REGULATION OR INFORMATION : CAN WE INFLUENCE CITY COMPETITION?

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Abstract

In this paper we model the impacts of competition between two cities when considering demand management strategies on both the optimal tolls and residential location choices. An isolated city is studied first and a simplified welfare function is used to determine the optimal toll around the central area. A twin city is then added. Traffic from the neighbouring city may be charged and the revenue retained - a form of tax exporting behaviour which should increase the welfare of the city. We show that there exists only one non-co-operative solution which forms a Nash trap with higher tolls than under the regulated case. We then set up a *game* in the form of a flight simulator and report on results of the game played by pairs of students who are asked to act as local authority decision-makers. The aim is to test (a) whether the strategies adopted are as theory predicts and (b) whether the players recognise the benefits of lower tolls when given information about the regulated solution and collaborate or continue to play to win. The results show that players respond to the information and maintain a collaborative solution which may have significant implications for regulation and the development of cities within regional partnerships.

Key Words : Transport policy; road pricing; competition; land-use transport interaction; game theory.

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1. INTRODUCTION

Recent changes to policy in the UK (DCLG & DPMO 2012) have resulted in several local authorities being combined into regional partnerships with cities and towns forming large city regions (e.g. Leeds City Region, LCR 2013). One of the aims of forming such regional governance is for the cities to benefit from collaboration. However, from the literature we know that cities compete with each other. Public Choice Theory has explored the notion that cities compete to attract and retain residents and businesses (Tiebout, 1956; Basolo, 2000). Likewise, the Public Finance & Tax Competition literature identifies competition between cities on tax-and-spend policies (Wilson, 1999; Brueckner, 2001). This then raises the issue of how cities will react to regional collaborations.

In this paper we focus our attention on competition between cities in the application of transport policy, in particular in the use of road user charging and how interactions between cities may evolve. To do this we need a model which deals with more than one city. However, urban transport models are usually developed for a single city in isolation or large metropolitan areas with one city as its focus, and they are rarely used to study the dynamics of competition between cities/towns. Our paper addresses this gap and develops a model of two cities following a system dynamics approach.

In particular, this paper investigates how simulation tools can improve or change the decision-making processes used. It firstly applies the Land Use Transport Interaction Model MARS, Pfaffenbichler et al (2010), as a planning tool to demonstrate the potential optimal tolls for two neighbouring cities. It then applies the simulator in a game playing mode to test how decision-makers would update their strategies in response to cues including charges set by the other city and changes in own city welfare over the previous periods. The aim is to test (a) whether the strategies adopted are as theory and the optimisation approach would predict and (b) whether the players recognise the benefits of lower tolls when given information about the globally regulated solution and collaborate or continue to play to win.

1.1 Background

Earlier work by Marsden and Mullen (2012) looked at the motivations of decision-makers in local government in different towns and cities of four major city regions in England. It showed that towns and cities both compete and collaborate to maximise their own competitive position. The major cities are seen as the main powerhouses of growth, with other towns and cities trading on particular distinctive skills sets or tourist offers and spill-over effects from the major cities. Working together they can act as a more powerful voice to argue for investment from central government.

So whilst these interviews with local authorities confirmed that cities do consider competing cities, they consider different cities as competitors for different aspects. For example when competing for investment from creative industries to locate jobs then cities from further afield will be considered as competitors, when competing for regional funds from government they will team with neighbouring cities but when it comes to charges for transport such as parking then they will consider local neighbours as competitors and will consider the charges levied in other more local towns. When it comes to road user charging (which is not yet common in smaller cities within the UK), the cities suggested that there would be a hierarchy of charges to consider akin to the parking charges and so some form of strategic charging or competition may well evolve.

Here lies the problem, whilst cities seem to compete through the use of parking charges or tolls, research in the transport literature has focused predominantly on intra-city issues. The strong focus in recent years has been on road user charging, economic theory suggesting benefits will accrue to a city from a combination of congestion relief and recycling of revenues within the city (Walters, 1961). Beyond the theoretical benchmark of full marginal cost pricing, the design of practical charging schemes, such as those adopted by local authorities in recent Transport Innovation Funds (TIF) bids in the UK, have generally focused on pricing cordons around single, mono-centric cities (Shepherd et al, 2008). As our own research has demonstrated, it is possible in such cases to design the location and level of charges for a cordon so as to systematically maximise the potential welfare gain to the city (Shepherd and Sumalee, 2004; Sumalee et al, 2005), yet there is an implicit premise here that the city acts *in isolation*.

Whilst we have found no empirical studies examining competing cities in the transport sphere, a handful of studies address aspects of competition. In the context of toll roads, several authors have studied the welfare implications of competition between a public and private operator (Verhoef et al, 1996; De Palma & Lindsey, 2000; Yang et al, 2009). The focus in these studies is on the impacts of alternative ownership regimes, and of public versus private control in the form of either monopoly pricing or competitive Nash equilibria. De Borger et al (2007) and Ubbels & Verhoef (2008) studied a more closely related problem of competition between countries/regions setting tolls and capacities, investigating the implications of players adopting two-stage games or different strategies.

In parallel, several recent studies have appeared on the evolution of city structures and tolls under different assumptions. Levinson et al (2006) and Zhang et al (2007) used an agent-based approach to investigate how networks evolve over time. In this area of study, while Mun et al (2005) focused on the development of a non-monocentric, linearised city, others have opted to develop two-dimensional continuum models (solved using finite element methods) capable of representing multiple CBDs (Ho et al, 2005; Ho & Wong, 2007). From the field of Economic Geography, Anas & Pines (2008) analyse the move away from monocentric models to polycentric ones. In spite of their relevance to the proposed study, none of the above approaches considers direct competition between cities, nor the inter-play between parking charges and road user tolls either within or between cities (for which Marsden, (2009), found evidence).

When we move to a polycentric case reflecting either neighbouring cities within an authority or neighbouring authorities then competition between cities and/or authorities may arise as described above. Issues of short-term destination changes and potentially longer term household and business relocation decisions thus need to be considered.

Whilst Mun et al (2005) studied optimal cordon pricing in a non-mono-centric city, they assume a one dimensional linear city but with more than one CBD. Their research revealed that cordon pricing is not always effective for congestion management in non-mono-centric cities and it tends to be effective as the urban structure is more mono-centric. Our work differs significantly from that of Mun et al. in that we analyse the optimal toll between *two cities* competing with each other whereas Mun et al. consider *one city* with many CBDs. Moreover, our model considers cities developed in two-dimensional space that is to say that the transport network represents a real-world physical network as opposed to the one-dimensional model adopted by Mun et al (2005).

The aim of our paper is firstly to model the impacts of competition between cities when considering demand management strategies and to find optimal tolls for single and multi-player scenarios under competitive and regulated cases. Secondly we aim to investigate how decisions are updated within a dynamic setting. This is done by setting up a dynamic game version of the problem within the simulator which is then tested with pairs of students who are acting as local authority decision makers. The research uses a dynamic land use transport interaction model of two neighbouring cities to analyse the impacts by setting up a game between the two cities who are assumed to maximise the welfare of their own residents. The work builds on our earlier work by Koh et al (2012) who studied competition in a small network using a static equilibrium approach for private car traffic alone.

The dynamic model is used first to study an isolated city (representative of Leeds) and a simplified welfare function is used to determine the optimal toll around the central area. A twin city is then added to the model thus introducing traffic between the cities. This traffic may be charged to enter the central area along with own residents, however the revenue may be retained by the city; a form of tax exporting behaviour which would in theory increase the welfare of the city. However as shown by Koh et al (2012), both cities will have an incentive to charge and a game may evolve where in the long run both cities may be worse off in terms of welfare than if none had charged in the first place.

The rest of the paper is set out as follows- section 2 describes the MARS model, section 3 introduces the case study, welfare measures used, the scenarios investigated and reports the optimal tolls for the long term planning scenarios. Section 4 develops the dynamic game set up and section 5 describes the results. Section 6 provides conclusions and discusses the implications for policy and future research.

