THE ECONOMIC EFFECTS OF ROAD PRICING IN THE RANDSTAD AREA

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Key words: road pricing, road traffic congestion, applied input-output modelling
JEL codes: R41, R48, D57

Abstract
This paper gives an empirical analysis of the aggregate economic impacts of the planned introduction of road pricing in the Randstad area. A model is developed that allows distinguishing between the welfare effects on various types of traffic (freight, business and commuting) for different sectors. The welfare effects on sectoral profitability considered include the full travel time gains and tax payments for business and freight transport. For commuting, account is taken of the extent to which employees will be able to shift the welfare effects to their employers. An input-output model is used to determine the 'full' economic effects for the situations with and without 'tax recycling'.

Acknowledgement
This paper is based on research carried for the Dutch Ministry of Economic Affairs, and the Dutch Ministry of Transport. The views expressed in this paper, however, are solely the authors' own.

1. Introduction

Road traffic congestion is one of the most important and fastest growing problems facing urbanized areas throughout the western world. For decades, the most popular policy response to traffic congestion was the supply of additional road capacity. However, for various reasons – including environmental concerns, growing scarcity of space, or growing doubts on the long run effectiveness of such demand-following policies – policy makers have become increasingly interested in policies that aim at reducing the demand for road usage, at least at particular times and places, rather than simply accommodating this demand. This has induced a revived interest in the optimal solution to excessive road traffic congestion already proposed as early as 1920 (Pigou, 1920): road pricing. Small and Gomez-Ibañez (1998) provide an overview of the growing number of recent practical applications of (or experiments with) road pricing, and also the EU's recent green paper on "Fair and Efficient Pricing in Transport" (EC, 1996) makes a strong plea for the use of road pricing in congestion management.

It is well-known, however, that various social, political, practical and technical barriers may exist that could prevent, or at least slow down, the actual introduction of road pricing (Button and Verhoef, 1998). Especially from a social perspective, it can be observed that road pricing is probably among the least popular of instruments in congestion management, and democratically elected politicians may therefore often find it unattractive to give strong support to price measures. The basic problem of road pricing is that, although it will lead to a strict Pareto improvement, it will initially leave most and sometimes all road users worse off, whereas the regulating government is the main winner (this holds true particularly when users have an identical value of time, and before toll revenues are redistributed; Verhoef, Nijkamp and Rietveld, 1997).[1] It has been asserted that the redistributional effects of road pricing may thus 'dominate' the efficiency gains (Segal and Steinmeier, 1980; Andrew Evans, 1992). Various authors have consequently proposed schemes of spending the funds raised by road pricing in such a way that as many actors as possible eventually benefit, so that the opposition be minimized (Goodwin, 1989; Jones, 1991; Small, 1992). As will become clear below, the toll revenue redistribution may, apart from possibly increasing the social feasibility, also affect the eventual economic impact of road pricing.

At the moment of writing this paper, the expectation is that road pricing will be introduced in the Dutch 'Randstad area'. This is the dense, central area in The Netherlands, including the relatively close cities of Amsterdam, Den Haag (The Hague), Rotterdam and Utrecht. The Dutch Parliament has given its green light already in 1994; the introduction is foreseen no earlier than the year 2001. The details of the system have not yet been identified, but the general expectation is that a cordon scheme will be used, where all entrances by car into each of the four

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[1] A well established result from the literature, however, is that some road users may benefit from road pricing when heterogeneity of road users is allowed for. The typical case considered concerns income differences. Starting with Richardson (1974), most authors conclude that road pricing is likely to be regressive (Layard, 1977; Glazer, 1981; Niskanen, 1987; Arnott, De Palma and Lindsey, 1994)

cities on weekdays between 7 and 9 a.m. will be taxed at a rate of DFl 5,- (just over 2 ECU). For those drivers that do not wish to pay electronically, a somewhat higher rate of DFl 7,- would apply. What has not yet been made specific at all is the politically highly sensitive matter of 'how to use the money'. Earlier empirical research (Verhoef *et al.*, 1997) revealed that this is probably going to be one of the key factors for the indispensable public acceptance of road pricing. For the time being, it is even not yet clear at which level of government (municipal, regional, national), these toll revenues should initially be collected – let alone the question of what should happen with these revenues afterwards.

A potentially important element for the eventual acceptance of road pricing concerns the possible effect on the local, regional or national economies in terms of 'traditional' criteria such as economic productivity and employment. Although the 'primary incidence' of the welfare effects due to road pricing (in terms of toll payments, travel time gains, and valuation of alternative options chosen in case of behavioural responses) are of course important for the public acceptance, these eventual economic effects can be estimated only after the secondary effects – taking account of tax burden shifting, but also induced effects on final and intermediate demands – have been incorporated in the analysis. Such an analysis should actually be the primary input in a cost-benefit analysis of road pricing, and should govern an economically rational government's decision of whether and how to introduce road pricing. As already suggested above, economic research into the effects of road pricing is often directed to the aforementioned primary incidence, which follows from the researchers' concern with the distributional effects and the social acceptance. In this paper, we wish to change the focus somewhat, and try to assess the 'full' economic effects of road pricing. Because of this somewhat divergent focus, we therefore pay no explicit attention to the distributional effects according to 'standard' criteria, where different classes of individuals are usually distinguished (such as different income groups). However, we do present economic effects subdivided for 9 economic sectors. Furthermore, the analysis distinguishes 4 types of traffic (freight, business, commuters, and 'other'), and 4 cities. It will be clear that the implied differentiation in the model is therewith already too large to allow us to report all results on the most disaggregated level (one could distinguish as many as $4+4\times3\times9=112$ groups).

