Modelling a social dilemma of mode choice based on commuters’ expectations and social learning

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Abstract

This study attempts to apply an agent-based approach to modelling a social dilemma of travel mode choice considering psychological and sociological aspects. A traveller is modelled to have expectations, which shows the traveller’s beliefs about the influence of other group members on his action, as decision-making rules. Social interaction using a group-based interaction is hypothesized to be important. We apply an imitation game based on social learning mechanisms to the model. Two kinds of mechanism are used: payoff-biased and conformist transmission. The model reveals the conditions that make cooperation as a possible outcome are optimistic bandwagon expectations, group-based interactions, and strong conformist transmissions.

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1. Introduction

As more individuals commute by car, people may experience the negative consequences of the traffic congestion and environmental pollution. It is in the interest of all if more people decide to commute by public transport, as this will minimize impacts to congestion and pollution. This particular type of interdependence with conflicting individual and collective interests can be framed as a social dilemma.

Let us think of a simple bi-modal transport system which comprises car and bus as the two modes of transport, where both modes share the same highway space. If all commuters travel by car then they all face severe congestion. When some individuals choose to switch from car to bus, a number of cars are removed from the road and therefore marginally reduce the traffic level and improve the journey for all users. However, these individuals gain payoff less than individuals who do not switch to bus. According to the first property (of two properties) of a social dilemma defined by Dawes (1980); regardless the decisions of others, car users always gain better payoffs. If all individual are rational, then the best decision for an individual is to ‘free-ride’ on others by keeping up their car-use. However, according to the second property; if all travellers switch to bus then they all will receive better payoff, which is less congestion, hence less travel time, cost, etc.

Measures in travel demand management (TDM) have addressed the social dilemma by incorporating both on structural approach (often called ‘hard’ measure) and on individual-psychological approach (often called ‘soft’ measure). Structural approach seems to be effective since it eliminates the dilemma by changing the payoff structure, but consideration of psychological factors has received more attention recently. Gärling et al. (2002) suggested a research direction into exploring...
the effects of other users on the transport system given the interdependencies present in the system. They highlighted that users’ actions may affect the actions of others, and that the actions of others may affect a target user in a different way from the one intended by a particular TDM measure.

Some agent-based models in transport have focused on travel route choice, emphasizing day-to-day simulations. Several works on route choice behaviour by Nakayama et al. (1999, 2001) and Nakayama and Kitamura (2000) are in this category. Travellers were modelled to have bounded rationality, limited information, and also capability to do cognitive learning. Klugl and Bazzan (2004) also studied route choice behaviour by using a simple heuristic model. They also simulated agents’ learning to avoid the Braess Paradox by considering agents’ past experiences and adaptation (Bazzan and Klugl, 2003). A philosophical and cognitive science-based framework, which is named as belief–desire–intention (BDI), was used for modelling route choice behaviour (Rossetti et al., 2002). Route choice and departure time choice behaviour of commuters’ were modelled by endowing mental attitudes embedded in BDI framework. Dia (2002) simulated route choice behaviour of commuters under the influence of real-time information, also incorporating BDI framework. These researches demonstrated the feasibility of agent-based approaches to develop more complex driver behavioural dynamic.

In travel mode choice, not so much work has been carried out by researchers. As an exception is one inspiring work by Kitamura et al. (1999) which modelled a social dilemma within a simple bi-modal transport system by using cellular automata. Our previous work on modelling mode choice decision making of travellers by using finite-state machines is also relevant (Sunitiyoso and Matsumoto, 2005).

Our study focuses on commuters’ travel mode choice. Most modal-split models rest on the presence of equilibrium. Equilibrium analyses presuppose that the driver is rational and homogeneous, and has complete information. Many studies assume that a user predicts costs of transport modes and chooses the mode with the smallest cost. Actually, they do not necessarily minimize cost but may adopt a strategy, such as continuing to take the same mode, changing to other modes periodically, or even using a kind of decision-making rules.

