Congestion Management with Tags or Smart Cards

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Abstract
We considered toll cordons to manage congestion in eight English towns. In a cordon-pricing scheme a trip maker is charged a fixed amount to enter and/or leave the charged area at all or only some times of the day. Two electronic charging technologies were considered: tags and smart cards with transponder. The first one consists of tags that communicate identifying information about the vehicle to an antenna/reader, through radio frequency or infrared. Information can be written on some of them but they have no processing capabilities. The second one consists of a transponder that communicates with the antenna/reader. The smart card is an integrated circuit device, which contains a microprocessor and memory and stores account balance information. The physical location of the roadside sensors determines the boundary of the charged area and defines the cordon. We based the decision of where to put the cordon on two main considerations: what seems to be the most congested area in the town in question, and what cordon would not allow too many alternative routes. We compared implementation and operation costs for both technologies, performed a cost-benefit analysis, and arrived to the conclusion that in borderline cases the use of a cheaper technology may make a non-viable scheme viable.

1 Introduction

It is widely accepted by engineers, economists and policy makers that an effective way of reducing demand at peak times is charging drivers to enter congested areas. The disadvantages of manual tolling or papers permits are also well known (ease of forgery, queues to pay, etc). Although electronic road pricing is not yet widespread, mainly because road pricing itself has not been widely implemented yet, it appears as the most attractive alternative that would do away with the kind of problems that other road pricing systems face.

An electronic road pricing scheme will be worth introducing only in those cases where the benefits exceed the costs. It is a common misconception that benefits are measured by the revenue collected – a mistake that can lead to faulty decisions. Revenues are transfer payments and the benefits depend on road users' responses to the road prices. These should reduce journeys that impose greater social costs than private benefits. Benefits are measured by the reduction in total travel costs, less any reduction in travel benefits.

In this paper we simulate electronic cordon tolls in eight English towns and compare costs and benefits of two different technologies. In a cordon-pricing scheme a trip maker is charged a fixed amount to enter and/or leave the charged area at all or only some times of the day. The charge does not depend on the time or distance travelled within the charged area or the levels of prevailing congestion. Cordon tolls have been already tested in Singapore, Oslo, Trondheim and Bergen. Other systems would be more expensive, more complex, and may have less predictable effects. If cordon tolls are unsuccessful, then other schemes are less likely to succeed. If cordon tolls work well, the experience on traffic behaviour they provide may indicate the value of more complex systems, whose cost is likely to continue to fall. For these reasons, cordon tolls are very interesting to study as a possible system of congestion pricing.

Benefits and costs incurred by vehicles and the charging authority were assessed for two different technologies: tags and smart cards. In the case of tags, a radio frequency (RF) or infra-red (IR) tag is installed in or on the vehicle and used in conjunction with an in-lane RF or IR antenna/reader to communicate identifying information about the vehicle and customer to the toll system. The information stored in the tag is fixed (read only) and cannot be altered nor processed (Kolb, 2000).

Smart cards with RF/IR transponders, on the other hand, have greater capabilities. The smart card contains a micro-processor and memory and stores account balance information. The RF/IR interfaces to the smart card and allows the smart card to communicate with the in-lane antenna/reader. The transponder also contains information about the vehicle, which can be transmitted to the antenna/reader together with the smart card information (Kolb, 2000).

In all these cases, each toll lane is equipped with an antenna, which is usually installed on or above the roadway. Each antenna is connected to a reader, which controls the communications between the tag installed in the vehicle and the antenna itself. The reader sends out a signal (via the antenna) to the tag, which lets the tag know that it should begin communication. The tag returns a unique ID number, which is used to identify the vehicle (customer) to the system. In the case of smart cards with a transponder, additional information may be transmitted by the card, such as account balance or point of entry, and the reader may send back updated information to be encoded on the smart card.