Figure 1 schematically illustrates the steps taken in the analysis. The initial inputs for the analysis are the toll level, the effect on mobility and the implied travel time gains. Next, the primary incidence of the tolls is defined in terms of taxes paid, the costs associated with induced changes in behaviour, and the economic value of the travel time gains for freight transport, business travellers and commuters. For a given sector, the primary incidence of freight and business is considered to be a full effect on profitability. Apart from that, commuting employees may to some extent succeed in shifting the net burden of road pricing to their employers, by demanding higher wages. The commuters' 'propensity to shift' is assumed to depend not only (positively) on the tolls paid, but also (negatively) on the travel time gains enjoyed, and the extent to which they receive recycled tax revenues. The commuters' remaining financial costs (i.e. tolls paid but not compensated) will affect the final demand in the economy. The same holds for 'other' road users. Therefore, recycled tax revenues will so to speak 'flow back' to the final demand. The total change in the final demand thus calculated, together with the implied cost changes for the 9 sectors considered, are fed into an input-output model, and the new economic equilibrium (taking account of forward and backward linkages in the economy) is then calculated.

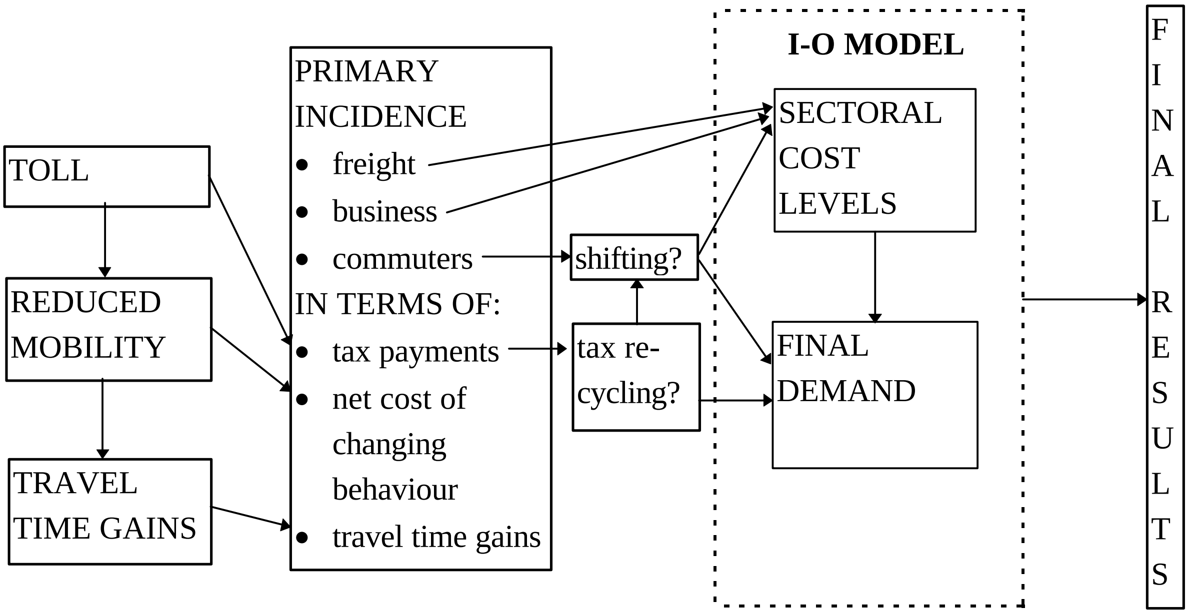

Figure 1. The main structure of the analysis

The plan of this paper is now as follows. Section 2 discusses the initial data, in particular the tolls and mobility effects considered. Section 3 presents the procedure used to estimate the costs of behavioural changes. Section 4 proceeds by considering the issues of 'tax recycling' and 'burden shifting'. Section 5 discusses the input-output model used, and presents the results obtained with it. Finally, Section 6 offers concluding remarks.

2. Initial data: tolls and mobility effects

Throughout this study, it is assumed that a passage toll of DFl 5,- is levied for each passage of a 'toll point' in the morning peak. This level applies to those who pay electronically; the others pay a higher price of DFl 7,-.[2] For the full study, two tolling variants were considered (Lijesen *et al.*, 1998); in this paper we mainly consider the so-called 'cordon variant', where all passages into each of the four cities are tolled. The other variant (ASW^+) did not produce significantly different outcomes, although the total effects were somewhat smaller due to a more limited coverage of the road network.

As will become clear in Section 3, the mobility effects generated by such tolls form an important building block for the further analysis. Therefore, we pay some attention here to the

[2] Strictly speaking, the choice of whether to pay electronically ought to be endogenized. For this study, the rather arbitrary 'guesstimate' was used that 80% of all road users be 'equipped' and pay the lower toll (based on Tweede Kamer der Saten-Generaal, 1998).

mobility effects considered. These effects were estimated using the LMS-model, which is a rather detailed, and probably the best-known transport network model for The Netherlands. Table 1 shows the numbers of 'passages' (vehicles entering the city by passing the cordon) during the peak, for the four trip purposes and the four cities, before and after the introduction of road pricing according to the cordon-variant, as generated by this model.

	Amsterdam		Den Haag		Rotterdam		Utrecht		Total	
	no toll	toll	no toll	toll	no toll	toll	no toll	toll	no toll	toll
business	18 473	25 511	12 776	14 655	14 916	18 615	17 521	22 024	63 687	80 806
freight	10 964	10 887	8 273	6 387	13 822	13 600	13 868	13 411	46 927	44 286
commuters	81 089	48 410	43 485	17 568	54 519	32 548	45 393	22 924	224 487	121 450
other	10 993	3 650	7 267	2 049	9 464	4 401	10 559	3 759	38 282	13 859
total	121 519	88 458	71 802	40 659	92 721	69 165	87 342	62 118	373 383	260 399

Source: HCG

Table 1. Numbers of passages with and without road pricing (cordon variant)

In order to get an idea of the relative size and the plausibility of the effects, Figure 2 shows the implied 'mobility ratios' (usage with road pricing divided by initial usage without road pricing), subdivided for the four cities and for the four types of traffic considered.

