	1	1	-34,2	2,1
	1,3	1	-5,7	2,1
	1,5	1	4,3	2,1
A	1	1	-18,9	2,1
	1,3	1	5,9	2,1
	1,3	1,3	-1,5	2,1

This table shows also that this result highly depends on the value of the CPF. The optimal IC level increases with the CPF of the IM. Additional simulations indicate that in the monopoly case under review (the s parameter being equal to 1 and without any externality), optimal IC is close to the marginal infrastructure cost for values of CPF around 1,4 for the IM and 1,0 for the operator; and that in a large number of cases tested, values of CPF in the range [1,5; 1,8] rise the optimal IC close to the (observed) reference level of IC.

The same results appear in the case of a duopoly (for example, a duopoly between rail and air transport for passengers), as shown in table 3. Here, the near coincidence between optimal IC and marginal cost is observed for slightly lower values of CPF than in the monopoly case; this result is in line with the expectation: when competition gets tougher, the optimal IC becomes higher than the marginal infrastructure cost.

Table 3: Comparison of optimal IC and marginal infrastructure cost in the case of a duopoly.

<i>Link</i>	<i>Costs of Public Funds</i>		<i>Optimal</i>	<i>Marginal</i>
	IM	RO	IC	infra cost
D	1	1	-22,1	3,4
	1,3	1	2,0	3,4
	1,3	1,3	-4,1	3,4

Taking into account the external costs increases the IC if the mode is less environment friendly than its competitor, and decreases it in the reverse situation which is usually the case for rail vis-à-vis air or road transport. Table 4 shows examples of these effects.

³ In the case of a profit maximiser monopoly, when CPF of the IM and of the operator are equal, optimal IC increase with these CPF and become equal to the marginal cost of infrastructure when CPF are infinite.

We see that, in the range of values considered in our simulations, external costs tend to have observable but lower impacts on prices and optimal charges, as compared to the impact of CPF (in this table, CPF of the IM is 1,5 while CPF of the Rail Operator is 1,0)

Table 4: Effects of external costs.

Link	External Costs		Rail Price	Optimal IC
	e1	e2		
B	0	0	32,9	0,4
B	2,25	9,9	30,9	-2,0
E	0	0	64,4	20,4
E	4,5	19,8	59,1	14,0

Another striking fact is the change in welfare induced by changes in the IC. It is clear from table 5 and figure 1 that the changes in welfare are small and that the effect of a sub-optimal IC bears mainly on the revenues of the IM and the operator's revenues and consumer surplus.

Table 5: Consequences of a sub-optimal IC (CPF of the IM=1,3; CPF of the RO=1,0).

Link	Comment	IC	Welfare	Revenues	
				IM	operator 1
D		16,1	45,1	5,6	5,9
D		9,0	46,3	2,9	7,6
D	In this simulation the IC is the marginal cost of infrastructure	3,4	46,5	0,1	8,9
D	In this simulation the IC is the optimal one	2,0	46,7	-0,9	9,7

So as to give an idea of the relative orders of magnitude obtained in our simulations, a loss of IM revenue through a reduction of IC level often benefits to the rail operator for one third and to the consumers for two thirds.

The relative share of the effect of external costs within the change in welfare depends highly, of course, on the unit level of externality gain or loss. This relative share depends also highly on the relative number of clients that rail takes from the competing mode within the total rail traffic increase obtained when the IC gets lower.

For sensible estimates of the unit level, this relative share of external costs' effects varies widely from a few per cent (the far more frequent case in our simulations) to the great majority of welfare gains. Figure 1 shows the relative orders of magnitude as taken from one of our simulations.