2. THE MARS MODEL

MARS is a dynamic Land Use and Transport Integrated model. The basic underlying hypothesis of MARS is that settlements and activities within them are self-organising systems. MARS is based on the principles of systems dynamics (Sterman 2000) and synergetics (Haken 1983). The present version of MARS is implemented in Vensim®, a System Dynamics programming environment. MARS is capable of analysing policy combinations at the city/regional level and assessing their impacts over a 30 year planning period. Figure 1 shows an overview of the MARS model. There are three sub-models within MARS, viz., transport, residential location and workplace location sub-models. The transport sub-model determines the demand for travel between zones for a given land use pattern and estimates the number of trips by a given mode of transport such as car, bus, train, walking and cycling for peak and off-peak periods. The output of the transport sub-model includes an accessibility measure which influences the residential and workplace location choices. Rents, land prices and land availability also influence where land is developed and the location choice of residents. These sub-models then interact over time and the system responds to exogenous inputs for growth in residents, jobs and car ownership and to any policy intruments simulated.

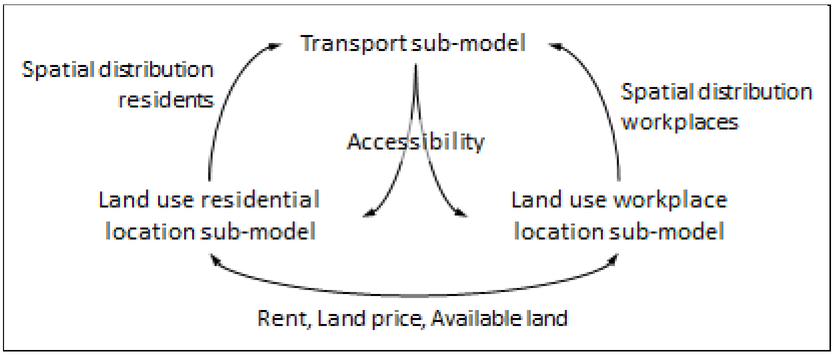


Figure 1 Overview of the MARS model

Figures 2 and 3 show examples of the causal loop diagrams (CLD) for the main responses included within MARS for commute trips by car and for development and relocation of residences respectively.

Figure 2 shows the CLD for the factors which affect the number of commute trips taken by car from one zone to another. Starting with the balancing feedback loop B1, commute trips by car increase as the attractiveness by car increases which in turn increases the search time for a parking space which then decreases the attractiveness of car use – hence the balancing nature of the loop. Loop B2 represents the effect of congestion – as trips by car increase speeds decrease, times increase and so attractiveness is decreased. Loop B3 show the impact on fuel costs, in our urban case as speeds increase fuel consumption is decreased – again we have a balancing feedback.

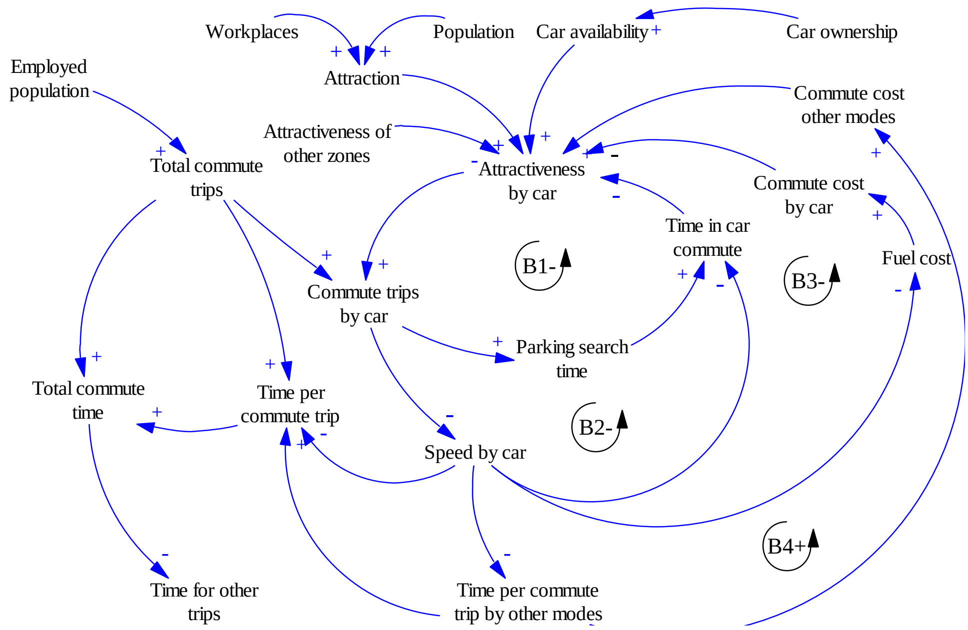


Figure 2 CLD for the transport model – commute trips by car in MARS

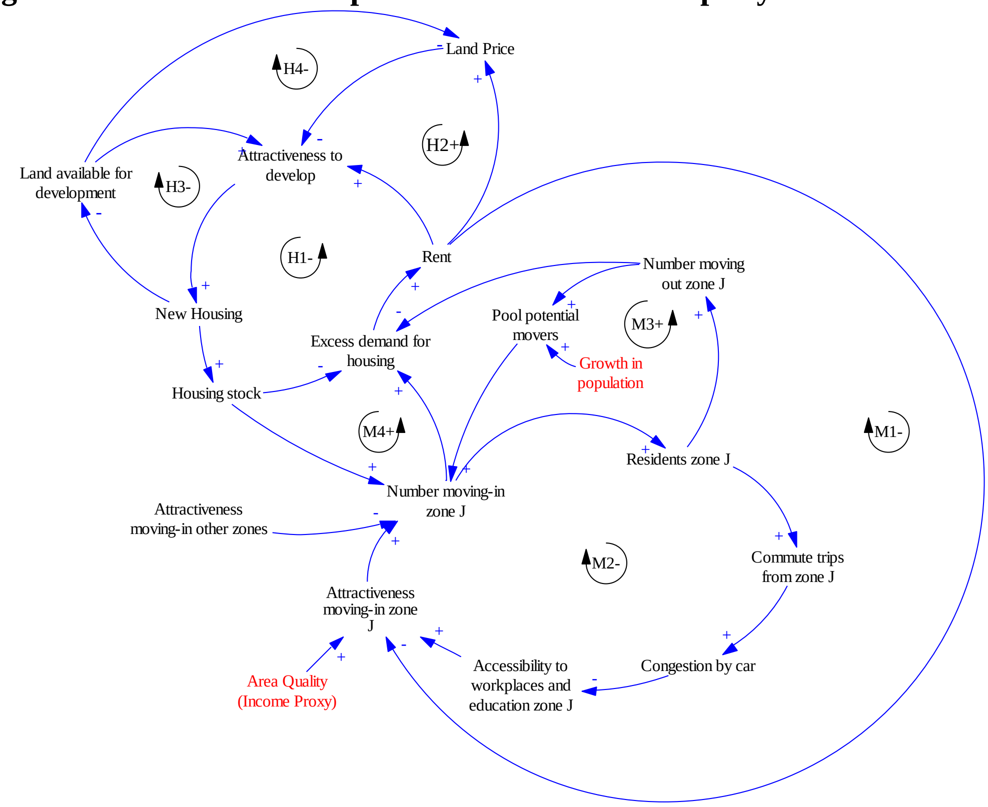


Figure 3 CLD for development of housing in MARS

Figure 3 shows the CLD for the development of housing and the interaction with location choice of residents in MARS. Starting with the development of housing, loop H1 is a balancing feedback loop which shows that the attractiveness to the developer to develop in a given zone is determined by the rent which can be achieved. The level of the rent is driven by the excess demand for housing which in turn is related to the housing stock and new housing developments. As new houses are developed the stock is increased which reduces the excess demand which then reduces the rent achievable which reduces the attractiveness to develop – resulting in a balancing loop. Loop H2 is a reinforcing loop as new housing reduces the excess demand which reduces rent and hence land price which in turn makes development more attractive all other things being equal. Loop H3 represents the restriction of land available for development; as land available is reduced then the attractiveness to develop is reduced. Loop H4 extends H3 to represent the effect of land availability on land price.

The housing development loops are linked to the residents' location choice. Firstly the main elements considered to influence the choice of location are rent, accessibility and area quality. As area quality is difficult to measure it is normal to take some kind of proxy for quality, in this case average income. The main loops in the residential choice are M1which is a balancing feedback loop – as more people move-in excess demand increases which increases rent which then reduces attractiveness to move in. M2 is also a balancing loop which shows that as the number of residents increases in a zone then congestion out of that zone increases which reduces accessibility to workplaces and so reduces attractiveness to move in.