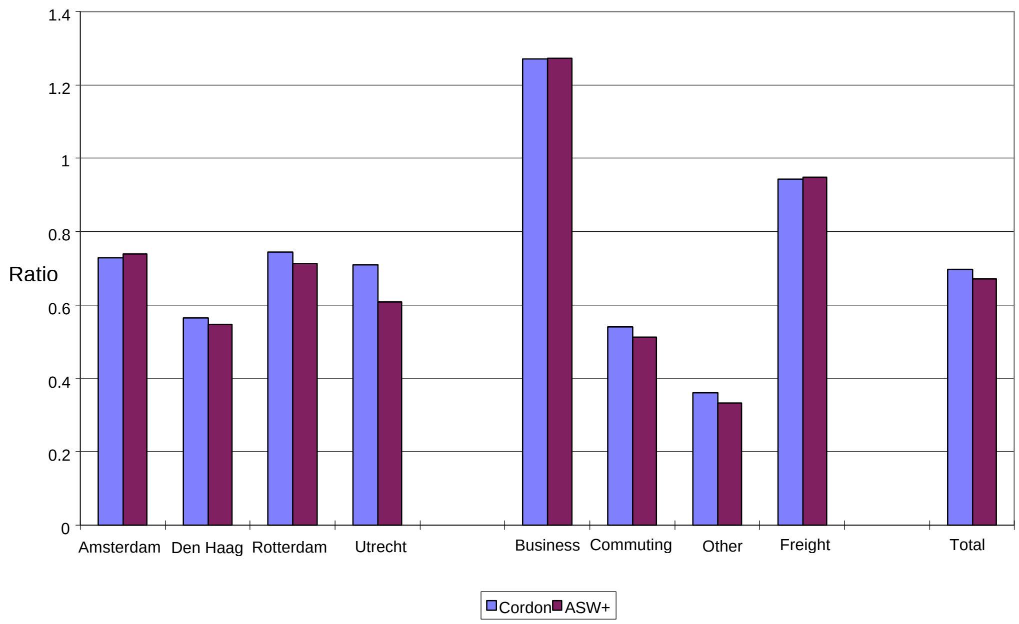

Figure 2. Mobility ratios by location and trip purpose

First of all, the mobility effects seem reasonably evenly distributed among the four cities (although Den Haag, probably because of the combination of its rather central location – increasing the probability of 'double passages' – and the relatively low initial congestion levels, stands out), and do not vary too strongly according to the tolling scheme chosen. A far more pronounced differentiation is found for the sub-division by trip purpose. The total reduction in passages of 32% is almost fully accomplished by reductions in commuting and 'other' traffic. In particular, note that business traffic will even increase during the morning peak due to road pricing. Apparently, the travel times saved outweigh the total toll payments for these users. This seems plausible: with an average value of travel time of DFl 51,50 per hour (HCG, 1990b), a time gain of 6 minutes would already leave the average business traveller indifferent. It is from that perspective surprising that freight transport, where the value of travel time gains per vehicle is even higher – namely DFl 67,- per hour (HCG, 1992) – should have so much lower ratios. A ratio of 1 could still be explained by a zero cross-elasticity for travelling inside and outside the peak (which may well be the case for freight transport, for instance due to JIT-logistics). However, the ratios smaller than 1, in conjunction with ratios exceeding 1 for business trips, could only occur if freight trips were significantly shorter than business trips. We have no reason to believe that this is the case.[3] It was concluded for that reason that the figures for freight transport are probably inconsistent. Hence, for the further analysis, the mobility ratios for freight were increased to a conservative level of 1. This is the lowest level that could be consistent with decreased generalized costs for freight transport after the introduction of road pricing.

For commuting, with 60% of the total passages before road pricing the most important group, the mobility ratio shown in Figure 2 is remarkably close to what was found in an earlier stated preference study for the same area (Verhoef *et al.*, 1997). Also there, a 'passage toll' (a fixed toll per trip) of DFl 5,- would lead to a reduction in usage by commuters with some 45%. Finally, observing that the mobility effects predicted in Figure 2 are in the same order of magnitude as the 44% reduction in total passages that was realized when Singapore introduced road pricing (also a toll of around DFl 5,-) in the morning peak in 1975 (see Small and Gomez-Ibañez, 1998), and because further evidence is from cases even less comparable to the foreseen scheme for the Randstad area (and, despite that, not even at odds with the results reported there), we conclude that, apart from the slight modification in the figures for freight transport mentioned above, the LMS figures seem sufficiently reliable to use them in the further analysis.

3. The primary incidence of road pricing

For the determination of the primary incidence of road pricing, it is supposed that this incidence is made up by the following three welfare effects:

1. Taxes paid by those who do not change their behaviour due to road pricing
2. Travel time gains enjoyed by those who do not change their behaviour due to road pricing

3a. Costs incurred from the selection of a less-preferred alternative by those who leave the road during the peak due to road pricing

3b. Benefits enjoyed from the selection of a more-preferred alternative by those who start using the road during the peak due to road pricing

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[3] Moreover, as a considerable share of time losses occur with bottleneck queuing near the cities (in reality as well as in the LMS-model), time losses are most probably less than proportional with trip length.

The first element can be calculated as the product of the number of users not changing their behaviour *times* the toll levels (see the previous section). For the second element, what is needed are travel times after introduction of road pricing (these were obtained from the LMS model), and a valuation of travel time gains. The latter were obtained from HCG (1990ab, 1992), which are generally accepted as ‘the’ value of time estimates for the Netherlands, and which are also used in the LMS model.