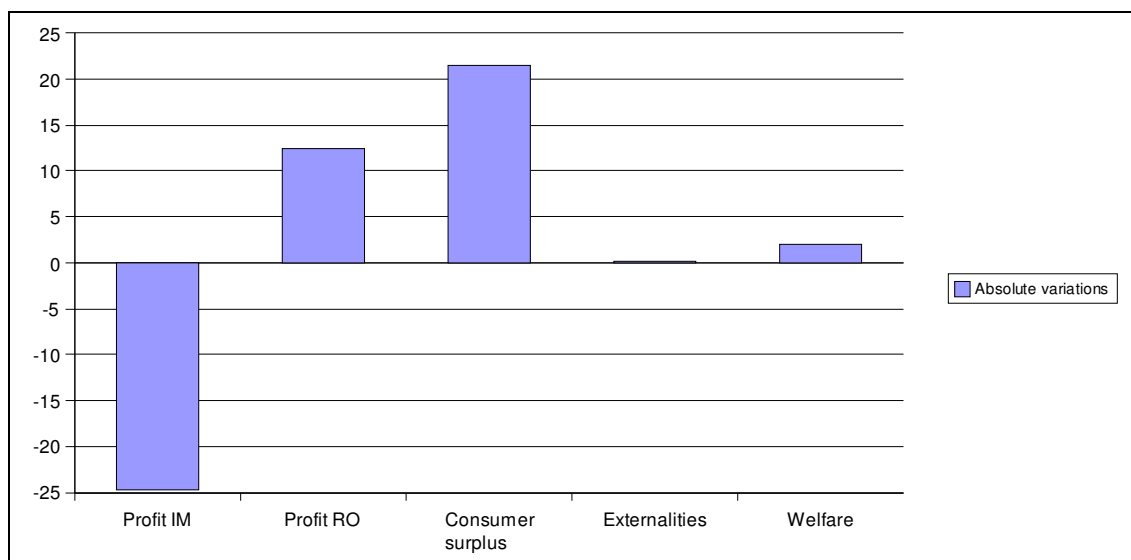


Figure 1: variations in profits of infrastructure manager, profits of rail operator, consumer surplus, externalities and welfare when the IC is set at its optimal level (link A, $CPF(IM)=1,3$ $CPF(RO)=1$).

As a conclusion of this first set of simulations, it appears that, depending on the circumstances (level of CPF, externalities, market structure), marginal social cost pricing can be either a good approximation or lead to non negligible welfare losses; in any case it leads to important changes in the distribution of welfare. Circumstances under which non negligible welfare losses may occur are variable; if we dare to give some hints from our simulations, this situation seems to be more likely to occur when $CPF(IM)$ is low and rail has a strong market power.

5.2. Effects of differentiation of the IC

Infrastructure Charges can be differentiated in many ways. Simulations have been designed to explore some of them. A first set of simulations relates to individual differentiation criteria: operator's marginal costs, elasticities and marginal infrastructure costs; then, the question of averaging the IC level over several links is treated: does it make sense, what is the loss in welfare, what are the impacts on the operators' profits? Finally, the case of competing rail operators is treated. We will now address these points.

5.2.1. How much should IC be different when operator's costs are different?

Table 6 below shows the impact of differences on the operators' marginal costs: the effect of an increase of operator's marginal cost is to decrease the optimal tariff. The decrease seems to be similar in situation of duopoly than in situation of monopoly, but it could well be lower in other cases than those simulated since, in a duopoly, the competitor exerts an effect which limits the market power of the operator. In any case it appears that the positive but rather low effect on welfare implies important effects because of the distributive effects between the agents: infrastructure manager, operators, and consumers. This point, illustrated further down for the issue of IC averaging (see figure 2), is a general conclusion of all the simulations.

Table 6: Effect of differences on operator's marginal cost.

	Market Structure	Operators' Costs	Prices		Optimal IC
			P1	P2	
C	Monopoly	16,2	50,3		4,3
		19,5	52,9		4,0
E	Duopoly	24,0	64,4	90,3	20,4
		28,8	67,9	90,8	19,9

5.2.2. How much should IC be different when demand elasticities are different?

The following table shows that the optimal tariff is rather sensitive to the demand characteristics.

Table 7: Effect of differences in elasticities in the case of monopoly.

	Elasticities	Prices	Optimal
	e11	p1	IC
B	-1,0	46,4	-9,2
B	-1,5	36,9	-5,9

Note: the values of p1 and of the Optimal IC differ from the values given in table 4 because in table 4 the s1 parameter is 0,4 while it is 1 in table 7.

In the case of a duopoly with logit demand function, assessing the effect of elasticity is a bit difficult technically as elasticities depend on the value of the parameter « h » of the demand function that represents the weight given to the price: the higher h , the higher the elasticities, everything else being equal. The test has been to increase h by 15%; the results are shown in the following table:

Table 8: Effect of differences in elasticities in the case of duopoly.

Link	h	$p1$	$p2$	Optimal IC
F	0,042	52,99	73,57	7,32
F	0,047	50,70	72,80	7,71

The optimal IC is sensitive to the elasticities: the higher the elasticities, the higher the IC. This point is understandable: when elasticities are high, the market power of the operators is lower and the IC can be increased without reducing too much the consumers' surplus.

From these results two conclusions can be drawn:

- First, it is important to have a good knowledge of elasticities, since the optimal tariff is highly varying with them. Unfortunately these elasticities are known with a large uncertainty, and efforts should be made to improve our knowledge in this field.
- Second, it may be wise to differentiate the infrastructure tariffs according to the characteristics of the demand.

5.2.3. Differentiation according to the infrastructure costs

Table 9 shows the effect of differences in infrastructure costs. It relates to situations where the same link bears several traffics, for instance freight traffic and passenger traffic, or passenger trains with different number of carriages or different types of carriages (for instance double and simple deck), which damages to the track are different. Wrong prices signals come from an abusive assimilation of different ICs, but the impact seems to be rather minor when compared with the impact of other elements such as cost of public funds or elasticity level.

Table 9: Effects of changes in infrastructure costs.