The physical location of the roadside sensors determines the boundary of the charged area and defines the cordon. The decision where to put the cordon was based on two main considerations: what seems to be the most congested area in the town in question, and what cordon would not allow too many alternative routes. If too many alternative routes were available for drivers, congestion would be shifted to these routes and the problem would not be solved. In many cases the local authorities were contacted for advice. The cordon was often placed just inside the inner or the outer ring road.

Finally, only inbound cordons were simulated. With an inbound cordon, some people reverse commuting from the city centre to the area outside the cordon may cross the cordon outbound during a peak period, generating congestion, and cross it inbound during a non-congested period paying only a small charge or even no charge at all. Bi-directional cordons are an answer to this problem and could also be considered. However, this problem would only exist if congestion during the morning peak were serious outbound as well as inbound. In general inbound roads are congested during the morning peak and outbound roads are congested during the evening peak. In such cases, inbound cordon tolls should be sufficient to improve efficiency. During the off-peak hours, if the level of traffic does not lead to congestion, as is the case in the towns studied, there should be no charge to cross the cordon.

In order to decide whether a scheme would be worthwhile or not net present values of the increases in social surplus were compared with the costs of the scheme.

2 Programs used

The potential impacts of the schemes were estimated using results from SATURN (Simulation and Assignment of Traffic to Urban Road Networks) and its batch file procedure to simulate road pricing, SATTAX. SATURN, developed at the Institute for Transport Studies at University of Leeds, simulates and assigns traffic in towns until it finds the equilibrium, defined as the least cost assignment of traffic. SATTAX allows the number of trips to respond to the cost of the trips and the routes chosen to depend on the tolls introduced.

SATTAX is a batch file procedure, also developed at the Institute for Transport Studies at University of Leeds, that can be added to SATURN in order to simulate road charging (Milne and Van Vliet, 1993). It tries to replicate the kind of responses that drivers would have to a road pricing scheme. These can be classified in two main types: change of route and transfer off the road.

For each link on the simulation network, there is usually an associated fixed travel time, with delays treated as taking place at junctions. This fixed travel time can be increased to emulate road charging. SATTAX is based on the assumption that trip makers consider tolls alongside and in equal weight to the costs of running a car and the value of their time. If the cost for a driver to go from origin zone *i* to destination zone *j* is \$14.6 (£10) including both time and distance (vehicle operating) costs and a toll of \$3.7 (£2.5) is introduced in the central area of town which he has to enter to reach his destination, the total cost of his trip will now be increased to \$18.3 (£12.5) in the first instance. After adjustments are made however some drivers will be 'tolled-off' and some drivers will change route, and with less vehicles in the charged area, travel times will be lower and the total cost of the trip will be less than \$18.3 (£12.5).

If a cordon toll is introduced in the central area of a town, an extra delay is added on to the fixed travel time to traverse the appropriate link or turn. The magnitude of the additional cost is computed from the value of time (VOT) assumed, which in this case was 34.2 cents per PCUmin[1] (23.4 pence per PCUmin). The time penalty required to reflect a toll of \$3.7 (£2.5) per crossing with an assumed VOT of 34.2 cents per PCUmin is 641 seconds. This delay is added onto the links leading to the charged area. The tolls assumed in this study are therefore effectively tolls per PCU to cross the cordon. In particular, a lorry with a PCU value of 2.5 will pay two and a half times the toll a car would pay and a light good vehicle with a PCU value of 1.5 will pay one and a half times the toll a car would pay. The same reasoning applies for buses. However, it may be the case the local authority wishes to get people out of their cars and use public transport instead. In order to encourage them to do that it may decide that buses are exempt of paying any toll.

As stated above, the SATTAX model has two responses:

- Route choice within the current time period, represented through the assignment model
- Transfer off the road, out of the current time period or making less frequent trips, represented through the elasticity model.

Transfer off the road includes all trips that for one reason or other are dropped from the original trip matrix for the time period under study. The reasons for these trips to be excluded include:

- Change of departure time, provided it is outside the time period modelled
- Change of mode
- Car pooling, sometimes treated as a change of mode, i.e. from driver to passenger
- Cancellation of the trip.