The third element, 3a or 3b, requires some further thought than a straightforward multiplication of variables. Evidently, there are many alternatives that someone may choose from when she’s being priced off the road due to road pricing. Alternatively, there are many alternatives she may have chosen before road pricing was introduced, and that should be valued when she returns to the peak due to road pricing. The question is of course how one could place a reliable monetary value on each of these alternatives. Instead of trying to make explicit estimates of the monetary value placed upon the behavioural changes due to road pricing, we take a different route, which basically rests on the assumption that, both with and without road pricing, individual actors make rational decisions that maximize their utility given the circumstances. In that case, one can be sure that those who are ‘priced off the road’ due to road pricing will suffer a loss in net benefit that should not exceed the rise in generalized costs they would incur if they would remain using the road. Otherwise, they would of course remain using the road during the peak, and would not be priced off the road. Likewise, those who return to the peak due to road pricing – in particular business travellers; compare Figure 2 – cannot enjoy a gain in net benefits that exceed the fall in generalized costs for the option of using the road during the peak. Otherwise, their initial choice of not using the road during the peak could not have been optimal.

Figure 3 shows the practical implications of this assumption. Two groups are considered: commuters (denoted with subscript c) and business travellers (subscript b). As in our data shown in Figure 2, we consider the case where the first group reduces in size (N) while the second group increases after a toll f is imposed (superscript 0 shows the situation without, and * with road pricing). As the toll has the same value for both groups, this can only be consistent with downward sloping demand curves (D) if for the commuters, the monetary value of travel time gains (mvt_c) does not outweigh the toll so that the generalized costs c_c increase, whereas mvt_b does outweigh f for the business travellers, so that the generalized costs c_b decrease. Under the assumption of homogeneous speeds, and if trips were equally long, this would require a higher value of time for business travellers than for commuters.

The primary incidence of road pricing can then be determined as the surface of the two shaded areas. The N_c^* commuters who remain on the road face a welfare loss per driver equal to the change in the generalized costs, while those who are priced off the road face on average smaller losses, ranging from that same level to zero for the initial marginal driver at N_c^0. The N_b^0 business travellers enjoy a benefit equal to the decrease of the generalized costs, while those who ‘return to the peak’ enjoy on average smaller benefits, ranging from that same level to zero for the new marginal driver at N_b^*. For both groups, under the assumption that the demand function can be approximated linearly, the total welfare effect can the be written out as the ‘rule of half’: the average usage (with and without road pricing) *times* the change in generalized costs.

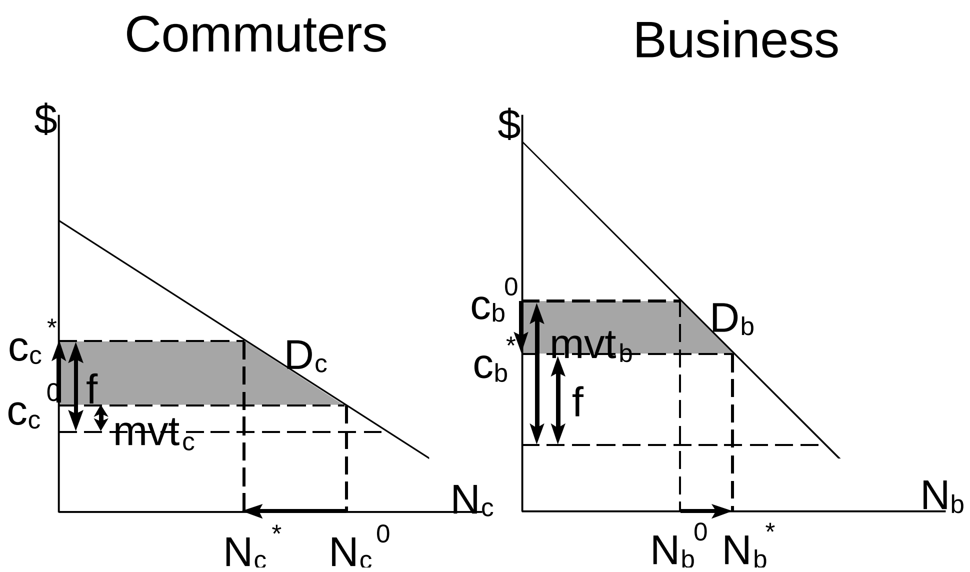

Figure 3. The ‘rule of half’ for the determination of the primary incidence of road pricing

This rule was used to determine the ‘primary incidence’ of road pricing, before tax recycling and burden shifting. For that purpose, the total traffic levels for each city were first distributed among the 9 sectors according to the following keys (the details of the exact procedures can be found in Lijesen *et al.*, 1998):

- business travel: the sectoral share in total business travel for the Netherlands (KPMG-BEA, 1997), which had to be refined due to a higher aggregation level in the present study. This refinement was done using weights reflecting the sector’s regional total value added (CBS, 1995a)
- commuters: sectoral labour volumes in each of the 4 municipalities (CBS, 1994, 1995ab)
- freight: at this stage no distribution was necessary, since all freight was assigned to a separate single sector in the input-output analysis

The ‘other travellers’, of course, were not assigned to any of the sectors. They only enter the analysis to follow through the tax revenues they generate, and by their contribution to the final demand. Furthermore, note that the distribution of commuters over sectors becomes relevant only when ‘burden shifting’ is considered, as will be done in the next section. This means that in Table 2 below, where we list the results obtained for the primary incidence at the level of sectors and trip purposes, one cannot meaningfully sum figures over the three columns, because that would be allowed only in case of ‘full shifting’.