By using a simple bi-modal transport system, the social dilemma situation of travel mode choice is modelled. Bus users are considered as cooperative travellers, since they behave cooperatively for the sake of all people’s benefit. Private car users are non-cooperative travellers since they only consider their personal interest. Each traveller has a decision-making rule, which is used to decide her mode of commuting, and receives payoff of her choice of mode.

This study aims at providing a model of travel mode choice utilizing the agent-based approach in order to understand behavioural process of commuters on choosing mode of commuting. The role of expectations on travel mode decision making is investigated, as well as the influence of social learning as the way of spreading a mode choice behaviour. Group-based interaction among travellers is one of factors that are predicted to be influential on choice behaviour of travellers. A user-equilibrium point may also be reached, but we are more interested on the process of reaching the point and the behavioural-change of travellers during the process. By introducing an evolutionary approach into travellers’ learning process, the model is expected to provide an insight into the way of solving the social dilemma.

The Intelligent Transportation Systems (ITS) (e.g. Advanced Traveller Information System (ATIS)) as well as media (e.g. newspaper, radio, TV, etc) may also have influence on travellers’ decision making. However, they are beyond the scope of this paper. We specifically focus on direct processes (person-to-person) of social interaction and social learning between travellers.

2. Agent-based simulation model

Travellers’ commuting behaviour can be represented by the behaviour of autonomous agents in a simulation model. The behaviour of agents is based on mechanisms updated by an evolutionary approach. The model is also used to represent interactions among travellers and complex decision-making processes within each traveller’s mind.

Our model consists of two submodels: a transport model and a traveller model. Fig. 1 provides an overview of the way the simulation model works. In the traveller model, each traveller chooses a travel mode based on the rules of expectations. After all travellers have chosen their mode of commuting, the travel time is calculated in the transport model. After that, the generalized travel cost for each mode can be calculated and returned to travellers as payoffs. Payoff of each traveller depends on her choice of mode. These decision-making processes are repeated for 10 iterations (t). Each 10-iteration is considered as one generation (g). Before a new generation starts, an evolutionary process is used to evolve each traveller’s type of expectations by means of simulating social learning mechanisms.

2.1. Transport model

The transport model is a simple bi-modal transport system, which comprises private car and bus as choices of commuting. The two modes are assumed to be operated in the same lane so that a social dilemma exists within travellers on choosing between the two choices. Each traveller, for instance traveller i who is a member of a set of travellers $S (i \in S)$, owns a car so that in each iteration $t$ she may alternate mode of travel $m_i(t)$ between bus $B$ and car $A$ ($m_i(t) \in \{A, B\}$). In each
iteration, she knows the cost of chosen mode but not the other mode that is not chosen. Private car users are assumed to be solo drivers who drive cars on their own. As for buses, their operating frequency and fare are adjusted so that bus passengers can pay the full cost of operating buses.

Equations and their parameters of generalized travel costs for car and bus are derived from the work of Kitamura et al. (1999). The generalized costs of travel by car and by bus can be expressed as follows respectively:

\[
V_A = K_{A0} + K_{A1}T_A, \\
V_B = K_{B0} + K_{B1}T_B + K_{B2}(FR_B/2) + K_{B3}W_B,
\]

where \(V_A\) and \(V_B\) are generalized one-way travel costs of car and bus respectively, \(T_A\) and \(T_B\) are one-way travel times by car and bus respectively, and \(K_{A0}\) and \(K_{B0}\) are constant coefficients of car and bus respectively. Since both car and bus operate on the same lane, their travel times are similar (\(T_A = T_B = T\)). In the model, payoff functions of using car and bus are simply given by these equations:

\[
P_A = \text{Const} - V_A = \text{Const} - (K_{A0} + K_{A1}T), \\
P_B = \text{Const} - V_B = \text{Const} - (K_{B0} + K_{B1}T + K_{B2}(FR_B/2) + K_{B3}W_B).
\]

Detailed equations for travel time (\(T\)), bus fare (\(FR_B\)), and bus waiting time (\(W_B\)) can be found in Kitamura et al. (1999). For the simulation run, the parameter values are given in Table 1.