This model considers only one time period. It takes into account the reduction of traffic linked to changes in departure time but it does not take into account the increase of traffic at other time periods. Increase in traffic at other time periods could be modelled by running the model for other times and including the trips that would

[1] PCU stands for passenger car units. It is the weight given to each vehicle type. A car for example, has a PCU rating of 1, whereas a van has a PCU rating of 1.5, and a lorry has a PCU rating of 2.5 or 3, according to its size.

change departure time. The other alternative would be to prepare a trip matrix for a two or three hour period. There are no trip matrixes available for such long periods of time, probably because they are quite expensive to build.

The elasticity level of the demand response relationship in SATTAX represents all likely travel choices that would reduce the volume of motorised vehicle trips in the time period represented. The demand function assumed was the constant elasticity demand. The independent variable was number of trips (measured in PCUs per hour). The demand elasticity was defined to be a positive number:

$$\eta = -\frac{d \ln Q(P)}{d \ln P}$$

where *Q(P)* is demand for trips at price *P*, with both *Q* and *P* referring to a particular origin and destination and time. The constant elasticity demand function is

$$Q(P) = Q_0 * \left(\frac{P}{P_0} \right)^{-\eta}$$

and its inverse is

$$P(Q) = P_0 * \left(\frac{Q}{Q_0} \right)^{-1/\eta}$$

Three elasticities were assumed: 0.2, 0,4 and 0.7, spanning the plausible range of values.

3 Costs of cordon tolls

The costs of a cordon toll scheme for each town considered in this study are presented in Table 1. The number of inbound tolled crossings per day was assumed to be 3.7 times that during the morning peak, 8 to 9 AM. The number of intra-vehicular units (IVUs) to be installed was assumed to be three times the daily number of cordon crossings. The IVUs' implementation costs, $22 (£15) for the tag and $58 (£40) for the card (Cheese and Klein, 1999), were multiplied by the number of IVUs required in each case. Infrastructure costs, of $66,100 (£45,300) per point (Cheese and Klein, 1999)[2], were multiplied by the number of cordon points. One fourth of the cordon points were assumed to be dual lane, and would therefore require gantries. According to Cheese and Klein (1999), the cost of one gantry is $141,600 (£97,000).

Operating costs, which include all costs of running the tolls, such as labour costs, costs of maintenance and costs of operating the infrastructure, were estimated using data from the Norwegian Public Roads Administration. These are in the order of ten cents (seven pence) per transaction at most. This figure was therefore multiplied by the number of transactions per day and by the number of days on which the scheme would operate per year, assumed to be 250. The IVUs were assumed to have a life of six years.

The net present value (NPV) of the costs presented in Table 1 are presented in Table 2. The scheme was assumed to last 30 years. An IVU would have to be replaced every six years (Cheese and Klein, 1999) and the life of the roadside equipment is estimated to be five years (Cheese and Klein, 1999). In 30 years, the IVUs would have to be replaced four times, and the infrastructure, five.

In the case of Cambridge a second alternative entailing two cordons instead of one was also tried. It was found that while one cordon around the city centre would

[2] MVA (1995) estimates infrastructure costs at £110,000 per point. Cheese and Klein's (1999) estimate was chosen instead because it is more recent and prices for this type of equipment are likely to decrease with time and technological progress.

not be worth implementing, a double cordon scheme, one in the city centre and one for virtually the whole town, would be worth implementing, with benefits being considerably higher than costs.