Loop M3 is a positive feedback loop which simply shows that as the number of residents increases in a zone then the potential for moving out also increases (set as 10% of residents per year in the simplest case). This increases the pool of potential movers, which also includes growth in population (which could come from natural growth or in-migration and is taken from an exogenous forecast per annum). Loop M4 is a positive feedback loop which extends H1 – as more people move in this increases excess demand which increases rent and so increases attractiveness to develop which in turn increases the housing stock. Here it should be noted that housing stock available can limit the number of people allowed to move in to a zone as any excess demand is reallocated to other zones. This process reflects reality where excess demand must be taken up elsewhere if the capacity for residential occupation is reached in any one time period.

For further details on MARS readers are referred to Pfaffenbichler et al (2010).

3. CASE STUDY

In order to investigate the competition between cities and the impacts of competition on optimal tolls and other indicators, it was decided to use a simple hypothetical case study based on an aggregate representation of an existing more "spatially" complex model. This follows the discussion in Ghaffarzadegan et al (2011) who highlight the benefits of using small system dynamics models in addressing public policy issues. They found that small models are beneficial in conveying the essence of the feedback mechanism in a concise manner especially to decision makers. We therefore developed our small system dynamics model by aggregating to 2 zones from our previously validated 33 zone model of Leeds. We then formed a copy of the two zone model and allowed for interactions between cities to develop our hypothetical twin city 4-zone model (see figure 4).

In the single city model the population of Leeds is split between the inner zone 1 and outer zone 2 with more growth predicted in the outer zones by 2030. We call this City A and the additional hypothetical neighbouring city we will call City B.

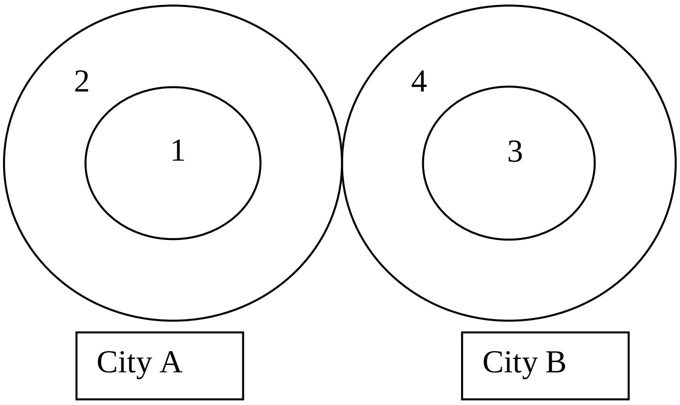


Figure 4 The Twin City zones

The forecast population in the 2-zone model of Leeds was validated against that of the full sized Leeds model with 33 zones. This full sized Leeds model in turn was calibrated to UK TEMPRO forecasts of population, jobs and workers (DfT, 2010). Table 1 shows the population in the inner and outer areas (zone 1 and 2 in the 2 zone model) for the 2-zone and 33-zone model of Leeds. This validates the 2 zone model and note that both models exhibit more growth in the outer zones i.e. urban sprawl continues in Leeds as forecast by TEMPRO.

Table 1 Population of Leeds in Year 30

Region	2-zone model	33-zone model
Zone1 (1-13 of 33 zones)	342879	343384
Zone2 (14-33 of 33 zones)	621780	621801
Total	964659	965185

In what follows, each city may decide to charge car users to travel to the central area (zones 1 or 3) within the peak period. The charge will be applied to their own residents as well as those from the other city (where it exists).

3.1 Welfare measures

Before explaining the scenarios considered, we first have to explain the welfare measures used.

For a single city in isolation, the local authority is assumed to maximise the welfare of their citizens. The traditional form of welfare measure within the transport field is the Marshallian measure which sums consumer and producer surplus. For tolling, the welfare measure includes the assumption that all revenues collected are recycled within the system i.e. shared back between the residents. For our case the measure may be estimated by the so called "rule of a half" (Williams, (1977)) and so the welfare measure is written as follows for the single city case :-

$$W \;= \sum_{i=1}^{n} \sum_{j=1}^{n} \left\{ -\frac{1}{2}\left[\propto \left(t_{ij}^{1} - t_{ij}^{0}\right)\left(T_{ij}^{1} + T_{ij}^{0}\right)\right] - \frac{1}{2}\left[\tau \left(T_{ij}^{1} + T_{ij}^{0}\right)\right] + \; T_{ij}^{1}\tau \right\} \qquad (1)$$

where,
t_{ij}^{1} = travel time between each OD pair *ij* with road charge
t_{ij}^{0} = travel time between each OD pair *ij* without road charge
T_{ij}^{1} = trips between each OD pair with road charge
T_{ij}^{0} = trips between each OD pair without road charge
τ = toll charge to central zone
n = number of origins/destinations
α = value of travel time

We simplify the welfare measurement even further by considering the impact on private traffic in the peak hours only. Whilst this is a simplification of the full appraisal, it does account for the main impacts of a peak charging scheme, i.e. private traffic time savings and the monetary impacts of a peak charge whose revenue is assumed to be ear-marked for the city[2].

It should be noted that for the isolated city, the local authority objective to maximise welfare will coincide with the objective of a higher level regulator e.g. the national government or some appointed regulator. Once we move to the twin city case, we now have two authorities whose aim is to optimise the welfare of their residents – including their journeys to/from the other city region. The welfare measure for each city is similar to that used in the isolated city, but now we need to consider transfers of revenue from city A to city B and vice versa. The welfare for city A may be written as follows :-

$$W_A = W_{i\in A} + R_{B\ to\ A} - R_{A\ to\ B} \qquad (2)$$

where,
$W_{i\in A}$ = welfare of residents from city A (origin i lies in city A), based on (1) above
$R_{B\ to\ A}$ = revenue collected by city A from residents of city B
$R_{A\ to\ B}$ = revenue paid by the residents of city A to city B

Now in the twin city case the higher level or global regulator would consider the total welfare of all residents i.e. $W_{total} = \; W_A + W_B$.

In all cases below, the benefit streams generated over the 30 year study period will be discounted to form a Net Present Value of benefits (discounted at 3.5%, DfT 2011).

Before presenting the various scenarios below, it is useful to look at how the welfare measures evolve over time and how the individual and collective benefits vary when a

[2] In reality transport appraisal in the UK takes into account impacts on other modes, wider economic benefits, environmental impacts as well as more qualitative impacts. See for example: https://www.gov.uk/transport-analysis-guidance-webtag#guidance-for-the-appraisal-practitioner

toll is imposed. Figure 5 shows how the welfare varies over time for City A, City B and in total as city A charges a toll of 5€ from year 5 onwards.