By using these parameter values, the generalized costs of car and bus can be plotted against the fraction of car users as in Fig. 2. The generalized cost of a car trip (\(V_A\)) is equal to that of a bus trip (\(V_B\)) at points A and B. In the equilibrium analysis, Point A is considered as the user-equilibrium point. Point B is an unstable equilibrium point. Above this point, the bus has a higher generalized cost, and the difference in travel cost between the two modes increases as the fraction of car users increases. As the consequence, a slight increase in the number of car users may trigger a larger increase, and finally the system ends up with 100% of fraction of car users.

### 2.2. Traveller model

Huberman and Glance (1993) argued that individuals’ decisions on whether or not to contribute to the collective good depend not only on the past experience but also on their expectations as to how their actions will affect those of others and
vice versa. In this study, the decision-making rules of a traveller is represented by an expectations curve, which shows the traveller’s belief about the influence of others on her action.

There are two types of belief that may represent an individual’ expectations: the bandwagon and opportunistic expectations (Huberman and Glance, 1993, 1994). Three types of bandwagon expectations will be used in the simulation experiments, by assuming that all individuals are willing to cooperate without ever thinking to ‘free-ride’, but their willingness depends on their types of bandwagon expectations’ curve: the pessimistic ($E_{pes}$), normal ($E_{norm}$) or optimistic ($E_{opt}$) bandwagon. In addition to these, possible effects of ‘free-riding’ in the opportunistic expectations ($E_{opp}$) is also investigated, so that in the simulation model each traveller has one of these four types of expectations which may change into another type in another generation $g$ ($\text{Exp}(g) \in E; E = \{E_{pes}, E_{norm}, E_{opt}, E_{opp}\}$; see Fig. 3). In a bandwagon expectations’ curve, the more people cooperate, the more this action will influence the others to cooperate. However, a critical mass exists between cooperation and non-cooperation. The critical mass is the fraction of people cooperating at the point where an expectation curve crosses the 45° straight line, which is the criteria line $Cr$. Below the critical mass, the more people do not cooperate, the more it will influence the others not to cooperate. For details regarding the mathematical functions of the expectations’ curves, please see Huberman and Glance (1994).

2.3. Decision making of traveller

Fig. 4 shows decision-making processes of a traveller. Initially at generation $g = 1$ and iteration $t = 0$, traveller $i$ is provided with a type of expectations’ curve $\text{Exp}(g = 1) \in E$ which may change after a generation is finished (or after 10 iterations). A choice of mode for the initial iteration ($t=0$) is randomly chosen ($m(t=0) \in \{A,B\}$). Please note that $t = 0$ is only for $g = 1$. For $g > 1$, iteration starts from $t = 1$. Travel costs and payoffs are not calculated at $t = 0$ since this initial iteration is only used to get the initial value of fraction of cooperation $FCoop(t = 0)$, which is the proportion of bus users to total number of travellers, that will be used for the next iteration ($t = 1$).
At \( t = 1 \), traveller \( i \) starts making decision using her decision-making rules, which is her expectations’ curve \( \text{Exp}_i(g = 1) \), by obtaining the value of probability of cooperation \( \text{PCoop}_i(\text{FCoop}(t = 0)) \) given a fraction of cooperating \( \text{FCoop}(t = 0) \) using the expectations’ curve. The value of criteria \( \text{Cr}_i(\text{FCoop}(t = 0)) \) is also obtained by plotting \( \text{FCoop}(t = 0) \) on the criteria line \( \text{Cr} \) (see Fig. 3). Then, traveller \( i \)’s choice of mode for the next iteration \( t = 1, m_i(t = 1) \), is decided using this rule:

\[
m_i(t) = \begin{cases} 
B & \text{if } \text{PCoop}_i(\text{FCoop}(t - 1)) \geq \text{Cr}_i(\text{FCoop}(t - 1)) , \\
A & \text{if } \text{PCoop}_i(\text{FCoop}(t - 1)) < \text{Cr}_i(\text{FCoop}(t - 1)) , \\
m_i(t - 1) & \text{always cooperate}.
\end{cases}
\]