Table 1: Costs of implementing a cordon toll in different towns (1998 US dollars)

Town		Number of vehicles crossing the cordon between 8 and 9 AM	Number of crossings per day	Number of IVUs	Number of cordon points	Implementation costs ($ million at 1998 prices)			Operating costs ($ million at 1998 prices)
						IVUs		Infrastructure	
						Tag	Card		
Cambridge	*One cordon*	10,527	38,950	116,850	16	2.56	6.82	1.62	0.99
	Two cordons	17,074	63,174	189,521	27	4.15	11.07	2.74	1.62
Northampton		14,189	52,499	157,498	12	3.45	9.20	1.21	1.34
Kingston upon Hull		14,529	53,757	161,272	14	3.53	9.42	1.42	1.37
Hereford		6,494	24,028	72,083	8	1.58	4.20	0.82	0.61
Lincoln		9,074	33,574	100,721	20	2.20	5.88	2.03	0.86
Bedford		10,335	38,240	114,719	14	2.51	6.70	1.42	0.98
Norwich		12,164	45,007	135,020	22	2.96	7.88	2.23	1.15
York		6,444	23,843	71,528	21	1.56	4.18	2.13	0.61

Source: See text

Note: IVUs and infrastructure costs are capital one-off costs that take place in year zero. IVUs and infrastructure will need to be replaced every five and six years. Operating costs are annual costs.

Table 2: Net present value of the different costs (1998 US dollars)

Town		Implementation costs (IVUs + Infr.)		Replacement IVU (every six years)		Replacement infrastructure (every five years)	Operating costs	Total costs	
		Tag	Smart card	Tag	Smart card			Tag	Smart card
Cambridge	*One cordon*	4.2	8.5	5.4	14.3	1	13	23.5	36.6
	Two cordons	6.9	13.9	8.8	23.2	1.6	21	38.3	59.7
Northampton		4.7	10.4	7.3	19.3	0.7	17.4	30.1	47.9
Kingston upon Hull		5.0	10.8	7.4	19.7	0.9	17.8	31.1	49.3
Hereford		2.3	5.0	3.4	8.8	0.4	8	14.2	22.3
Lincoln		4.2	7.9	4.7	12.3	1.3	11.1	21.2	32.6
Bedford		3.9	8.2	5.3	14.0	0.9	12.7	22.8	35.8
Norwich		5.3	10.1	6.1	16.5	1.3	14.9	27.7	42.9
York		3.7	6.3	3.2	8.8	1.3	7.9	16.2	24.2

Source: Own calculations
Note: elasticity assumed:0.2, test rate: 6%, project life: 30 years

4 Benefits of cordon tolls

The benefits that would be derived from electronic cordon tolls do not depend on the technology used. If road side sensors are placed at exactly the same points with both technologies and the toll paid by drivers is the same, then it can be assumed that the reaction of drivers and change in traffic levels will be the same, regardless of whether the technology chosen entails simple tags or smart cards with processing capabilities.

Revenues cannot be accounted for as benefits. They are transfer payments typically between two and three times the benefits of the scheme. The criterion used to assess the benefits from a cordon toll was the increase in social surplus. Social surplus was defined as the trip makers' surplus, which can be expressed as:

Social surplus = Sum of individual utilities[3] *- Sum of individual costs*[4]

In the case of a unique origin-destination pair, the utility of driving is the integral of the demand function between zero and the actual level of traffic. Individual social costs are expressed in the following equation:

$$SC_{ij} = VOT * time_{ij} + (VOC - VAT - duty) * dist_{ij}$$

where SC_{ij} is the social cost in cents per PCU to go from origin zone i to destination zone j, VAT is a weighted average of the Value Added Tax on fuel and duties and $duty$ is a weighted average of the average fuel duty paid by trip makers exclusive of VAT on duties. The sum of all SC_{ij} can also be represented by the integral of the marginal social cost (MSC) between zero and the actual level of traffic.

Total social costs should also include costs of pollution and accidents. Both effects are ignored in this study. The effects of a toll on accidents are controversial and are discussed further below. The environmental benefits that would derive from cordon tolls are small, typically below 5% of the annual increase in social surplus (Santos, Rojey and Newbery, 2000).

As explained above, a constant elasticity demand function was assumed together with three different elasticity values: 0.2, 0.4 and 0.7. These were assumed to hold for all origin-destination pairs *ij*. It should be noted that although the functional form and the elasticity are the same, the specific coefficients for each origin-destination may be different.