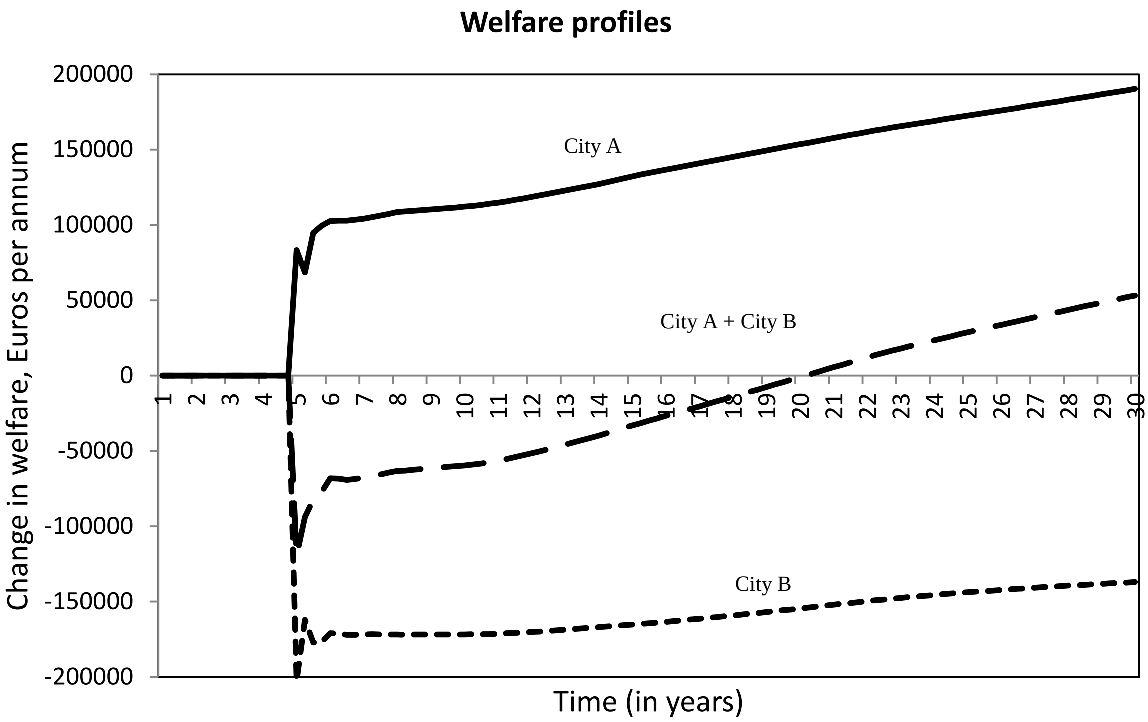


Figure 5 Variation in welfare over time when city A charges €5

From the figure we can see that when the charge is applied there are immediate positive benefits to city A which increase steadily over time as the demand from exogenous growth in population provides more potential for time savings compared to the do-nothing case. The benefits are made up from a combination of time and money benefits and a significant proportion comes from the revenues collected from city B's residents. City B's residents whilst benefitting from some time savings, lose all the toll revenues paid to city A and so the welfare change for City B is negative. The total welfare only becomes positive after year 20 when the time savings out-weigh the money losses in the system. Note that in the first year of implementation the benefits oscillate for a few months as the users take time to respond to the charges by changing behaviour until a new dynamic equilibrium is found. Whilst city A gains significantly from a charge of 5 €, city B obviously loses out and given the symmetry of this case study we would expect them to react with a charge of their own. There is obviously an incentive to begin charging for both cities from the above figures assuming that the other does not also charge.

Taking this analysis further, Figure 6(a) shows the how the NPV of welfare for city A (and due to symmetry city B) varies with combinations of tolls from city A and city B in the range 0-8 € while figure 6(b) shows the NPV of total welfare surface. The surfaces are smooth and convex in nature which indicates that we do not expect multiple local Nash equilibria as was found in Koh et al (2012). Looking at the city A surface, it can be seen that when city B does not charge, we should expect a maximum change in welfare for city A to occur for a toll of around 5 €. However as city B would have the same welfare surface with tolls transposed they would also be incentivised to toll. The Nash solution in this case will be where the derivatives of own city welfare with respect to own toll are zero for both cities. Due to the symmetry in this case, we can plot the point of intersection between the line where the gradient equals zero and the equal toll line and so the Nash solution should be found for a toll of around 6€ as shown by point N.

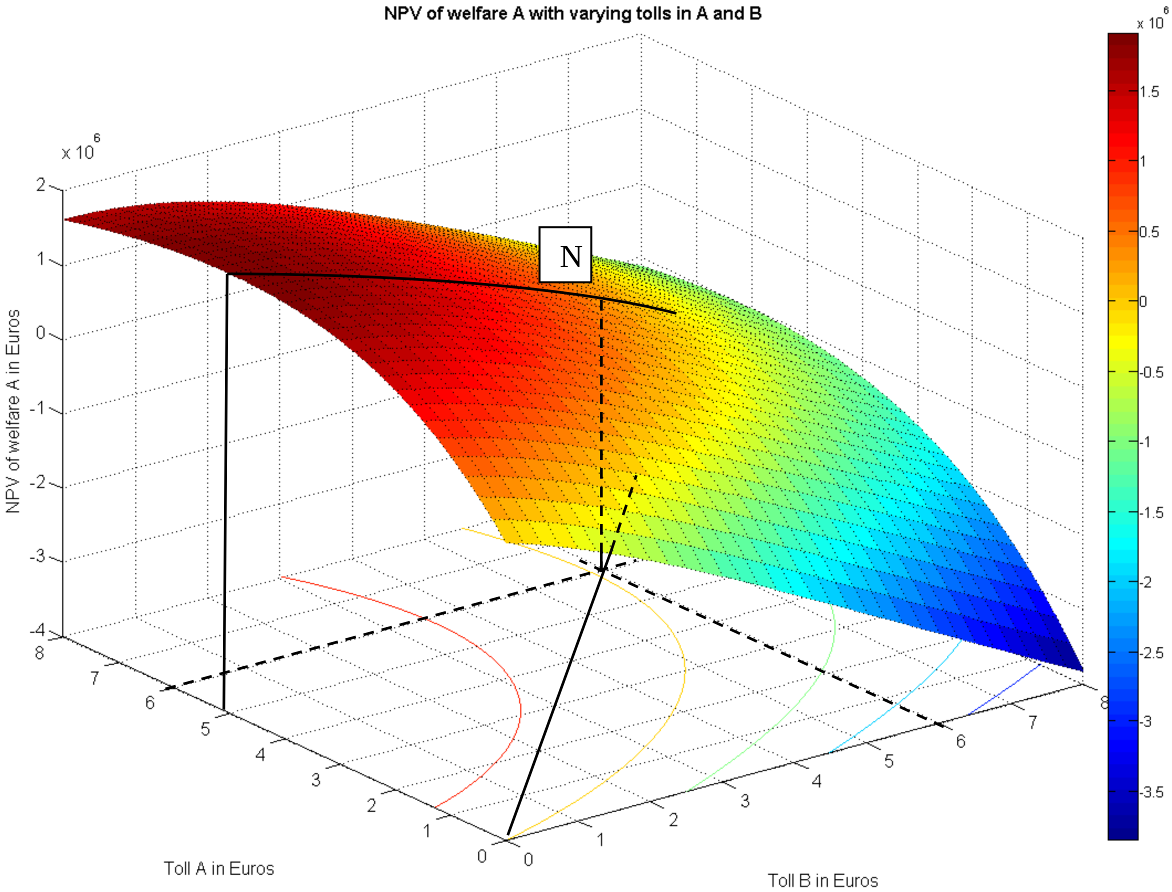


Figure 6(a) NPV of welfare in city A

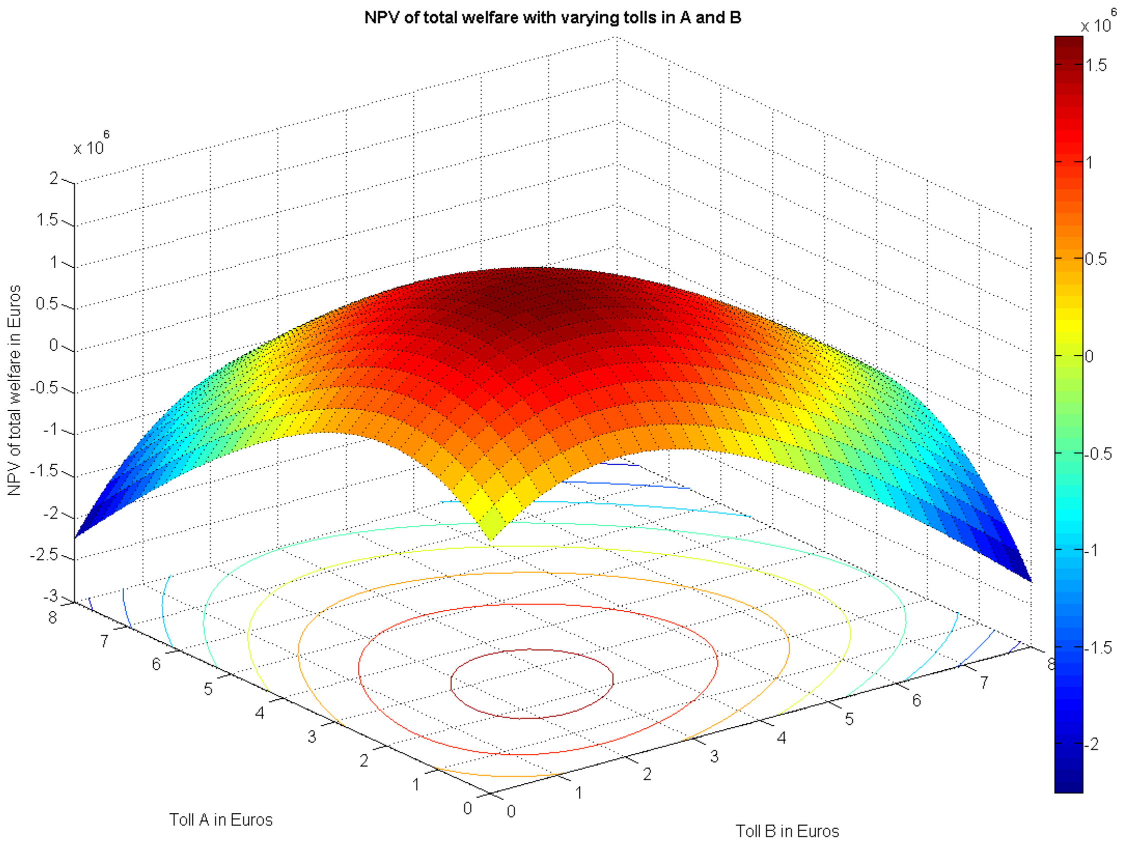


Figure 6(b) NPV of total welfare

Figure 6b shows the NPV of total welfare as tolls are varied. From this we may expect a global regulator to implement equal tolls of around 2.5€ to maximise total welfare.