After traveller \( i \) and all other travellers make a choice of mode, then travel time \( T \), hence travel costs of car \( V_A(t = 1) \) and bus \( V_B(t = 1) \), can be calculated. If traveller \( i \)’s choice is car \((m_i(t = 1) = A)\) then her travel cost is \( V_A(t = 1) = V_A(t = 1) \), otherwise, if bus is chosen then \( V_B(t = 1) = V_B(t = 1) \). The payoff to be given to this traveller is then calculated \((P_i(t = 1) = \text{Const} - V_A(t = 1))\) and will be accumulated with payoffs in the following iterations until \( t = 10 \left( \sum_{i=1}^{10} P_i(t) \right) \).

These decision-making processes can only happen if the current iteration \((t = 1)\) is the time for traveller \( i \)’s to make a decision \((t_{Deci} = 1)\), otherwise traveller \( i \) continues choosing her previous choice \((m_i(t = 1) = m_i(t = 0))\). In each iteration \( t \), travellers make decision at an asynchronous time displaying inertia depending on their decision-making time \((t_{Deci})\), where only 10% of them observe current level of cooperation and make a choice at the same time (when \( t_{Deci} = t \)). Another 90% continue to use their current mode of commuting (when \( t_{Deci} > t \)).

After \( t = 10 \), which marks the end of \( g = 1 \), the accumulated payoff is used as the measure of performance (fitness) of the traveller’s expectation curve \((\text{Exp}_i(g = 1))\). Before \( g = 2 \) starts, traveller \( i \) may consider changing her type of expectations’ curve by means of social interaction and social learning mechanisms which are explained in the following subsections. These decision-making processes will continuously take place in next generations until the end of a simulation run.

### 2.4. Social interaction between travellers

An experiment by Olson (1971) revealed that small groups are more likely to secure voluntary cooperation than are larger ones. It was also revealed that repeated interactions tend to promote cooperative attitudes. The amount of cooperation further increases when communication between participants are permitted.

Taking into account these findings, we simulate social interactions by introducing a group-based interaction within a group of individuals \( G_k(G_k \in C; C \subseteq S, k = 1,2, \ldots c) \). In a real world practice, a group may represent employees of a company. The interactions simulate interdependencies and social learning between employees of a company, for example in complying with an employer-based TDM, such as travel plan, voluntary programs to reduce car use, public transport vouchers, etc.

Traveller \( i \) interacts with her neighbouring travellers \( \forall j, (\forall j \subseteq G_k ; i \neq \forall j) \) in an imaginary spatial 3D plane named as a torus plane which consist of many cells on its surface. The plane shapes a doughnut-like figure, where each traveller occupies a cell and is interlinked with other individuals who occupy neighbouring cells. Each traveller may have many levels of neighbourhood based on the closeness of her cell with other individuals’ cells. The number of neighbours for each neighbourhood level is a function of the level \( f,(\|\bar{\theta}_i\|_f = 8f) \). In this study, we consider only the first level of neighbourhood, so that
each traveller has eight neighbours surrounding her who may influence her behaviour \( (||\theta||_1 = 8) \). For comparison, if a spatial 2D plane is used, some travellers who occupy cells at the corners or edges of the plane have only three or five neighbours. The other reason of using a torus plane is the ability to better represent interdependency between travellers which may later give reinforcing effects whenever a choice of behaviour becomes common.

Each group is independent from the others \((G_k \not= G_l, \forall k,l \in C)\) so that there is no interaction between members of different groups. Assuming limited information, each traveller only knows information about the results of collective choices (travel time) and of her chosen mode (travel cost/payoff), but not the choices and payoffs of all other travellers. However, during social interactions with neighbouring travellers, a traveller may have access to information about their neighbours.