The difference between *ij* drivers' utility before and after the introduction of the toll was computed. That was done for each origin-destination pair and then all the changes in utilities were added up to get the overall change in utility.

The change in total costs was obtained directly from the new cost matrix produced by SATTAX, adjusted to exclude VAT and fuel duties.

SATTAX was run for several levels of tolls ranging from 40 cents (£0.25) to \$5.8 and \$7.3 (£4 and £5). The towns for which the cordon toll was simulated are Northampton, Kingston upon Hull, Cambridge, Lincoln, Norwich, York, Bedford and Hereford. The model was run for the morning peak (8 to 9 AM).

Matlab was used to find the optimal toll, defined as the toll for which the social surplus, computed as the difference between the sum of individual utilities of making trips *minus* the sum of individual costs is maximum. The increase in social surplus that would result from the introduction of this optimal toll was computed and defined to be the benefits that would be derived from the scheme. Table 3 shows the results for each town.

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[3] Utility in this study was measured in cash terms and computed as the area under the demand curve.

[4] The expressions 'individual costs' and 'individual benefits' refer to the costs and benefits of trips from origin zone *i* to destination zone *j*.

Table 3: Optimal tolls, benefits and revenues (1998 US dollars)

Town	Elasticity	Optimal toll ($ to cross the cordon)	Increase in annual social surplus ($ million)	Annual gross revenues ($ million)	Revenues over increase in social surplus
	0.2	4.38	3.46	12.05	5.11
Northampton	0.4	4.38	4.83	11.61	3.50
	0.7	5.11	7.08	12.15	2.48
Kingston	0.2	3.65	4.73	11.23	3.50
upon	0.4	4.38	6.51	12.51	2.77
Hull	0.7	5.11	7.50	13.21	2.63
	0.2	1.10	0.66	2.56	5.69
Cambridge	0.4	1.46	1.33	3.17	3.50
	0.7	2.19	1.85	4.09	3.21
	0.2	0.37	0.64	0.76	1.75
Lincoln	0.4	0.73	0.76	1.39	2.63
	0.7	1.46	0.79	2.28	4.23
	0.2	0.73	1.31	1.81	2.04
Norwich	0.4	0.73	1.34	1.81	1.90
	0.7	1.10	1.88	2.44	1.90
	0.2	1.10	1.05	1.77	2.48
York	0.4	1.10	1.23	1.69	2.04
	0.7	2.19	1.27	3.26	3.80
	0.2	0.73	0.76	1.77	3.36
Bedford	0.4	0.37	0.16	0.89	8.03
	0.7	2.19	0.51	3.94	11.24
	0.2	5.11	0.77	6.22	11.68
Hereford	0.4	2.56	1.12	3.21	4.23
	0.7	2.19	1.24	2.66	3.07

Source: Table 2 (Santos, Newbery and Rojey, 2001)

The benefits are simply the increase in social surplus. They are presented in Table 4. The increase in social surplus for a whole day was assumed to be three times the increase in social surplus from 8 to 9 AM. This is a conservative but reasonable assumption. The inefficiency is almost as high during the evening peak as during the morning peak (Newbery and Santos, 1999). Santos (2000) finds that deadweight loss during the evening peak is typically between 70 and 90% that during the morning peak. The scheme would also improve social welfare in the shoulder peaks, i.e., the congested time-periods that surround the morning and evening peaks. Therefore, to assume that the introduction of a cordon toll during the morning and evening peaks and shoulder-peaks would yield an increase of only three times the increase in social surplus during the hour 8 to 9 is may be an underestimate. At this stage it is preferable to underestimate benefits, particularly bearing in mind that calculations for other times of the day cannot be done due to lack of data.

Benefits increase with the elasticity, so at the assumed value of 0.2 they are likely underestimated. If a scheme is worthwhile with this value, then it will certainly be at higher and possibly more reasonable values.