	Infrastructure Costs operator 1	s Parameters		Prices		Optimal IC	Traffic mode1	Traffic mode 2
		s1	s2	p1	p2			
A	2,06	0,29		40,25		10,18	0,18	0,29
A	1,03	0,29		39,11		9,03	0,19	0,29
D	3,44	0,42	0,18	42,44	61,18	9,14	0,30	0,30
D	1,72	0,42	0,18	41,13	61,14	7,59	0,31	0,30

It appears in our simulations that an increase in infrastructure costs leads to an increase in OIC of the same order of magnitude.

5.2.4. Averaging of IC between links

Table 10 shows that averaging the optimal ICs over two or three links does not induce a large loss in welfare if the differentiated ICs are not too far. But if they are far from each other, the loss may be important and the effect can be to exclude profitable services from the market. This point is a caveat for the temptation to use a unique IC over a too large set of links whenever the characteristics are different in terms of both costs and demand.

Table 10: Effect of IC averaging (in this table, the first group of rows relates to fully differentiated tariffs; the second group of rows relates to a uniform tariff per km; the additional welfare lines show simply the sum of welfare values for the 3 market cases).

	s1	s2	p1	p2	Optimal IC	Length of the link in km	Q1	Q2	Welfare
A	1,00	-	51,68	-	-10,11	200	0,14	-	27,82
E	1,00	1,00	87,41	128,80	13,45	900	0,36	0,35	-15,76
F	1,00	1,00	60,27	101,83	8,33	700	0,31	0,33	-6,83
									5,23
A	1,00	-	62,92	-	2,56	200	0,11	-	27,49
E	1,00	1,00	86,14	128,56	11,52	900	0,37	0,35	-15,78
F	1,00	1,00	60,71	101,90	8,96	700	0,31	0,34	-6,84
									4,88

Figure 2 shows that the positive (but often rather low) effect on welfare of diverse infrastructure pricing strategies may imply important effects because of the distributive effects between the agents: infrastructure manager, operators, and consumers.

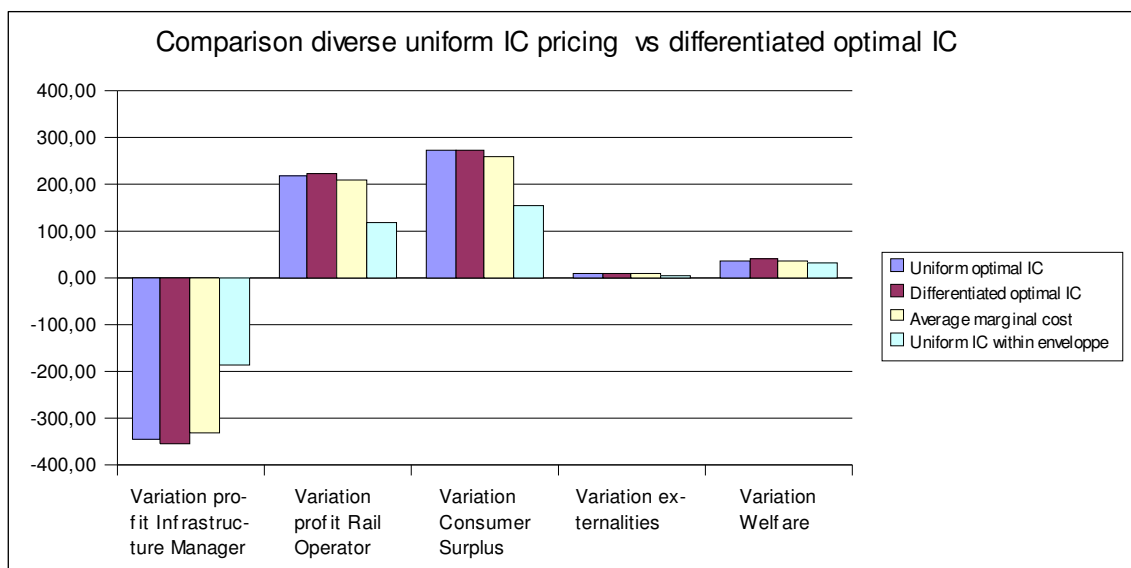


Figure 2: relative differences of diverse alternative IC pricing strategies as compared to actual (different) infrastructure charges on a set of 3 markets (A, B, C). Variation values are added over the 3 markets.

The 4 infrastructure pricing strategies presented in figure 2 are:

- uniform optimal IC: optimal IC level under the constraint that all markets A,B, C have to pay the same IC
- differentiated optimal IC: the uniformity constraint is suppressed, A, B and C pay different ICs
- average marginal cost: all markets A,B, C pay the same IC, equal to average marginal cost over the 3 markets
- uniform IC within envelope of reference ICs (RICs): this is the optimal IC within the interval $[\text{Min}(\text{RIC}(A), \text{RIC}(B), \text{RIC}(C)); \text{Max}(\text{RIC}(A), \text{RIC}(B), \text{RIC}(C))]$.

Simulations made for sub-markets that were all over-charged as compared to optimal levels, as well as for sub-markets that were all under-charged, showed the same results: low impact of differentiation on welfare, but possibly high impact on revenue distribution. Still, the impact of IC differentiation on welfare may become more important when the envelope of actual (reference) ICs does intersect the envelope of optimal ICs. This can be the case when demand or supply parameters are broadly dispersed; for instance, when both freight and passenger markets are considered.