3.3 Modelled Scenarios

This section sets out the optimal tolls and welfare implications for a number of different cases, namely :-

- Isolated city (2 zone model) – for the Leeds model only - City A
- City A or B tolls alone (within the twin city set up i.e. 4 zone model)
- City A and City B - regulated (4 zone model)
- City A and City B - Nash game (4 zone model)

In the first case, City A is considered in isolation and the local authority solution is to maximise the welfare of all residents. In this case there is no tax exporting behaviour and only one case to investigate. The next case considers City A or City B tolling within the twin city set up so some tax exporting behaviour is now possible. Finally there are two cases to consider where both cities are tolling users. The first is a regulated scenario where tolls are set to maximise the total welfare of all residents, the second is the Nash game where cities are maximising their own residents' welfare in a non-co-operative game. In this final scenario, tax exporting behaviour is assumed and revenues are not recycled between the cities. Note that for this symmetric case we only need to consider one city in presenting the results as the tolls will be identical.

Next, it should be noted that as the model predicts the impacts over a 30 year period we could in theory allow the tolls to vary over time. We would expect as the population is set to increase, that congestion would increase so we may expect the tolls to increase over time as potential time benefits increase. However to simplify the discussion and presentation of results we instead only consider constant or flat tolls over time.

In order to find the optimal toll levels, the VENSIM optimisation tool was used to maximise the appropriate welfare measure by varying the values of the relevant tolls. Note that to calculate the Nash outcome, a diagonalisation approach was used whereby City A maximises their own welfare first with tolls for City B held constant, then city B optimises their welfare with tolls for city A held at the previous iteration value. This was repeated until convergence which was usually found to be within three to four rounds of each game.

3.4 Optimal Tolls and Welfare

Table 2 shows the optimal tolls and Net Present Value (NPV) of welfare change for each city per day plus the total welfare change for both cities for the symmetric cases.

Table 2: Tolls and NPV of welfare changes per day

Scenario	Optimal Tolls €	NPV of Welfare A €	NPV of Welfare B €	NPV of Total Welfare €
City A 2-zone only	2.63	325,991	N/A	325,991
Single City A	5.00	1,905,000	-2,282,000	-376,847
Regulated 2-city	2.53	815,761	815,761	1,631,522
Nash Game	6.08	-127,729	-127,729	-255,458

Table 2 exposes a number of observations. Note first of all that the optimal tolls found by the VENSIM optimisation facility for the single city (in the twin city setting), the Nash game and the regulated 2-city scenario are in line with the grid search shown in figures 5(a)-(b). Next, if a city is assumed to be an isolated city then the optimal tolls are lower than when the same city has a neighbour and is able to extract toll revenue from a neighbouring city. The welfare for city A is also significantly higher when A tolls alone and toll exporting behaviour is included in the model. This increase in the welfare of city A is at the expense of those residents in city B, but the total welfare change over both cities shows that together they are worse off as the total welfare change is negative.

Due to symmetry, the tolls under the two city regulated case are equal and are the lowest tolls from all scenarios. As expected, the regulated two city case returns the highest total welfare but the welfare to each city is much lower than could be achieved in the single city case. The most interesting case is the Nash game where both cities engage in a game and this results in the highest tolls. As a result, both cities are worse off than in the no toll case with a reduction in welfare. This is the classic prisoner's dilemma which appeared in the work of Koh et al (2012) as described earlier. Note that whilst we have found a classic prisoner's dilemma as in our earlier work, we have shown that in our case we have no local Nash equilibria (LNE) as in Koh et al (2012). The local LNE arose in the earlier model due to the inclusion of route choice within the model. The fact that we have only one Nash solution simplifies the discussion around policy implications as there are no local solutions which lie close to the regulated solution as was the case in our earlier work.

4. DYNAMIC GAME SET UP

The Nash solution above has been generated assuming that both cities have access to the same model of the future and that they plan tolls in advance of actual time. It does not simulate the real time strategies of the cities. In order to test how cities may set a strategy, we now set up a game within the simulator whereby each player will act as a city authority and will have access to information on changes in current welfare for their city, revenues collected and tolls set by the opposing player (in preceding periods). The game is more akin to the five year local transport planning process used in the UK whereby cities update their five year plans and monitor and evaluate the impacts over time via a set of mandatory indicators, (DETR 2000).

Figure 7 shows a screen shot of the view available to player A. The player sees his own charge which can be set every 5 years with the slider, the impact of both player's charges on their own residents' welfare measure, the total revenue collected in their city and the charges set in previous periods by the other player. At the end of the game they can also view the NPV of welfare change over the whole period in the table for their residents only (bottom left of the screen).

Within each game, five charging decisions are made simultaneously by both players in years 5, 10, 15, 20 and 25. (The first five years have no charge applied). The game is then repeated for each pair of players a total of six times. So in total each player will make 5*6=30 decisions. Sixteen pairs of players were recruited from Masters and PhD students from the Institute for Transport Studies, University of Leeds and as such could be considered to have some knowledge of transport policy. Players were instructed to play the game to maximise their NPV of welfare change at the end of each round (paper was provided so that they could record NPV and tolls charged at the end of each game). Eight of the sixteen pairs formed the control group and played the game six times. The other eight pairs were given the same instructions but after the third game they were presented with information about the low toll regulated solution (see later). The idea behind this was to investigate whether provision of information about the low toll solution changed the way in which decisions were made in the subsequent games.

Whilst we will be comparing the results to those of the flat-toll one-shot Nash game presented above, the game itself does not fit into standard games in the literature. On the one hand it is a repeated simultaneous game as each 30 year period is simultaneously played out six times between each pair. On the other hand, decisions within the 30 year period are not repeats of the previous five year period as the welfare or pay-off evolves over time with increased population and congestion as explained using figure 3 above even for a constant charge. It is expected that players will react to the cues provided from the previous time periods within each game and from the previous rounds. Each player is however not aware of what the other player has decided for the current five year period thus making it a simultaneous game.