The final input that was necessary to calculate the figures in Table 2 was the ‘value of time’ for the different trip purposes. The following values were used: business DFl 51,50 per vehicle-hour; freight DFl 67,- per vehicle-hour; and commuting DFl 18,- per vehicle hour.

These values, based on various HCG-studies (HCG 1990ab, 1992) are consistent with those used in the LMS model itself. Since the valuation of travel time gains for ‘other trips’ is irrelevant for the further analysis, these gains are left as a p.m. in Table 2.

Sector	Business traffic	Freight traffic	Commuters
Agriculture	+0.1 (-0.9)		-0.5 (-0.3)
Industry	+0.8 (-6.1)		-17.3 (-12.5)
Building	+1.1 (-8.4)		-8.7 (-6.2)
Trade	+2.2 (-17.3)		-25.6 (-18.1)
Horeca	+0.6 (-4.7)		-7.1 (-5.0)
Transport	+1.2 (-9.9)	+37.7 (-54.5)	-20.9 (-14.8)
Business services	+2.1 (-16.8)		-19.0 (-13.5)
Other services	+1.4 (-11.4)		-32.9 (-23.1)
Government	+2.4 (-18.3)		-69.1 (-47.7)
Total	**+11.9 (-93.8)**	**+37.7 (-54.5)**	**-201.1 (-141.2)**
Other traffic		p.m. (**-21.3**)	
Total incidence		**-172.8**	
Total tax sum		**-310.8**	

Table 2. The primary incidence of road pricing before tax recycling: total welfare effect, and tax sum paid between brackets(mln DFl per year)

Table 2 shows that business travellers indeed benefit due to road pricing, which is consistent with the result shown in Figure 2 that business traffic increases during the peak due to road pricing. For commuters, the opposite holds. If we look at the sectoral breakdown, in particular the gains for the transport sector and the large losses for commuters from the government sector stand out. The latter effect can in part be explained by the fact that Den Haag is the country’s residence, where the central government and all ministries are located.

Note that differences between sectors in Table 2 only reflect different shares that these sectors have in the initial mobility (for each purpose). It was assumed that behavioural responses are homogeneous over sectors for each purpose. For instance: commuters for business services do not respond any different than commuters for the industry do. An important reason for this simplifying assumption is the lack of reliable data. The only source of information we had was directed to sector-specific reactions to road pricing by commuters, as predicted by their employers in a stated preference study. Clearly, the reliability of such figures is questionable: not only are the data obtained via SP techniques, but more seriously, the questions were asked to others than whom they concerned. Nevertheless, we used the figures from that study in a sensitivity analysis of the final results, and – fortunately – the effect was very small: the sectoral representation in the three main types of mobility considered indeed is the dominant factor for the primary incidence of road pricing.

4. Tax recycling and (tax) burden shifting

The following steps in the analysis concern the issues of 'tax recycling' and '(tax) burden shifting'. These are addressed in this section. We start with recycling in Section 4.1, consider burden shifting in 4.2, and present the implications for the figures given in Table 2 in Section 4.3.

4.1. Tax recycling

As already outlined in the introduction, the issue of tax recycling in the context of road pricing has for long been recognized as a major determinant of the social acceptability of the policy. For that reason, it has already been emphasized by the Dutch government that special attention will indeed be given to this issue of tax recycling. Also in the context of the present study, we therefore pay explicit attention to the effects of tax recycling. The implications of such recycling are certainly relevant also from the perspective of the full economic effects of road pricing, represented in aggregated criteria. However, the relevance here is probably somewhat less delicate an issue than it is for the social feasibility of road pricing. In the latter case, the question is namely to what extent the various groups affected by road pricing receive (partial) compensation. However, for the present study, where we are mainly interested in the economic effects on an aggregate level, the important question is especially whether the depressing effect that the tax transfers from road users to the regulator may have on the aggregate demand is dampened – or, indeed, nullified – by recycling the toll revenues back to the consumers.

A distinction between different types of consumers (for instance, according to income groups) would in that respect only be meaningful if we had reason to expect that, for instance, marginal propensities to consume vary strongly among the toll payers and among those groups that benefit relatively strongly from different recycling schemes. In that case, one could also meaningfully analyse various ways in which the toll revenues can be recycled. We do believe, however, that on an aggregate level, the 'economic' effects of different recycling schemes, in terms of different implications for the final demand, are small if not negligible. In any case, these differences cannot be studied with the input-output model we have at our disposal for the present study, which has only one single 'final demand' category. We do admit, however, that this is a potential weakness of our model.

Therefore, we confine ourselves to two polar cases. The first is the extreme situation where the tax revenues are not recycled at all, and also are not given any other economically relevant destination through increased government spending. The second case is full recycling, where all toll revenues are redistributed directly to the (homogeneous) consumers, and hence add to the final demand in the economy. Finally, we will ignore potentially important 'double-dividend' arguments, that could be put forward especially when recycling would take the form of lowering distortionary taxes, in particular on labour.

For our modelling exercises, it was further assumed that tax recycling does not affect the mobility behaviour during the peak. In the short run, such effects do not have to be considered as long as the recycling is sufficiently 'lump-sum'. However, on the longer run, different indirect mobility effects for the Randstad could result when different recycling variants create different incentives affecting (1) locational choices (Randstad versus the rest of The Netherlands) and (2) car-ownership decisions (when recycling would take place by lowering fixed vehicle taxes). Also these effects are ignored in the present study.

4.2. Burden shifting

Apart from the effect on final demand, tax recycling may also in a different way affect the analysis, because the recycling can be expected to reduce the overall primary welfare loss for employees due to road pricing. We need this information, because it is likely that it will be eventually this sum that employees will try to shift to their employers in wage negotiations.