Table 4: Annual benefits of implementing a cordon toll in different towns in $ million at 1998 prices

Town		Increase in social surplus morning peak	Total increase in social surplus
Cambridge	*One cordon*	0.7	2.1
	Two cordons	3.9	11.7
Northampton		3.5	10.5
Kingston upon Hull		4.7	14.1
Hereford		0.8	2.4
Lincoln		0.6	1.8
Bedford		0.8	2.4
Norwich		1.3	3.9
York		1.1	3.3

Source: Own calculations done with SATURN outputs
Note: elasticity assumed: 0.2, total increase in social surplus assumed to be three times the increase in social surplus during the morning peak

5 Cost-benefit analysis

In order to decide whether a scheme is worthwhile or not we have compared the net present value (NPV) of the streams of costs and benefits that would derive from a cordon toll scheme in the different towns considered in this study. The main benefit would be the increase in social surplus. Revenues are not benefits and therefore do not enter the calculations. There would also be some other benefits linked to the reduction in emissions, but these have not been included in the final estimates of NPV. Finally, there would perhaps be a benefit resulting from fewer accidents. Traffic accidents, however, are related to both speed and traffic volume. If road charging increased speeds, accidents would increase, but since road pricing reduces traffic volumes, accidents would decrease. If a cordon toll increased speeds not by increasing running speed but by reducing queuing delays, the number of accidents would probably decrease (MVA, 1995), but the remaining accidents would (perhaps) be more severe. We have ignored this benefit as well as we believe a separate careful study would have to be conducted to arrive at a robust estimate.

Ideally, a comprehensive cost-benefit analysis should also include the impacts on the urban economy. The MVA study of road charging in London (MVA, 1995) considers four classes of impact: those on employees, on costs of the inputs of organisations, on costs of outputs of organisations, and on organisations' customers. We have only included the direct transport cost changes, and ignored indirect effects arising from such changes, as they are not modelled by SATURN.

There is a further problem, in the analysis, which can only be solved by using a more comprehensive model that would account for changes in the long run. SATURN and the batch file procedure SATTAX are medium run models in that they hold constant car ownership and use, and specifically the pattern of origin and destination of trips, and therefore medium run elasticities have been used. We have assumed that the changes in social surplus computed for the first year would hold during the whole life of the project. This is of course unrealistic. In the long run higher elasticities should be used as people and businesses might relocate and even more, there could be changes in the local authorities' land use plans. We are unable to allow for those responses in a model that only accounts for time or route switching, which are clearly medium run responses. The stream of costs and benefits we are comparing therefore may help to give an idea of what the result of a cost benefit analysis would be, but it should not be taken as definitive. To assess the real impact of a scheme a more complex model would need to be used so that all possible responses could be taken into account. It would be possible to make cruder forecasts of traffic growth, but it is likely that traffic management arrangements would be adapted to deal with such growth and our model would no longer give an accurate measure of congestion costs. Our defence of this simplifying assumption is that the long-run impacts of relocation caused by road pricing are likely to reduce traffic, while economic development is likely to increase traffic, making a no-change assumption not unreasonable. If anything, it is likely to underestimate the benefits of road pricing.

To estimate the costs the toll was assumed to operate from 7 to 10 AM and from 4 to 7 PM. The toll should depend on the level of congestion and should be set lower at the shoulder-peak hours, 7 to 8 and 9 to 10 in the morning, and 4 to 5 and 6 to 7 in the afternoon.[5] The number of vehicles crossing the cordon during this time period was deduced from the number of vehicles crossing the cordon between 8 and 9 AM using SATTAX and from the daily traffic distribution inbound on Cambridge radial routes.[6] The number of transactions per day was estimated to be 3.7 times the number of transactions between 8 to 9 AM. As argued above, the daily benefits are taken as three times those measured for the period 8 to 9 AM, erring on the side of under-estimating benefits (as is the case for valuing the results at an elasticity of 0.2).