5.2.5. Does it make sense to differentiate the IC of two competing rail operators?

The situation here is a duopoly on rail: both operators run rail services, and they are competing in a Bertrand mode. Their market shares and quality characteristics are different. Is it good to differentiate their tariffs? The evidence obtained from our data set is that, generally, differentiation between rail operators induces a very small extra welfare, as shown in the following table 11, where the last line displays the values

obtained with uniform optimal IC and the line before displays the results for differentiated optimal ICs :

Table 11: Effect of tariff differentiation in a situation of competing rail operators.

<i>CPF IM</i>	<i>CPF operator</i>	<i>s1</i>	<i>s2</i>	<i>p1</i>	<i>p2</i>	<i>Optimal IC operator 1</i>	<i>Optimal IC operator 2</i>	<i>Q1</i>	<i>Q2</i>	<i>W</i>
1,5	1,0	0,35	0,12	66,7	55,7	30,2	33,8	0,4	0,4	-10,8
1,5	1,0	0,35	0,12	68,2	54,2	32,1	32,1	0,4	0,4	-10,9

But in some cases when one of the operators does not bring much welfare (either because of its bad quality of service or of its cost inefficiency), a differentiated IC allows to exclude it from the market, while a uniform IC allows this inefficient operator to remain in the market, at the price of a loss of welfare. Still, even though being somewhat inefficient, an operator may play a strategic role for keeping an incentive for the main operator to behave reasonably.

5.3. Impacts of changes in the market structure and in the operators' behaviour

Imperfect competition is often changing. New entrants can appear then disappear, and the market structure then comes from monopoly to duopoly and vice-versa. Do these changes have an important effect on IC?

First, let us consider a possible misunderstanding of the market structure: while the true market structure is duopoly with air, the IM does not take this point into account and assumes that the market structure is a monopoly. It estimates the market structure (i.e. the parameter $s1$ and the demand function). In that case large mistakes result from ignoring the competition, as shown in the following table that explores the consequences of such mistakes.

Table 12: Effect of changes in market structure: monopoly versus duopoly.

	<i>Market Structure</i>	<i>s Parameters</i>		<i>Prices at optimal IC level</i>		<i>Comment</i>	<i>Welfare</i>
		<i>s1</i>	<i>s2</i>	<i>p1</i>	<i>IC</i>		
D	Monopoly	1,0		50	-0,3	Optimal IC	-11
D	Duopoly	0,4	0,2	45,5	12,8	Optimal IC	-3,7
D	Duopoly	0,4	0,2	34,6	-0,3	IC fixed at the level of Optimal IC if the market structure were monopoly	-5,0

Indeed, taking into account the regulating effect of the competitor increases optimal IC levels, therefore reducing the optimal charging policy's negative impact on IM revenues. It is interesting to assess the loss of welfare incurred by charging as if the market structure were a monopoly whereas, actually, it is a duopoly. In the case of table 12, this loss of welfare would be equal to 1,3, corresponding to a 5% increase in the marginal cost for rail.

Another example of the effect of a change in the market structure is expressed through changes in the value of the parameter s . As shown in the table 13, the behaviour of the rail's competitor (the value of $s2$) does not impact too much the optimal solution, while

large changes from the initial value s_1 lead to important differences between the calculated IC and the optimal one.

Table 13 Impact of the values of the behaviour parameters s_1 and s_2

Link	s Parameters		Prices		Optimal IC
	s_1	s_2	p_1	p_2	
C	0,52	1,00	50,3	97,7	4,3
	1,00	1,00	59,2	97,7	-12,6
	0,00	1,00	39,0	97,7	23,0
F	0,84	0,17	53,0	73,6	7,3
	0,84	1,00	69,6	354,7	10,3
	1,00	1,00	65,9	100,8	11,6
	0,00	1,00	50,5	97,7	34,3

In our simulations, we observed that the parameter s allowing for a competitor's pricing behaviour is frequently strictly less than unity, and takes values often very low, for instance between 0 and 0,5. The point is not surprising as far as the historical rail operator is concerned; it had clear welfare goals not so long ago, and may still be impregnated with such objectives. It is more surprising for the air competitors, as they are clearly in the private sphere, and their aims should be purely profits. This result could indicate that the behaviours of the operators are much inspired by welfare concerns or, more realistically, that strategic considerations (may they come from demand considerations or competition concerns) do lead them to exert less market power than what would be expected at first sight. The price regulation exerted by the State, although acknowledged as mild, may also contribute to lower this parameter. But this situation may change in the future, and not acknowledging these changes would lead to large mistakes.

6. Conclusions

This text explores the consequences of IC differentiation in a situation of imperfect competition, in the framework of a partial equilibrium model. In such situations of imperfect competition, the short run marginal social cost doctrine should be adapted. It appears that the optimal IC depends highly on the market structure and on the cost of public funds, and that in the simulations performed it rejoins the marginal cost only for costs of public funds of roughly 0,5 (λ values of 1,5), a rather high value compared to the current estimates.