Before a new generation \( g \) starts, each traveller receives information about her neighbours, which include information about her neighbours’ type of expectations \((\text{Exp}_i(g-1); \forall j \in \partial_i)\) and the accumulated payoffs received by them \( \left( \sum_{j=1}^{10} P_j(t); \forall j \in \partial_i \right) \) in the previous generation \( g - 1 \). The information is used in the social learning mechanisms described in the next subsection.

### 2.5. Social learning mechanisms

We apply an imitation game incorporating social learning mechanism in order to evolve the expectations’ curve of each traveller. Two kinds of mechanism are used: payoff-biased and conformist transmissions. Henrich and Boyd (2001) argued that conformist transmission can stabilize costly cooperative strategies without punishment, but only if it is strong enough to be compared with payoff-biased transmission. If system contains a combination of conformist and payoff-biased transmissions, then, if cooperation becomes common, conformist transmission will oppose payoff-biased transmission and favour cooperation.

The strength of conformist transmission in human psychology can be represented by parameter \( x \). For each traveller, there is a probability of using conformist transmission and \( (1 - x) \) probability of using payoff-biased transmission (Henrich and Boyd, 2001; Henrich, 2004). For each traveller, a random number \( r_i \) is generated and the type of expectations of traveller \( i \) at generation \( g \) \((\text{Exp}_i(g))\) is chosen using this equation:

\[
\text{Exp}_i(g) = \begin{cases} 
\{3!E : ||3!E|| = \max(\forall q \in E : ||\forall j \in \partial_i : \text{Exp}_j(g-1) = q||)\} & r_i < x, \\
\{\text{Exp}_i(g-1) : \sum_{j=1}^{10} P_j(t) = \max(\forall s \in \partial_i : \sum_{i=1}^{10} P_i(t))\} & r_i > x, \\
\text{Exp}_i(g-1) & r_i = x,
\end{cases}
\]

(6)

where the first condition is for conformist transmission, the second one is for payoff-biased transmission, and if none of these two conditions is applicable, then traveller \( i \) use the same expectations’ curve as that of the previous generation, as shown in the third condition.

According to Henrich and Boyd (2001), the value of \( x \) is generally assumed to be positive and small, and varies from 0 to 1. They also stated that practically \( x \) must be less than 0.5, otherwise, beneficial (cooperative) behaviours would never spread. If \( x > 0.5 \), then conformist transmission dominates over payoff-biased transmission. Once a specific behaviour becomes common, it will remain common no matter it is not beneficial. Payoff-biased transmission should also be strong enough for ensuring that an existing behaviour gives a reasonably good outcome, before conformist transmission spreads the behaviour to others. These situations imply a need to balance between the two transmissions in order to elicit and maintain cooperative behaviours.

The processes of social learning can be illustrated in Fig. 5. For example, traveller \( i \) has the two options of social learning mechanism. The strength of conformist transmission is, for instance, \( x = .4 \).

Let us assume that at generation \( g \) the traveller has a type of curve, for instance, the normal type \((\text{Exp}_i(g) = E_{\text{norm}})\). At the end of generation \( g \), random number \( r_i \) is then generated. If \( r_i < 0.4 \), then traveller \( i \) uses the conformist transmission and imitates the behaviour of majority of travellers in her group. In this case, she changes her expectations’ curve to the

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Fig. 5. An illustration of social learning mechanisms.
optimistic type \((\text{Exp}(g + 1) = E_{\text{opt}})\). Otherwise, if \(r_i > 0.4\), then traveller \(i\) learns using the payoff-biased transmission. She changes her type into a pessimistic type, since a neighbour who receives highest payoff is a pessimistic bandwagon \((\text{Exp}(g + 1) = E_{\text{pes}})\). If \(r_i = 0.4\), then \(\text{Exp}(g + 1) = \text{Exp}(g)\).