Apart from that sum, we of course also need information that allows us to predict the extent to which employees will indeed succeed in shifting this burden to their employers. This will in reality depend on a variety of circumstances, including the degree of organisation in a sector, the importance of human capital, the tightness of the labour market, the spatial structure of the labour market, etcetera. Unfortunately, we do not have information that would allow us to give a reliable prediction of the extent to which burden shifting by employees will take place in the various sectors in the context of road pricing. The best information we have is from the wage equations in a sectoral model of the Dutch economy (Graafland and Verbruggen, 1993). For these equations, sector-specific tax-burden-shifting-percentages were determined. Table 3 shows the values for the sectors as distinguished in the present study.

Agri-culture	Industry	Building	Trade	Horeca	Transport	Business services	Other services	Govern-ment
54	25	39	18	14	10	16	16	14

Source: Graafland and Verbruggen (1993), further processing by the authors (Lijesen et al., 1998)

Table 3. Tax burden shifting percentages for sectoral labour markets in The Netherlands

One additional element is taken into consideration, and this concerns what we will call the ‘professional captives’. These are the commuters that will have to use the car during the day for business trips. For those commuters, it is assumed that they can fully shift the burden to their employers. The share of these commuters in the total commuters for a sector was derived on the basis of the sector’s ratio between business travellers and total passenger traffic during the morning peak (Lijesen *et al.* 1998).

4.3. The secondary incidence of road pricing after tax recycling and burden shifting

Using the information conveyed in the preceding tables, it is now straightforward to derive the incidence of road pricing after tax recycling and burden shifting by employees. We will call this the secondary ‘incidence’. Table 4 gives an overview. The costs incurred by a sector are made up of a direct part and an indirect part. The direct part is found as the incidence for business and freight transport (see Table 2). The indirect part is the shifted part of the employees’ total incidence: the incidence for the sectors’ commuters in Table 2 minus the recycling to these employees, multiplied by the shifting fractions implied by Table 3. Table 4 presents the resulting incidence of road pricing for categories that are relevant for the input-output analysis for the case with and without recycling.

Sector	No recycling	Full recycling
Agriculture	-0.2	-0.2
Industry	-6.0	-5.8
Building	-3.9	-3.7
Trade	-8.8	-8.4
Horeca	-2.2	-2.1
Transport	+32.4	+32.6
Business services	-4.6	-4.4
Other services	-9.2	-8.8
Government	-18.0	-17.3
Final demand	-92.5	+216

Table 4. The secondary incidence of road pricing after tax recycling and burden shifting by employees (mln DFl per year)

Again, the strong positive incidence for the transport sector and the strong negative incidence for the government sector stand out, for the same reasons as given above.

The unshifted part of the employees 'financial incidence' (the difference between tolls and recycling), as well as the tolls paid by 'other traffic', are all fed into the final demand. The stage is then set to perform the input-output analysis. That is the topic of the next section.

5. The input-output analysis

For both recycling schemes, the values presented in Table 4 can be fed into an input-output model. The model used is the traditional input-output model as developed by Leontief (1951). The data used to make the model operational are national input-output data as provided by CBS (1995c). A consequence of using this model is that from now on, we can only study impacts of road pricing in the Randstad area on the national economy. It would have been preferable if we could have used an inter-regional table, in order to distinguish also between effects in regions near the Randstad and more remote regions. Unfortunately, we do not have such a model at our disposal. The question could be raised whether the national model is apt for studying such a local measure. Since the tolls will affect most transport entering the Randstad, it is likely that indeed a relatively large share of the Dutch economy (also in a spatial sense, especially when weighted by economic activity) will be affected by the measure. We therefore think the analysis is still meaningful, although it could be improved upon by using an interregional model.

An extensive description of the input-output model as used here can be found in Miller and Blair (1985). In short, it is assumed that several economic sectors can be distinguished. Each sector sells part of its production to the other sectors and a part to final users. The goods sold to each other are the intermediate deliveries. Intermediate products are used as input in the production processes. The products sold to final users are sold to consumers, the government, and foreign countries. These transactions are called final demand. They are mainly used for consumption and investments. The total output of a sector is equal to the sum of all (intermediate) goods sold to other sectors and all (final demand) goods sold to final demand users. In formulas:

$$x_j = \sum_{i=1}^{n} z_{ij} + f_j \qquad (1)$$

where
x_j = total output of sector j
z_{ij} = intermediate deliveries of sector i to sector j
f_j = final demand of the products of sector j
n = number of sectors
For all sector together, the equation can be expressed in matrix notation as:

$$\mathrm{X} = \mathrm{Zi} + \mathrm{F} \qquad (2)$$

where X is an n by 1 vector of total outputs, Z is an n by n matrix of intermediate deliveries, i is an n by 1 vector with every element equal to 1, and F is an n by 1 vector with final demands.

Of course, there are also inputs which are not produced by other sectors, such as labour and capital. These inputs are called primary costs. The primary costs also include value added and imports. Since they are not produced by other sectors, primary costs do not appear in the intermediate deliveries. Instead, these inputs are in a separate vector P. Since total output of a sector has to be equal to its total inputs, the following equation also holds:

$$x_i = \sum_{j=1}^{n} x_{ij} + p_i \qquad (3)$$

where p_i denotes total primary inputs used by sector i.