Simulations of optimal tariffs have been made for various situations:

- market situations: monopoly, duopoly with another operator running a substitute service on another mode (air transport), duopoly with another rail operator.
- operator's behaviours: profit maximizing, welfare maximizing or intermediate behaviour
- various costs of public funds.

Various possible IC differentiation situations have been explored as well as the consequences of the reverse procedure: averaging over several services that differ only in one of these characteristics. The estimated impacts have been observed as regards optimal tariffs, prices of the operators, traffics and welfare.

From this simulation exercise, several conclusions can be drawn:

- Market structure has an important impact on the optimal IC; so the ICs of two services similar in everything except the market in which they are run should differ. Generally speaking, IC levels for monopoly should be lower than for a duopoly. In many cases marginal cost pricing leads to non negligible welfare losses, and in any case it provides very different welfare distribution than the optimal pricing
- The possibility for IC differentiation between two sub-markets can stem from differences in costs or demand or market structure (or a combination of these features) of these services
- In any case, IC differentiation brings small welfare changes when the two - or more- sub-market situations are close to each other; in such cases, the tiny improvement in welfare may lead to huge consequences on the distribution of welfare between the agents: the operators, the infrastructure manager and the consumers
- As far as costs are concerned, differentiation between two operators whose operating costs are different seems to bring minor welfare gains, which could possibly be more important when these operators are monopolies than when they bear competition with another mode. In the case of two links having different infrastructure costs - or two operators whose damages to the track are different- differentiation may have observable welfare consequences and is to be recommended, especially when the operator is a monopoly; in the case of a duopoly, the market power of the operator is limited by the operator of the other mode and differentiation, though desirable, may be less important
- In some cases, averaging the tariffs of several services may have important effects if these services have very different characteristics of costs and demand; in particular, it may happen that the average tariff excludes some profitable services, ending up in a large loss of welfare
- In case of a duopoly on track – meaning that two rail operators compete on the same track - welfare does not seem to be highly sensitive to an averaging of tariffs
- Last but not least, making non differentiated IC come closer to optimal IC levels could be much more worth than trying to differentiate finely around the initial IC levels, if those levels are far from the optimal ones.

Besides data requirements, the research field of imperfect competition in rail markets seems to be quite important if we want to explore more these important issues and to have a better understanding of what the final indirect impacts of infrastructure charging are, once interactions between competitors and demand converge to equilibrium. Trying to open and explore this “black box” of interactions is highly desirable, since the very basic usual representations such as perfect competition assumptions are clearly far from being fulfilled.

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Appendices

Appendix 1: Modelling operators' behaviour

The purpose of this annex is to show that various competition situations and behaviour of the operators can be expressed by a formula akin to the Ramsey formula:

$$\frac{p - c}{p} = -\frac{s}{\varepsilon}$$

Where:

p is the price of the operator

c is its marginal cost (assumed to be constant)

ε is the own price-elasticity of the operator

s is a parameter taking values between 0 and 1.

Profit maximiser monopoly

In that case, the previous formula holds with the value 1 for the parameter s ; it is the classical formula giving the price of a monopoly.

Price-taker monopoly (or perfect competition)

In that case, the operator sets its price equal to its marginal cost, and the parameter s is 0.

Public monopoly subject to budget constraint

Then the price is defined by the previous relation which boils down to the Ramsey formula, with $s = \frac{\lambda - 1}{\lambda}$ using our conventions for the CPF parameter. In that case, the parameter s depends on the tightness of the budget constraint: 0 if the budget constraint is not binding, 1 if the budget constraint is very high (so high that the operator has to behave like a monopoly to meet this constraint).

Mixed behaviour monopoly

Historical operators were very much like public firms aiming at welfare maximizing. Their behaviour is changing more or less quickly. It may happen that their behaviour is not yet profit maximising; another interpretation may be that the operator is subject to a more or less tight regulation. In that case, it is sensible to assume that their objective function is a combination of profit and welfare, this combination being characterized by a parameter s such that:

$$OF(p) = s * q * (p - c) + (1 - s) * [SU(p) + q * (p - c)]$$

Maximizing this objective function with respect to p leads to the same result as in the previous cases:

$$\frac{p - c}{p} = -\frac{s}{\epsilon}$$

Mixed behaviour, operators acting in a Bertrand duopoly market

If the two operators provide (partially) substitute goods, each of them maximizes its objective function with respect to its price, which leads to the following relations:

$$Max_{p_i} [OF_i(p_1, p_2)]$$

for $i=1,2$

where:

$$OF_i(p_1, p_2) = s_i * q_i * (p_i - c_i) + (1 - s_i) * [SU(p_1, p_2) + q_i * (p_i - c_i)]$$

This leads to the twin relations:

$$\frac{p_i - c_i}{p_i} = -\frac{s_i}{\epsilon_{ii}}$$

The numerical simulations used in the text are based on this type of Bertrand competition: the operators use the prices as an optimisation tool.