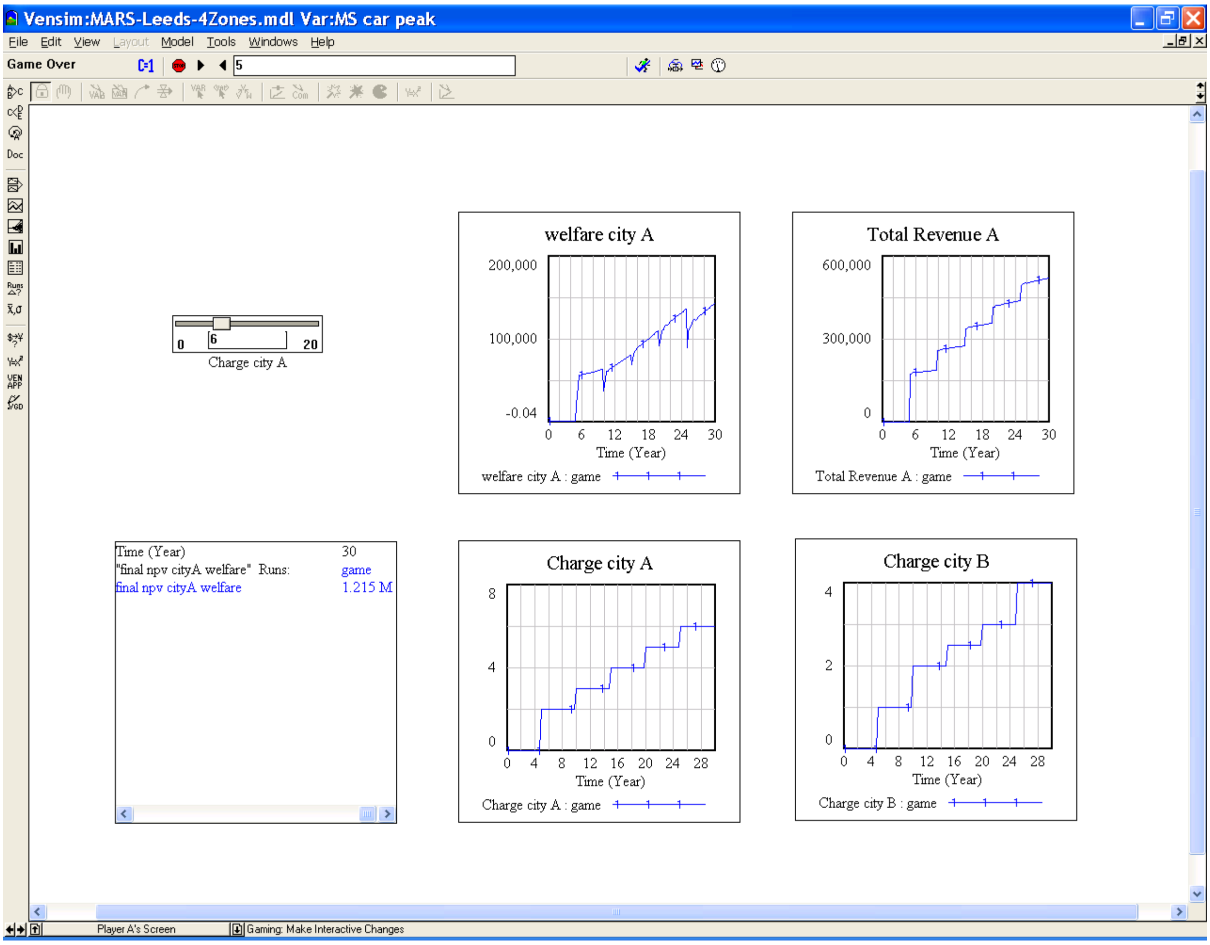


Figure 7 Screenshot of Player A's screen

From the previous analysis of the flat-toll game over the same period we may expect four types of strategy to emerge during the game as shown in table 3. As in the flat toll game presented above, there exists only one Nash Equilibrium with both players playing relatively high tolls but being worse off in terms of welfare than if no toll had been played and we may expect that players end up in this category after a number of rounds. We would not expect the high-low solutions to be stable as players have time to react within the round. Finally we are interested to see whether the players find the low toll solution close to the regulator one as they do not have full response surface information to hand.

Table 3 : Potential strategies

	B Low	**B High**
A Low	**Cautious movers** – both tolls low and end up near the low toll regulator solution.	B realises the benefits of charging higher than A – aiming for the single city optimal toll while A loses out.
A High	A realises the benefits of charging higher than B – aiming for the single city optimal toll while B loses out.	**Aggressive movers** – both players realise the sole benefits of high charges but end up near the Nash trap high toll solution.

While the control group played six games without any information, the informed group were allowed to play the first three rounds as per the control group. These games were used to let the players learn about the welfare changes as tolls are varied and we expect relatively poor decisions to be made on average over these three games with players falling into more aggressive play than cautious play as they can quickly see how charging more than your opponent can increase own welfare.

However as explained earlier, we then wished to investigate whether players would respond to information about the global regulator solution which requires both players to charge less than their own optimal toll, but which benefits both in the long run.

After the third round, both players of the informed group were shown information regarding the global regulator solution. They were shown the optimal flat toll of 2.53€ and a screen shot of how their welfare would evolve over time and the final NPV for each player (815,761) as in table 2 above. The next three games were then played out.

The entire gaming experiment was designed in such a way to test whether offering information about the benefits of collaboration or regulation would change the way in which the players behaved during the games. If the act of playing the game through the planning tool with information about the regulated solution can change behaviour, then this may have significant implications for the regulation of city strategies. We hypothesise that if they accept the regulated solution, then they avoid the Nash trap and education about collaborative benefits is something which may be pursued rather than regulation.

5. RESULTS

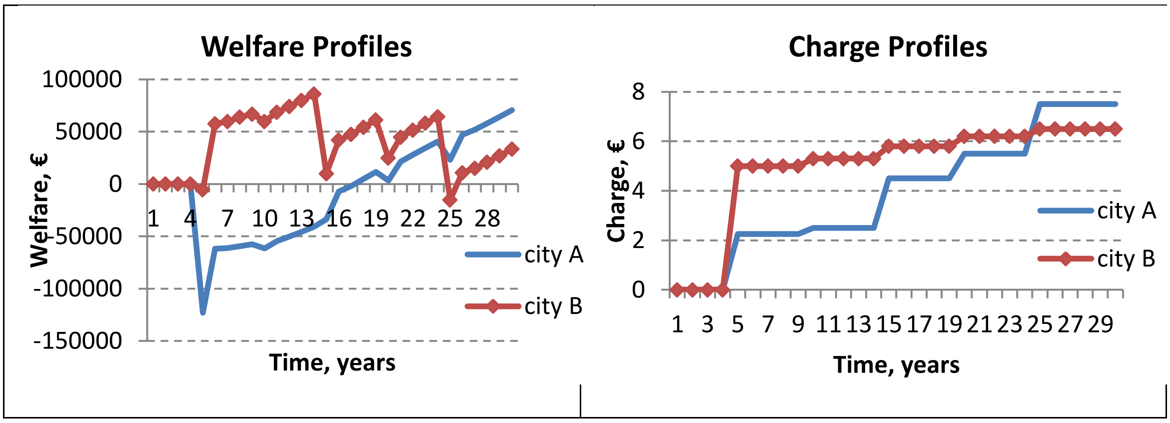
The eight pairs of players within each group were randomly assigned as player A or player B and in analysing the results it was useful to aggregate results of the informed group into four sub-groups as follows:-

A1-3 player A games 1-3
A4-6 player A games 4-6
B1-3 player B games 1-3
B4-6 player B games 4-6

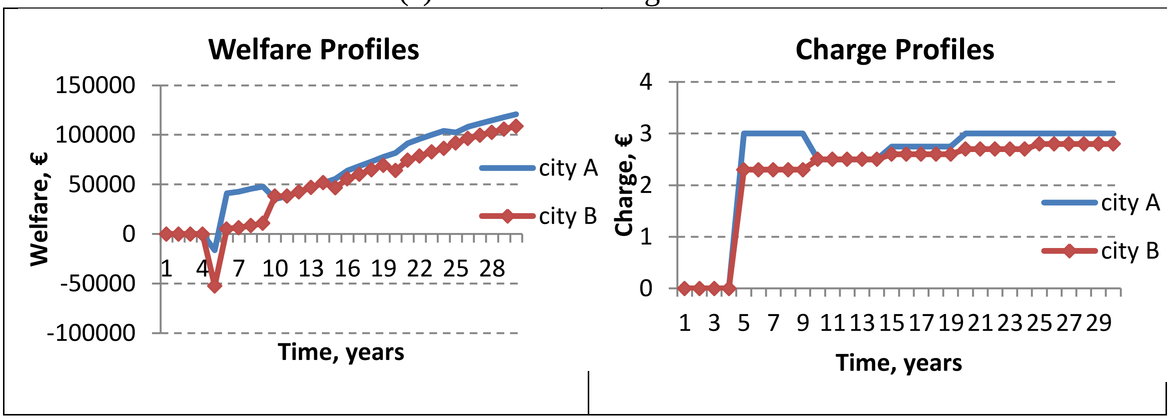
Within each sub-group there are 8 players, 3 games and 5 decisions per game i.e. a total of 8*3*5=120 decisions per sub-group. In addition we are also able to compare with the controlled group games 1-3 and games 4-6 for each player A and B.

Before going into the aggregate analysis of start charges, end charges and NPV of welfare we first discuss a typical game 3 and typical game 6 which represent behaviour before and after the regulator solution was shown i.e. to the players within the informed group.

Figures 8a and 8b show the charges and welfare changes per day for both players for games 3 and 6 from a typical pair of players within the informed group.