### 3. Simulation results and discussion

A number of agents, 4096 in total, are assigned into 16 homogeneous and independent groups with 256 agents in each group. Each agent has a type of expectations \(\text{Exp}(g)\), which can be one of the bandwagons \((E_{\text{pes}}, E_{\text{norm}}, \text{or } E_{\text{opt}})\) – used in all experimental runs) or opportunistic expectations \(E_{\text{opp}}\) (used only in the experimental run explained in Section 3.3). The initial type \(\text{Exp}(g = 1)\) is assigned randomly giving the same proportion of agents for each type of expectations’ curve. We run a simulation with various initial levels of cooperation \(LC = \{0.2, 0.3, \ldots, 0.8\}\), which are the proportions of the number of bus users \(N_B\) to the total number of travellers \(N = |\text{S}|\). Simulations are run up to 100 generations with 10 iterations per generation. Strength of conformist transmission \((a)\) ranges from 0.0 to 0.4. When \(a = 0.0\), travellers use only payoff-biased transmission to evolve their type of expectations’ curves. Combination of payoff-biased and conformist transmission is demonstrated by using \(a = \{0.1, 0.2, 0.3, 0.4\}\).

#### 3.1. Dynamics at \(a = 0.0\): Social learning by payoff-biased transmission

For \(a = 0\) and initial \(LC = \{0.2, 0.3, \ldots, 0.7\}\), the system converges to the user-equilibrium point (see Fig. 6; the straight dashed line in the figure is the user-equilibrium line.). At the user equilibrium point, the number of bus users is around 1200 or equal to 30\% of travellers \((N_B \approx 1200\) or \(LC \approx 0.3\)). Initial \(LC = 0.8\) results in a full level of cooperation \((N_B = 4096)\), since the probability of cooperating at this level of cooperation is higher than the critical mass for the three bandwagon types \((P\text{Coop}(0.8) > C_{\text{r}}(0.8)\); \(\forall\text{Exp}(g) \in \{E_{\text{pes}}, E_{\text{norm}}, E_{\text{opt}}\}\)), so that any travellers with these bandwagon types would favour cooperation and make the system quickly converge to full cooperation.

Observing types of bandwagon that survive until the end of a simulation run with initial \(LC = 0.5\), we can see that all three types still survive in most of the groups, as seen in Fig. 7. Most groups are also dominated by the pessimistic type. In general, the pessimistic type is chosen by the highest number of members, more than 50\% of travellers. The normal type and optimistic type share almost similar proportion with 25\% of travellers each. There are four groups that have all group members cooperating in \((LC = 1)\). In these groups, the pessimistic type has the lowest shares since the groups are domi-
nated by optimistic type and/or normal type. An example of this situation together with another situation whenever pes-
simistic type dominates can be seen in Fig. 8, presenting in-group dynamics of Group 2 and Group 1, respectively.

Fig. 8 is taken from a simulation run with initial $LC = 0.5$. The number of bus users $NB$ shown in the figure is the aver-
age value of 10 iterations for each generation. Within Group 1, all members finally choose car. The pessimistic bandwagon
domines the group with around 200 agents. A small number of agents with the normal or optimistic bandwagon cannot
increase the level of cooperation and furthermore they choose defection. A contrary situation happens in Group 2. Within
this group, no types of bandwagon dominate the group until around $g = 40$ and only a moderate level of cooperation with
$NB \approx 150$ can be maintained. Increasing number of the normal and optimistic bandwagons, as a result of the actions of
agents who change their types from the pessimistic type into the normal or optimistic type, is able to push the level of coop-
eration into maximum level ($LC = 1$ or $NB = 4096$). The spread of these normal and optimistic types of bandwagon expec-
tations is able to decrease the number of pessimistic agents and to maintain the level of cooperation.