Appendix 2: Detail of the simulation process

The simulation process has two phases: first, calibration of the parameters of the model; second, optimisation of the IC of the IM. This process is presented in the case of a rail operator in competition with an air operator, the market structure being a Cournot duopoly; the extension to other market structures is straightforward.

First step: behaviour calibration

The first phase starts from sensible values of current observable variables. They are, in the chosen case:

The rail traffic: qm

The infrastructure cost: bi and charge: ti

The cost of the rail operator: cr (including the infrastructure charge pi) ; its price pr

The cost, price and traffic of the air operator: cm , pm , and qm

The four demand own and cross elasticities.

If the demand function is linear, the parameters to be estimated are the 5 parameters a , b , c , kr , km such that:

$$Qr = a * pr + c * pm + kr$$

$$Qm = c * pr + b * pm + km$$

The behaviour parameters of the operators: $s1$ and $s2$

$s1$ is for instance such that the rail operator's behaviour is to maximize:

$$s1 * qr * (pr - cr) + (1 - s1) * \left[\int pr dq - cr * qr \right]$$

The calibration phase aims at giving good estimates of the demand function's parameters and of the behavioural parameters (here: the seven parameters a , b , c , kr , km , $s1$, $s2$) that reproduce the four elasticities, the two prices, and the two traffics.

This is obtained by minimizing the sum of the squares of the relative differences between, on the one hand, a set of the calculated values that conform perfectly to the model used and, on the other hand, the observed values of each parameter.

The procedure is the following one: let X^*i be the data observed and collected, and Yj the demand function and behavioural parameters. To each set of value of Yj corresponds a set of calculated values of Xi : $Xi(Y1, Y2, ...Yj)$. The optimal set of Yj minimizes the sum:

$$\sum_i [(X^*i - Xi(Y1, Y2, ..Yj))^2 / X^*i^2]$$

Second step: Optimisation

Once the parameters of the demand function and of the operator's behaviour are estimated, they are used in a maximisation process which aims at maximizing the total welfare. We assume that the infrastructure charge has to be determined by the IM in order to maximize welfare, with possibly a cost of public funds (or a budget constraint).

The second step consists in finding the infrastructure charge that maximizes the welfare:

$$SU + \lambda * PR_{im} + \lambda' * PR_r + \lambda'' * PR_m - e_r * Q_r - e_m * Q_m$$

Where: SU is the consumer's surplus, λ , λ' and λ'' are costs of public funds (or dual variables of budget constraints), e_r and e_m are environmental costs.

Appendix 3: Derivation of optimal infrastructure charges for linear demand - monopoly and duopoly

We will present here the derivations that give the expressions for optimal infrastructure charges, in the simple case where the value for parameter s is 1 (pure profit maximisation).

1. Monopoly

The first case will be a profit maximizer monopoly. Let us derive the algebraic formula for the optimal IC, using the following symbols and assumptions:

- The demand function of the down-stream market is :
 $Q = f(p) = \alpha p + \beta$, $\alpha < 0$ and $\beta > 0$
 where Q is the traffic and p is the price paid by the users to the rail operator (RO)
- The operating cost of the RO is assumed to be constant and equal to : c'
- The operating cost of the infrastructure manager (IM) is assumed to be constant per unit of traffic and equal to: b
- The IM sells the paths to the RO at a price t per unit of traffic
- Then the cost per unit of traffic for the RO is constant and equal to: $c = c' + t$
- The RO generates an external cost of e per unit of traffic
- The Cost of Public Funds (or shadow variables of possible budget constraints) are $(\lambda - 1)$ for the IM and $(\lambda' - 1)$ for the RO

It is easy to show that the RO, aiming at maximising its profit: $Q(p - c' - t) = Q(p - c)$, chooses the price p such as:

$$p = (c / 2) - (\beta / 2\alpha) = \frac{\alpha c - \beta}{2\alpha}$$

ie

$$p(t) = \frac{t}{2} + \frac{\alpha c' - \beta}{2\alpha} \quad (\text{E0})$$

$$\frac{\partial p}{\partial t} = \frac{1}{2} ; \quad \frac{\partial Q}{\partial t} = \frac{\alpha}{2} \quad (\text{E1})$$

$$Q(t) = \frac{\alpha t}{2} + \frac{\alpha c' + \beta}{2} \quad (\text{E2})$$

$$Q(t) = -\alpha(p(t) - (c' + t)) \quad (\text{E3})$$

The welfare is:

$$W(p) = SU(p) + \lambda PR_{im}(p) + \lambda' PR_{ro}(p) - eQ(p)$$

where PR_{im} and PR_{ro} are the profits of the IM and the RO.
The optimal IC is the value of t which maximises W .