(a) Before receiving information



(b) After receiving information

Figure 8(a),(b) Typical games before and after receiving information on optimal tolls

As can be seen game 3 ends with higher charges than in game 6 which as will be shown below is typical. In game 3, player B sets the higher charge initially and sees a positive welfare change. Player A seeing this and his associated negative welfare change responds with higher charges until both are charging over 6€. In game 6 the players have accepted the low toll regime and both see positive welfare changes. They maintain the low tolls and there is evidence of reciprocal behaviour. The next sections look at the aggregate results over the groups of players and games.

5.1 Mean value of charges before and after information

Table 4 shows the mean and variance of the charges at the start of the game and the end of the game period for each group. Taking the end values first, we can see that the mean values for both players A and B are reduced in games 4-6 after the regulator information compared with games 1-3. Paired t-tests show that these differences before and after information is given are statistically significant with p-values all below the Bonferonni adjusted critical value of 0.0083 (see appendix). The differences between players A and B for both sets of games were also shown to be insignificant so we can conclude that the players were acting in a similar manner whether assigned to A or B. It is noticeable that the mean values of 3.79 and 3.64 are still higher than the optimal flat toll of 2.53€. It should however be noted that other tests involving a linearly increasing toll over time showed the optimal toll to start at around 2€ and increase to 3.0€, so some higher value may be expected.

Table 4: Mean and variance of toll charges

	Charge at the start		Charge at the end	
Group	Mean, €	Variance	Mean, €	Variance
A1-3	3.99	6.75	6.29	15.47
B1-3	4.10	5.34	7.81	19.47
A4-6	2.88	1.27	3.79	2.93
B4-6	3.05	1.49	3.64	2.30
ConA4-6	7.46	19.7	7.76	27.6
ConB4-6	7.12	6.61	9.91	34.5

The start values show a slightly different pattern of results. Whilst the mean values for games 4-6 are reduced to 2.88 and 3.05€ for groups A and B respectively, these are not statistically different to the values from games 1-3. This is a reflection of the higher variance seen in the first three games where players are more prone to varying the starting point to assess the impacts of different charging regimes. The fact that the variance is reduced significantly in the subsequent games reflects the players' acceptance of the information and willingness to collaborate with a low toll solution. This fact is further confirmed by the comparison with the control group start and end charges for games 4-6 (ConA4-6, ConB4-6) in Table 4 where they are seen to be statistically lower than the control group charges (See Table A4, A5 in the appendix).

5.3 NPV of welfare results

This section compares the outcomes of the games in terms of NPV of welfare change for each city for each game and the mean values for the groups of games and players.

Figures 9 and 10 show the NPV for player A against the NPV for player B for games 1-3 and games 4-6 respectively (i.e. 24 points per figure). In addition the square symbols show the results from Table 2 of the regulator low toll solution, the Nash solution (both negative NPV) and the single player optimal toll solutions where only one player tolls high and the other does not respond. These act as benchmark solutions against which we can judge the performance of the players. Similar to the analysis of performance in the Fish Banks game using repeated simulation experiments reported by Kunc and Morecroft (2010) we may split the space into the four quadrants as follows :-

Quadrant 1 : Cautious movers. Both NPVs are positive. This comes about when tolls are relatively low and are bound by the optimal regulator solution.

Quadrant 2 : NPV A positive, NPV B negative : player A generally plays a higher toll than B while B chooses a low toll. The benchmark solution is the A solo optimal toll.

Quadrant 3 : Aggressive movers. Both NPVs are negative. Both A and B play relatively high tolls which may result in highly negative outcomes for both players. Outcomes can be much worse than the Nash solution if both tolls are very high.

Quadrant 4 : The symmetrical opposite of Quadrant 2.

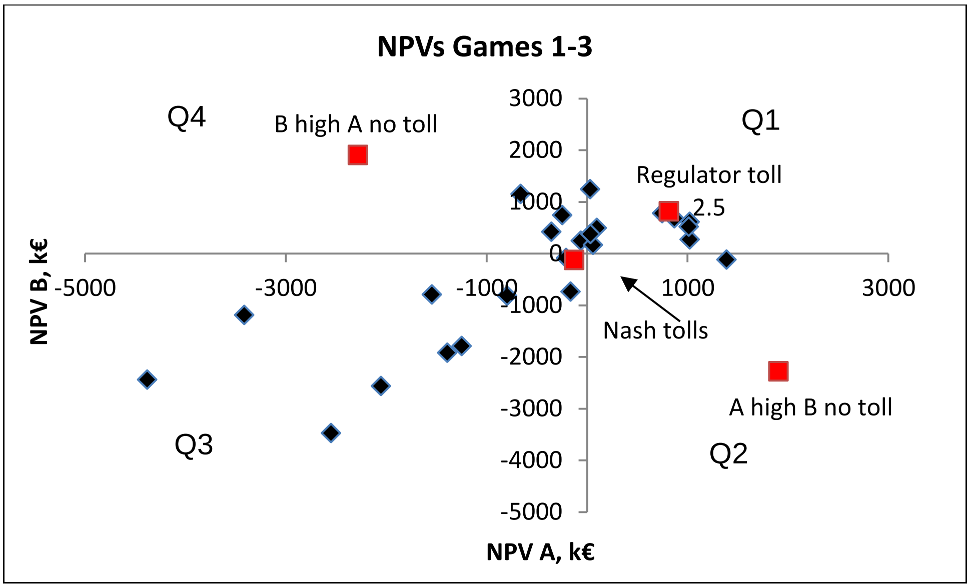


Figure 9 NPV results informed group games 1-3

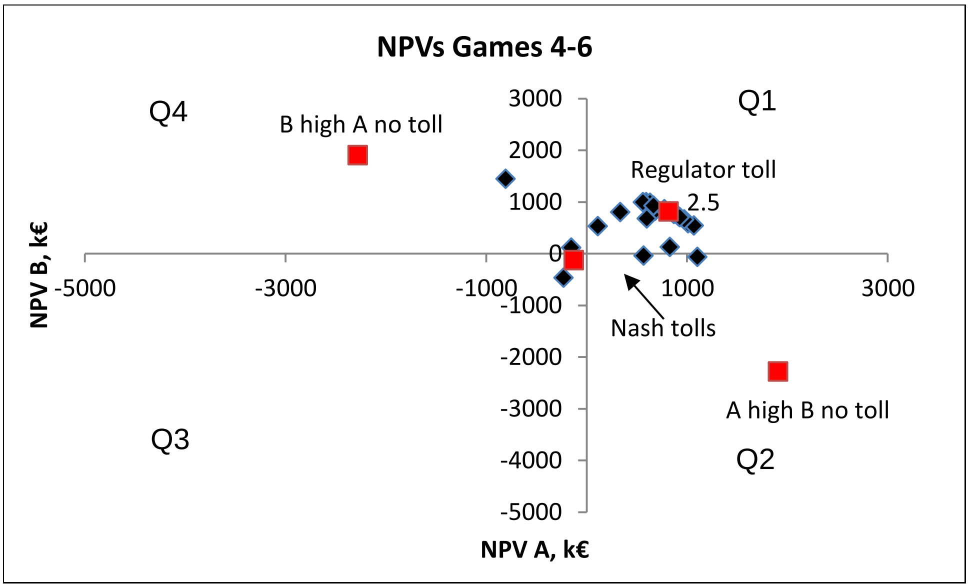


Figure 10 NPV results informed group games 4-6.

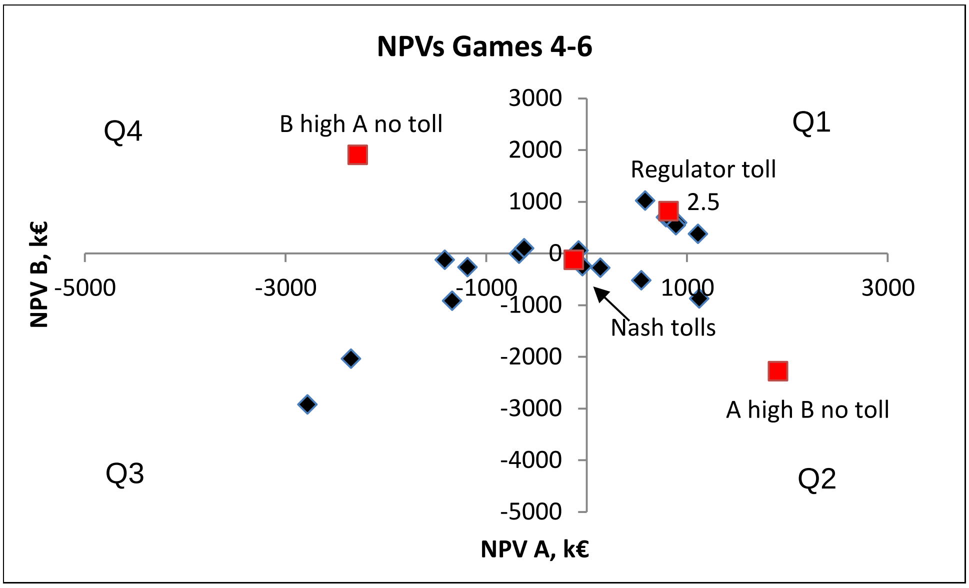


Figure 11 NPV results for the control group games 4-6

From the figures we can see that in the first three games there are more solutions resulting in negative welfare for at least one player than there are solutions which result in positive welfare for both players. There are nine solutions where the welfare is highly negative for both players and the welfare losses are orders of magnitudes worse than the Nash solution which shows that players can easily fall into a battle of the tolls.