In summary, there are three important results for simulation runs with $x = 0.0$. Firstly, the system converges to the user-
equilibrium point. Although it is not presumed in the beginning, the rational behaviours of individuals on utilizing payoff-
based transmission have produced the user-equilibrium point. Experimental studies on route choice behaviour by Selten
et al. (2007) produced results which are in line with our study, that the average number of road users tends to be very near
to the equilibrium even though fluctuations persist until the end of the experiments. The fluctuations were the results of
travellers’ attempts to improve their payoffs. This economically rational behaviour in maximizing payoff has brought
the system into the user-equilibrium point. Secondly, local behaviours within a group may converge to all car users, all
bus users or a mixed of car and bus users. Finally, cooperation level within a group is related to the type of expectations
which dominates the group. If the optimistic type dominates then it will result in cooperation of all group members, but if
the pessimistic type dominates then the result is defection by all members.

3.2. Dynamics at $x = 0.4$: Combination of payoff-biased and conformist transmissions

Combined payoff-biased and conformist transmissions are simulated using $x = \{0.1, 0.2, 0.3, 0.4\}$. The higher value of $x$
means the higher the probability of an agent to use conformist transmission. It is obtained from the simulation runs that
$x = \{0.1, 0.2\}$ give only small differences compared to the case of payoff-biased transmission only ($x = 0.0$) and the system
ends up at the user-equilibrium point. At $x = 0.3$, conformist transmission can push the system to converge to a higher level
of cooperation than the user-equilibrium point for several cases with various initial levels of cooperation. But at $x = 0.4$,
higher levels of cooperation than those of $x = 0.3$ can be reached for all initial levels of cooperation (Fig. 9).
At $\alpha = 0.4$, initial $LC = 0.2$ produces a relatively different behaviour of the system compared to cases with other initial $LC$s. In this case, at the initial condition, the cost of bus is lower than the cost of car (see Fig. 2), so that most users prefer bus to car. The level of cooperation suddenly increases and the conformist transmission spreads cooperative behaviour to other travellers. Since the conformist transmission is strong, cooperative behaviours spread quickly to make all group members cooperate and stabilize cooperation within the group, without giving the payoff-biased transmission a chance to push the global cooperation to the equilibrium point. It can be seen that initial $LC = 0.2$ gives a higher convergence value than initial $LC = \{0.3, 0.4, 0.5, 0.6\}$.

For cases with initial $LC = \{0.3, 0.4, 0.5, 0.6, 0.7\}$, the higher the initial level, the higher the convergence point is. In these cases, cooperation increases suddenly in early generations (until around $g = 10$). The reason is probably the existence of agents having the optimistic type who suddenly choose to cooperate, as for this type the initial $LC$ is higher than its critical mass of cooperation. They are followed by some agents having the normal type who later also cooperate, after observing an increasing level of cooperation which is higher than the critical mass of the normal type. However, in the later generations ($g > 10$), the payoff-biased transmission with probability of occurrence 0.6 (=1 − $\alpha$) pushes the cooperation level to a lower state before the system converges. Initial $LC = 0.8$ favours cooperation for all types of expectations so that full level of cooperation is quickly produced.

Analyzing in-group dynamics, conformist transmission could help the spread of a type of expectations’ curve within a group. When a type is quite common, a strong conformist transmission will help it spread and homogenize the group. In some groups, the optimistic expectations may dominate. But in other groups, the pessimistic or normal expectations may also be in charge.

The results of the simulation run show that during complex processes of interaction between agents, a combination of payoff-biased and conformist transmissions, together with other emergent components produced by social interaction between travellers, may produce other equilibrium points. Levels of cooperation produced at these equilibrium points are not very close to the system optimum, but they are higher than that of the user-equilibrium point. Conformist transmission could produce and stabilize cooperation, when it is strong enough (at $\alpha = 0.4$) compared to payoff-biased transmission. Henrich and Boyd (2001) theoretically predicted that the conformist transmission will stabilize cooperation when $\alpha > 0.333$. As mentioned earlier in Section 2.2, they also stated that practically $\alpha < 0.5$, so that in the range of $0.333 < \alpha < 0.5$ conformist transmission will stabilize cooperation. Our result is certainly in line with this theoretical finding. Unfortunately, to the knowledge of the authors, no empirical works yet could validate these findings.