Noting that $\partial SU / \partial p = -Q$, using (E1) and replacing the other terms by their expressions, it turns out that since:

$$W(t) = SU(p(t)) + \lambda[(t-b)Q(t)] + \lambda'[(p - (c' + t))Q(t)] - eQ(t)$$

$$\frac{\partial W}{\partial t} = \frac{-Q}{2} + \lambda \left[(t-b) \frac{\alpha}{2} + Q \right] + \lambda' \left[(p - (c' + t)) \frac{\alpha}{2} + \left(\frac{1}{2} - 1 \right) Q \right] - e \frac{\alpha}{2}$$

and using (E3):

$$\frac{\partial W}{\partial t} = \frac{-Q}{2} + \lambda \left[(t-b) \frac{\alpha}{2} + Q \right] + \lambda' \left[\left(-\frac{Q}{\alpha} \right) \frac{\alpha}{2} - \frac{1}{2} Q \right] - e \frac{\alpha}{2}$$

$$\frac{\partial W}{\partial t} = Q \left[-\frac{1}{2} + \lambda - \lambda' \right] + \lambda \left[(t-b) \frac{\alpha}{2} \right] - e \frac{\alpha}{2}$$

But, if Q_b is the traffic in the case of an infrastructure charge equal to the marginal infrastructure cost, (E2) gives :

$$Q(t) = \frac{\alpha t}{2} + \frac{\alpha c' + \beta}{2\alpha} = \frac{\alpha(t-b)}{2} + \left(\frac{\alpha b}{2} + \frac{\alpha c' + \beta}{2\alpha} \right)$$

$$Q(t) = \frac{\alpha(t-b)}{2} + Q_b$$

Therefore :

$$\frac{\partial W}{\partial t} = \left[(t-b) \frac{\alpha}{2} \right] \left[\left(-\frac{1}{2} + \lambda - \lambda' \right) + \lambda \right] + Q_b \left(-\frac{1}{2} + \lambda - \lambda' \right) - e \frac{\alpha}{2}$$

$$\frac{\partial W}{\partial t} = \left[(t-b) \right] \left[\frac{\alpha}{2} \left(2\lambda - \lambda' - \frac{1}{2} \right) \right] + Q_b \left(-\frac{1}{2} + \lambda - \lambda' \right) - e \frac{\alpha}{2}$$

since $\alpha < 0$, W is concave in t as long as :

$$\left[2\lambda - \lambda' - \frac{1}{2} \right] > 0$$

and W gets its maximum for IC value t such as:

$$t-b = -\frac{Q_b(1-2\lambda+2\lambda') + e}{\alpha \left(2\lambda - \lambda' - \frac{1}{2} \right)}$$

2. Duopoly

Let us present also the case of a duopoly, representing competition between air and rail. The demand functions are:

$$Q_r = \alpha p_r + \eta_m + q_r \quad \text{for rail traffic}$$

$$Q_m = \eta_r + \beta p_m + q_m \quad \text{for air traffic}$$

$$\alpha < 0 \quad \beta < 0 \quad \gamma > 0$$

The profit of the RO is (through profit maximisation):

$$PR_r = Q_r(p_r - c_r) = -\alpha(p_r - c_r)^2 = -\frac{1}{\alpha} Q_r^2$$

with a similar relation for the competitor m , and the equivalent formulations:

$$Q_r = -\alpha(p_r - c_r) \quad \text{and} \quad Q_m = -\beta(p_m - c_m) \quad (\text{E4})$$

These expressions also give us:

$$\frac{\partial Q_r}{\partial c_r} = -\alpha \left(\frac{\partial p_r}{\partial c_r} - 1 \right) \quad \text{and} \quad \frac{\partial Q_m}{\partial c_r} = -\beta \frac{\partial p_m}{\partial c_r} \quad (\text{E5})$$

We assume for simplicity that both operators are purely private: $\lambda'=\lambda''=1$ and that rail externalities are negligible when compared to air externalities: $e_r \approx 0$.

Welfare maximisation then leads to:

$$0 = \frac{\partial W}{\partial c_r} = -Q_r \frac{\partial p_r}{\partial c_r} - Q_m \frac{\partial p_m}{\partial c_r} + \lambda \left[(t-b) \frac{\partial Q_r}{\partial c_r} + Q_r \right] + \left[(p_r - c_r) \frac{\partial Q_r}{\partial c_r} + \left(\frac{\partial p_r}{\partial c_r} - 1 \right) Q_r \right] + \left[(p_m - c_m) \frac{\partial Q_m}{\partial c_r} + \frac{\partial p_m}{\partial c_r} Q_m \right] - e_m \frac{\partial Q_m}{\partial c_r}$$

and, using (E4) and (E5) so as to simplify the two following expressions:

$$-Q_r \frac{\partial p_r}{\partial c_r} + \left[(p_r - c_r) \frac{\partial Q_r}{\partial c_r} \right] = \alpha (p_r - c_r) \left(\frac{\partial p_r}{\partial c_r} \right) + (p_r - c_r) \left(-\alpha \left(\frac{\partial p_r}{\partial c_r} - 1 \right) \right) = \alpha (p_r - c_r) = -Q_r$$

$$-Q_m \frac{\partial p_m}{\partial c_r} + \left[(p_m - c_m) \frac{\partial Q_m}{\partial c_r} \right] = \beta (p_m - c_m) \left(\frac{\partial p_m}{\partial c_r} \right) + (p_m - c_m) \left(-\beta \left(\frac{\partial p_m}{\partial c_r} \right) \right) = 0$$