In contrast after receiving information, figure 10 shows that the outcomes are mainly located in quadrant 1 where both players receive positive outcomes. Three of the solutions result in negative outcomes for player A which are a result of player B defecting to a higher toll rather than collaborating. However there are many more games where the players collaborate and do not defect to higher tolls. This suggests there is some benefit in the information given and that as it is possible to change tolls every five years, there is a threat of both players receiving significant losses if both defect to higher tolls which appears to maintain the collaboration.

Figure 11 shows the same scatter plot of NPV for the control group games 4-6. The spread of results is similar to those from games 1-3 and contains only a few results within the first quadrant. This suggests that the uninformed players are continuing with the aggressive or defection strategies more often than the informed players.

In addition to the figures discussed above, table 5 shows the means and variances of the NPV of welfare values obtained in games 1-3 and games 4-6 for players A and B. As with the end charges, the mean values are not statistically different between players A and B but are statistically different between games 1-3 and games 4-6 (see appendix for p-values). The mean values are seen to change from negative changes in welfare to positive ones (although still lower than the value possible from the regulated solution). In addition the variance between games is also reduced all of which suggests that the players have learned that collaboration is beneficial. Finally, the informed group NPV of welfare for games 4-6 is also statistically different to that of the control group values shown in Table 5 (see Table A6 of the appendix for p values).

Table 5: Mean and variance of NPV of welfare

	Net Present Value of welfare per day	
Group	Mean, €	Variance
A1-3	-533,015	2.10E+12
B1-3	-344,356	1.64E+12
A4-6	599,235	2.10E+11
B4-6	632,732	1.78E+11
ConA4-6	-1,817,059	9.64E+12
ConB4-6	-1,586,921	7.93E+12

5.4 Logical outcomes – evidence of learning and collaboration

Within each game the players are developing a decision-making strategy based on previous tolls (of both players), revenue collected and welfare changes over time as a result of the tolls set by both players. One approach to investigate whether their strategies are rational and whether they are learning over time, is to check for satisfactory outcomes or logical outcomes after each decision point. We do this by checking whether the welfare increases between decision points (after 5 years) i.e. if welfare (t+5) > welfare (t) then this is said to be a satisfactory or logical outcome which reinforces the strategy of the player. We acknowledge that this is by no means a measure of whether the decision is optimal (we would not expect the decisions to be optimal at all points in time); rather we are counting the number of times a player feels satisfied that their decision is moving them in the right direction (increasing welfare).

Within each group of three games there are 16 players making 5 decisions per game i.e. a total of 240 decisions are made in games 1-3 and another 240 decisions are made in games 4-6. The number of satisfactory outcomes in the games 1-3 is 141 (58.8%) which then increases to 204 (85%) in games 4-6. Furthermore if we analyse the number of cases where both players make a satisfactory move at the same time this increases from 38.3% in games 1-3 to 70.8% in games 4-6. This is strong evidence that collaboration and learning takes place after information has been provided. In games 4-6, there is evidence that the players reciprocate the charges of the opposing player and maintain a collaborative state with lower charges rather than defect towards a self-serving higher charge strategy. This appears to come about naturally and has been observed in both the economics (Bolton and Ockenfels, 2000) and the game theory literature, Dufwenberg and Kirchsteiger (2004), Falk and Fischbacher (2006) who develop theories of reciprocity to explain the behaviour. Essentially, it appears that both players are willing to accept the lower toll regime and recognise that if one should defect to a higher toll then the other will follow suit in the subsequent period and so eliminate any potential gains. This behaviour is important as it suggests that by providing information about the regulated solution where both parties receive welfare improvements, that players will respond positively and that a Nash Trap may be avoided.

6. CONCLUSIONS

In this paper we first of all applied the MARS Land Use Transport Interaction Model as a planning tool to demonstrate the potential optimal tolls for two neighbouring cities. Used in this way we showed that for a one-shot game where cities set a toll for the future and stick to that toll then a Nash Trap exists which would result in negative welfare changes for both cities. We also showed that both cities would benefit from a lower toll regime under some form of regulation. These results were in line with our previous research conducted with a static network assignment model as reported in Koh et al (2012). We then applied the simulator in a game playing mode to test how decision-makers would update their strategies in response to cues including charges set by the other city and changes in own city welfare over the previous periods.

For the informed group, the game was repeated three times before information about the low toll regulator solution was presented to the participants and the game repeated a further three times. The mean values of the end charges for the games 4-6 were seen to be statistically lower than those in games 1-3 and those in games 4-6 from the control group. The NPV of welfare changes were also statistically higher and now positive in games 4-6 and were statistically different to the values from the control group. An analysis of the number of logical or welfare improving decisions demonstrated learning and evidence of collaboration in games 4-6.

Overall the results demonstrated that after receiving information about the low toll regime, the players chose to collaborate and maintain the low toll solution. Players were willing to accept the lower toll regime and recognised that if one should defect to a higher toll then the other may follow suit in the subsequent period and so eliminate any potential gains. This behaviour is important as it suggests that by providing information about the regulated solution where both parties receive welfare improvements, that players will respond positively and that a Nash Trap may be avoided.

This result brings into focus the question of how cities actually make decisions about future strategy. If they plan using models of the future and apply one shot strategies then they may find themselves in a Nash Trap with higher tolls imposed on the general public. If however they make decisions and regularly review them against a set of indicators and benchmark against others' actions then improving information about the benefits of collaboration may result in lower tolls and welfare improvements.

We suggest that education through gaming or simulators such as MARS rather than direct regulation may be used in developing transport strategies across regions or where there are more than one interested party involved. This education over regulation will though only be plausible in cases where there exists the opportunity to demonstrate reciprocal behaviour over a period of time or where it is obvious that defection may be punished in subsequent periods. These results could have significant implications for the development of city strategies within regional partnerships, something which will become more common with the current government's devolution of power and the establishment of local transport bodies to oversee spending on major schemes from 2015. Future research is needed to include not only the objectives of local authorities within the model but also objectives and responses of other stakeholders such as local transport operators.

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Appendix: Statistical inference of gaming results

Table A1: t-test: p-values for paired charge values at start

Group	A1-3	B1-3	A4-6	B4-6
A1-3	-	0.8817	0.0647	0.1184
B1-3		-	0.0271	0.0579
A4-6			-	0.6243
B4-6				-

Table A2: t-test: p-values for paired charge values at end

Group	A1-3	B1-3	A4-6	B4-6
A1-3	-	0.2158	0.0076	0.0044
B1-3		-	0.0003	0.0002
A4-6			-	0.7453
B4-6				-

Table A3: t-test: p-values for paired NPV values

Group	A1-3	B1-3	A4-6	B4-6
A1-3	-	0.6353	0.0011	0.0008
B1-3		-	0.0020	0.0014
A4-6			-	0.7933
B4-6				-

Table A4: t-test: p-values for paired charge values at start

Group	A4-6	B4-6
ConA4-6	0.002367	0.003896
ConB4-6	0.001464	0.002084

Table A5: t-test: p-values for paired charge values at end

Group	A4-6	B4-6
ConA4-6	0.001504	0.000998
ConB4-6	0.000225	0.000156

Table A6: t-test: p-values for paired NPV of welfare values

Group	A4-6	B4-6
ConA4-6	0.000939	0.000818
ConB4-6	0.000972	0.000834