By dividing the elements of the matrix with intermediate deliveries (Z) with the total inputs of the sector, we obtain the input coefficient matrix A:

$$\mathrm{A} = \mathrm{Z}\hat{\mathrm{X}}^{-1} \qquad (4)$$

A ‘hat’ indicates the diagonalized matrix of a vector, i.e. a matrix with the elements of the vector on its main diagonal and all other elements equal to zero. An element a_{ij} of this matrix can be computed as:

$$a_{ij} = \frac{z_{ij}}{x_j} \qquad (5)$$

It denotes the amount of product i needed to produce 1 unit of product j. With the input coefficient matrix, equation (2) can be rewritten as:

$$\mathrm{X} = \mathrm{Zi} + \mathrm{F} = \mathrm{AX} + \mathrm{F} \qquad (6)$$

or:

$$\mathrm{X} = (\mathrm{I} - \mathrm{A})^{-1}\mathrm{F} = \mathrm{LF} \qquad (7)$$

where the I denotes an n by n identity matrix and $L = (I-A)^{-1}$ is called the Leontief inverse. The last equation expresses X in terms of F. Therefore, it is possible to compute the vector of total outputs from the vector of final demands. Hence, if we know how much final demand changes, we can compute the induced changes for the vector of total outputs by multiplying the new final demand vector with the Leontief inverse. Furthermore, with the new vector of total outputs, the new primary costs can be computed. With this model, an estimation of a vector with final demand of the sector after the road tax leads to an estimation of the new total output and value added of the economic sectors.

The model thus gives the following outputs: effects on final demand, on turnover, on value added, and on labour volume. The results are given in Tables 5a and 5b below, for the cases with no and full recycling, respectively.

For the case where no recycling takes place, the overall economic effects of road pricing are clearly negative. Only the transport sector is a net winner, which is explained by the relatively high value of travel time gains in freight transport. The largest losses are again suffered by the governmental sector. However, with full recycling, the picture changes. The overall economic effects of road pricing are then positive, which is of course what one would expect from a, theoretically, economically optimal policy. Due to the positive effect of recycling on final demand, also the sectoral shares of gains are somewhat different than before. Looking at the value added as a criterion, business services, the trade sector and – perhaps surprisingly – also the government sector now become the main winners.

Apart from the absolute effects as given in the two tables, it is also instructive to see what road pricing means for aggregate economic criteria in a relative sense. These results are given in Figure 4. First of all, it should be stressed that in relative terms, road pricing has only a very limited impact on these variables: all effects are within a range of -0.03% – + 0.06%. Therefore, it seems that the impact of road pricing on the national economy should certainly not be exaggerated. On the other hand, significantly larger impacts would of course imply implausible effects for the Dutch economic growth. Without recycling, we again encounter the by now familiar result that all sectors except transport are worse off, and that the overall effect is negative. With full recycling of revenues, it follows that in relative terms, especially trade, transport, horeca, business and other services benefit. The overall aggregate economic effects, again, are found to be positive.

	Final demand	Turnover	Value added	Labour volume (person years)
Agriculture	-0.5	-3.9	-1.8	-8
Industry	-16.9	-32.2	-11.5	-79
Building	-3.0	-6.4	-2.3	-27
Trade	-1.7	-19.5	-12.3	-147
Horeca	-8.6	-10.6	-5.5	-99
Transport	+14.3	+10.4	+6.0	+31
Business services	-23.4	-27.3	-21.8	-22
Other services	-5.8	-13.6	-9.5	-106
Government	-41.5	-47.1	-30.6	-323
Trade margins	-17.6	-21.1	0	0
Total	**-104.7**	**-171.3**	**-89.4**	**-779**

Table 5.a Full economic impacts of road pricing, no recycling (mln DFl per year)

	Final demand	Turnover	Value added	Labour volume (person years)
Agriculture	+0.9	+7.7	+3.5	+16
Industry	+27.9	+56.5	+20.0	+125
Building	-0.6	+5.6	+2.0	+23
Trade	+0.8	+40.5	+25.5	+304
Horeca	+15.5	+20.0	+10.4	+187
Transport	+28.0	+38.7	+22.4	+115
Business services	+43.1	+49.2	+41.7	+30
Other services	+3.3	+17.7	+12.4	+137
Government	+44.9	+53.8	+34.0	+342
Trade margins	+41.3	+46.7	0	0
Total	**+205.1**	**+336.4**	**+171.9**	**+1 279**

Table 5.b Full economic impacts of road pricing, full recycling (mln DFl per year)

Finally, in Figure 5, we summarize the results for the three types of incidence that were distinguished. From this figure, the following general picture arises. The secondary incidence, after tax recycling and burden shifting, is a weighted average of the primary incidence for a sector's business and freight transport on the one hand, and the commuters involved on the other. This is what one might expect. Next, the full economic effects – given the secondary incidence – are strongly dependent on whether tax recycling takes place. If not, the full effect in terms of value added is in practically all cases a multiple of the negative secondary impact, where the magnification is a result of the fall in final demand. However, with recycling, all sectors enjoy positive effects in terms of increased value added.