Thus, we obtain for welfare maximisation:

$$0 = Q_r \left(\frac{\partial p_r}{\partial c_r} - 2 + \lambda \right) + Q_m \frac{\partial p_m}{\partial c_r} + \lambda \left[(t-b) \frac{\partial Q_r}{\partial c_r} \right] - e_m \frac{\partial Q_m}{\partial c_r}$$

Introducing the quantity values that would be obtained if the infrastructure charge was set equal to b (from now on, the subscript b will be used for the value of the variable that is obtained for $IC = b$):

$$Q_r = \frac{\partial Q_r}{\partial c_r} (t-b) + Q_r^b$$

$$Q_m = \frac{\partial Q_m}{\partial c_r} (t-b) + Q_m^b$$

where the partial derivatives are constant, in the linear model.

We then obtain:

$$Q_r^b \left(\frac{\partial p_r}{\partial c_r} - 2 + \lambda \right) + Q_m^b \frac{\partial p_m}{\partial c_r} - e_m \frac{\partial Q_m}{\partial c_r} = -\frac{\partial Q_r}{\partial c_r} (t-b) \left(\frac{\partial p_r}{\partial c_r} - 2 + \lambda \right) - \frac{\partial Q_m}{\partial c_r} (t-b) \frac{\partial p_m}{\partial c_r} - \lambda \left[(t-b) \frac{\partial Q_r}{\partial c_r} \right]$$

or:

$$t-b = -\frac{Q_r^b \left(\frac{\partial p_r}{\partial c_r} - 2 + \lambda \right) + Q_m^b \frac{\partial p_m}{\partial c_r} - e_m \frac{\partial Q_m}{\partial c_r}}{\frac{\partial Q_r}{\partial c_r} \left(\frac{\partial p_r}{\partial c_r} - 2 + 2\lambda \right) + \frac{\partial Q_m}{\partial c_r} \frac{\partial p_m}{\partial c_r}}$$

In the end, using again (E5):

$$t-b = \frac{Q_r^b \left(\frac{\partial p_r}{\partial c_r} + \lambda - 2 \right) + Q_m^b \frac{\partial p_m}{\partial c_r} + \beta e_m \frac{\partial p_m}{\partial c_r}}{\alpha \left[\left(\frac{\partial p_r}{\partial c_r} - 1 \right) \left(\frac{\partial p_r}{\partial c_r} + 2(\lambda - 1) \right) \right] + \beta \left(\frac{\partial p_m}{\partial c_r} \right)^2}$$

We can go further if we solve the two simple linear equations obtained by mixing (E5) with linear demand formulations, so as to obtain the exact expressions for prices, quantities, that are linear functions of c_r :

$$2\alpha \frac{\partial p_r}{\partial c_r} + \gamma \frac{\partial p_m}{\partial c_r} = \alpha c_r$$

$$\gamma \frac{\partial p_r}{\partial c_r} + 2\beta \frac{\partial p_m}{\partial c_r} = 0$$

Using the notation: $\Delta \equiv \gamma^2 - 4\alpha\beta$, the full set of prices and quantities obtained is the following:

$$p_r = p_r^b - \frac{2\alpha\beta(c_r - (c'+b))}{\Delta} \quad \text{and} \quad \frac{\partial p_r}{\partial c_r} = \frac{-2\alpha\beta}{\Delta}$$

$$p_m = p_m^b + \frac{\alpha\gamma(c_r - (c'+b))}{\Delta} \quad \text{and} \quad \frac{\partial p_m}{\partial c_r} = \frac{\alpha\gamma}{\Delta}$$

$$Q_r = Q_r^b - \alpha \frac{(2\alpha\beta - \gamma^2)(c_r - (c'+b))}{\Delta} \quad \text{and} \quad \frac{\partial Q_r}{\partial c_r} = -\alpha \frac{2\alpha\beta - \gamma^2}{\Delta}$$

$$Q_m = -\frac{\alpha\beta\gamma(c_r - (c'+b))}{\Delta} \quad \text{and} \quad \frac{\partial Q_m}{\partial c_r} = -\frac{\alpha\beta\gamma}{\Delta}$$

A fully explicit expression for optimal IC is then:

$$t-b = \frac{\Delta Q_r^b (2\alpha\beta(3-2\lambda) + (\lambda-2)\gamma^2) + Q_m^b \alpha\gamma + \alpha\beta\gamma e_m}{\alpha \left[2(\alpha\beta(3-4\lambda) + (\lambda-1)\gamma^2)(2\alpha\beta - \gamma^2) + \alpha\beta\gamma^2 \right]}$$