Table 5 summarises the costs and benefits were a cordon toll implemented in the towns in question.

Table 5: Net Present Value of a cordon toll in different towns in $ million at 1998 prices

Town		Total cost		Benefit	Net Present Value		Benefit/Cost	
		Tag	Smart card		Tag	Smart card	Tag	Smart card
Cambridge	*One cordon*	23.5	36.6	24.2	0.7	-12.6	1.03	0.66
	Two cordons	38.3	59.7	138.3	100	78.5	3.61	2.32
Northampton		30.1	47.9	131.4	101.3	83.5	4.37	2.74
Kingston upon Hull		31.1	49.3	180.3	149.2	131.0	5.80	3.66
Hereford		14.2	22.3	28.5	14.3	6.1	2.01	1.28
Lincoln		21.2	32.6	24.8	3.5	-7.9	1.17	0.76
Bedford		22.8	35.8	29.1	6.3	-6.7	1.28	0.81
Norwich		27.7	42.9	34.9	7.2	-8.0	1.26	0.81
York		16.2	24.2	40.0	23.8	15.8	2.47	1.65

Source: Own calculations
Note: discount rate: 6%, benefits assumed to be constant throughout the 30 years

A discount rate of 6% was used, as this is the standard rate of interest used by the Treasury in the UK.[7] A comparison of costs and benefits indicates that road pricing would be very beneficial in Kingston Upon Hull and Northampton, and to a lesser extent in Hereford and York. In all the other towns the NPV is negative. Conservative

[5] A sophisticated toll would increase gradually from zero to the prescribed level and back over the shoulder periods to prevent bunching of trips around the beginning and end of the charged periods.
[6] We are indebted to James Lindsay, from WS Atkins, who provided us with data on vehicle counts in Cambridge.
[7] The Treasury was, in early 2001, reconsidering the test discount rate and may reduce it somewhat. If so, the benefit cost ratio would be higher.

estimates were used. These schemes would become more beneficial if costs proved to be lower than the ones used or if the elasticity of the demand proved to be higher than 0.2.

Two cordons in Cambridge, one inner and one outer, at $2.9 (£2) per crossing yield a benefit-cost ratio well over 1. This shows that a single cordon scheme would not be worthwhile whereas a double cordon scheme would be worthwhile. Changing from one to two cordons can change the final result as to change the policy decision. This kind of analysis is therefore worth doing before deciding on the desirability of a road pricing scheme in any one town.

6 Conclusions

Introducing electronic road pricing is not always desirable. Even when using the cheapest technology in congested towns the costs of introducing a scheme may exceed the benefits. In borderline cases the use of a cheaper technology may make a non-viable scheme viable. This is the case of Lincoln, Bedford, Norwich and Cambridge (with a single cordon). If a smart card were used, the scheme would yield losses. If a tag were used instead, the scheme would just about make some profit. Another option for those towns in which the scheme would not have a positive net present value is to introduce a second outer cordon. Such is the case of Cambridge, where with one cordon only around the city centre electronic road pricing would not be worthwhile, whereas with two, it would. York and Hereford are towns with positive net present values. However they do not have much margin and it might be safer to go for a cheaper technology, specially if not all impacts or effects could be assessed as is the case in this study. Finally, there are two unambiguous cases: Northampton and Kingston upon Hull, where the benefit cost ratio is well above one, regardless of the technology used.

Back-office costs are the most significant usage-related cost and the one on which the viability of the schemes appears to depend most sensitively. It may be that these costs can be substantially reduced by improved electronic processing. If so, more schemes will become socially desirable. In the mean time, the most important lesson to draw from this study is that trials should be carefully targeted at the few towns (such as Kingston upon Hull and Northampton) that appear to have a considerable excess of social benefits over costs. These trials should be studied closely, to validate the travel responses upon which the benefits and cost so sensitively depend and to validate the estimates of implementation and operating costs. That knowledge will allow subsequent schemes to be better designed and subsequent cost-benefit analyses more accurately undertaken.

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