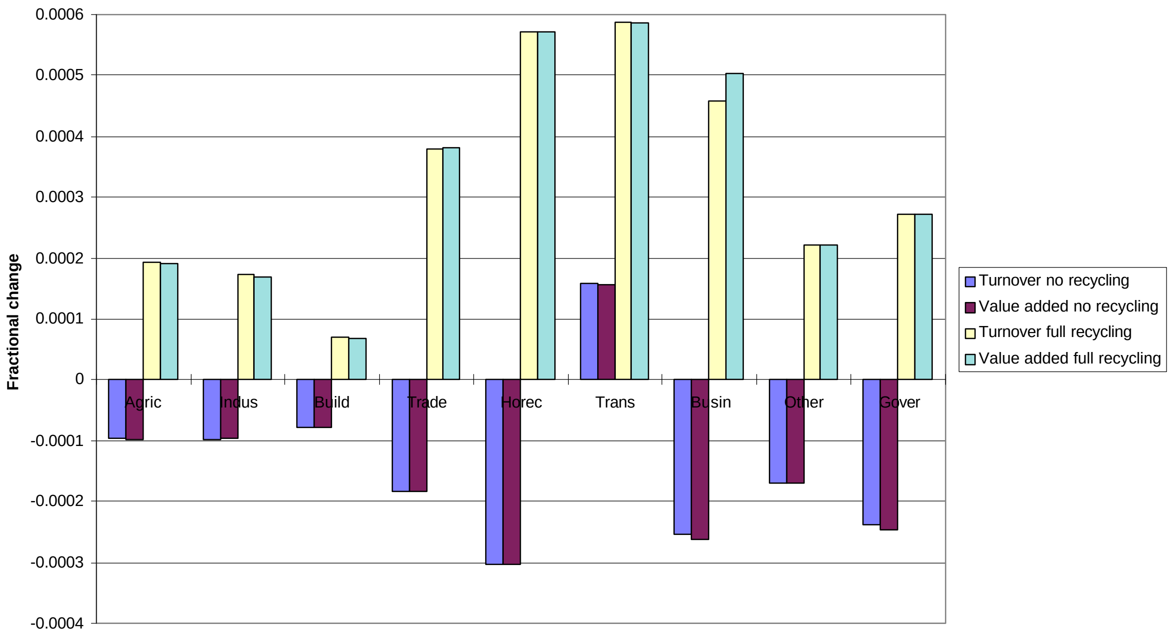

Figure 4. The full economic effects of road pricing in relative terms

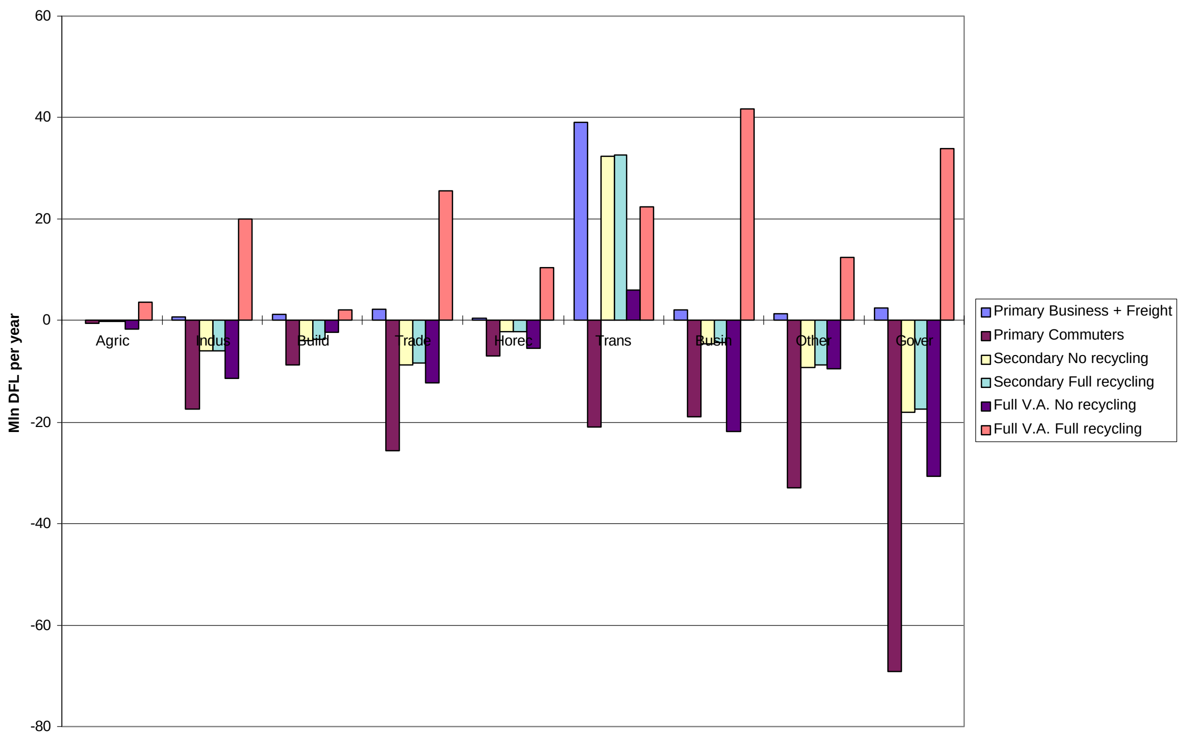

Figure 5. Three measures of incidence compared

6. Conclusion

In this paper, we investigated the economic effects of road pricing on aggregate criteria for economic performance. A distinction was made between different types of incidence: the more or less traditional primary incidence; the secondary incidence after tax recycling and burden shifting that can be derived from this primary incidence, and finally the ‘full’ economic effects that can be found after feeding the secondary incidence into an input-output model. In the analysis, we considered 9 sectors, 4 cities, and 4 types of traffic.

Given the complexity of the questions studied, it is no surprise that at some stages of the analysis, rather pragmatic solutions had to be found for practical problems of limited data availability. From this perspective, we ought to be modest about the accuracy of the results presented. Nevertheless, we have the impression that the results presented are rather robust. This was confirmed by various sensitivity analyses that were performed with the model (Lijesen *et al*, 1998).

The results indicate that the overall economic effect of road pricing is likely to be positive as long as the tax revenues are recycled into the economy. This is, of course, what one would expect from a policy that aims at achieving increased efficiency in the use of a certain ‘resource’, namely road capacity. In relative terms, road pricing appears to have only limited impacts on aggregate economic indicators.

The results also demonstrate that the incidence of road pricing calculated may strongly depend on the measure of incidence considered. Whereas the primary incidence presented benefits from relatively moderate data requirements and a more limited number of assumptions that have to be made, the full economic effects presented can be qualified as a probably more correct measure, which, however, will suffer from a greater degree of uncertainty. Due to the rather different patterns found, however, it seems worthwhile to accept this uncertainty in exchange for further insights into the eventual effects that can arise, after all primary impacts have fully ‘trickled down’ through the economic system.

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