3.3. Effects of opportunistic expectations at $\alpha = 0.4$

We introduce an opportunistic expectations’ curve in the simulation with $\alpha = 0.4$, so that there exist three types of bandwagon curves ($E_{pes}$, $E_{norm}$, and $E_{opt}$) and one type of opportunistic curve ($E_{opp}$). Each type is assigned randomly with similar proportions of agents. The existence of the opportunistic expectations produces a distinctive change of characteristics in all cases of initial $LC = \{0.2, 0.3, \ldots, 0.8\}$ (see Fig. 10). In early generations (until around $g = 4$), the system produces relatively high number of bus users ($N_B \approx 2450$ or $LC \approx 0.6$), which is the maximum level of cooperation that keeps an agent with the opportunistic expectations cooperating. Beyond this level, an agent with this type of expectations will be tempted to stop cooperating and just to ‘free-ride’ on other agents’ cooperation. In the following generations ($g > 4$), the number of bus users decreases and the system gradually converges to the user-equilibrium point. Conformist transmission cannot push the level of cooperation to a significantly higher point.

The simulation shows that the existence of opportunistic expectations’ type produces a significant effect to the system behaviour, since an agent with this type of expectations always has a temptation to get a higher payoff by ‘free-riding’, which is a typical characteristic of an opportunist. Basically, agents with this type prefer cooperation than defection,
but they prevent a group to converge to all cooperation, since they will be better off ‘free-riding’ when they observe a high fraction of cooperation inside the group. Given this characteristic, a small number of opportunists may have a big influence on changing the behaviour of other group members.

3.4. Policy and behavioural implications

Kitamura et al. (1999) revealed fundamental difficulties in solving the social dilemma by relying only upon people’s compliance. However, the result of our simulation suggests that, in supportive circumstances, there are some possibilities such that people change their travel behaviours following others’ behaviours. They may change their behaviour intentions from being a pessimistic into an optimistic bandwagon. This situation may apply during the implementation of some ‘soft’ travel demand management (TDM) measures, which are aimed to make people more conformist-oriented (bigger a) and make people change their expectations into a more optimistic one.

The results of the simulation experiments shed light on the possibilities of getting in-group cooperation even though ‘soft’ TDM measures are mostly voluntary. This finding is in line with the results of Olson (1971)’s experiment explained in Section 2.2. In relation to a travel awareness campaign, a more local and personalized campaign aimed at groups of people (e.g. in schools, companies, communities), may be more effective than a broad and national campaign aimed at whole population.

From the view of contribution to knowledge in travel behaviour, this study has also shown the importance of considering interdependency between travellers, as also suggested by Gärling et al. (2002). Travellers may take into account the choice of others and make decision based on expectations of others. The existence of social learning in travel behaviour is also an important factor that has never been considered before. This kind of learning may complement, and often, replace individual learning. Laboratory experiments by Kameda and Nakanishi (2002, 2003) provide empirical evidence on the existence of social learning in human behaviour and the benefit of this learning process. However, in travel behaviour studies, social learning is still rarely considered.

4. Conclusion

An agent-based simulation model of travel mode choice has been built and applied to examining behaviour of commuters. When travellers are rational and using payoff-biased transmission as the only learning mechanism, the system may reach the user-equilibrium point as predicted in the equilibrium analysis. This result is produced during social interaction between travellers in the system. However, there also exist some situations where the user-equilibrium does not become the convergence point, instead it is replaced by other equilibrium points. These equilibrium points outperform the user-equilibrium point since they produce levels of cooperation which are higher than that of the user-equilibrium point. These situations may happen when the conformist transmission, which is combined with the payoff-biased transmission as the travellers’ social learning mechanisms, is strong enough compared to the payoff-biased transmission.

Utilizing observations on in-group dynamics, it can be inferred that cooperation level within a group is highly related to the type of expectations that dominates the group. Domination of the pessimistic type on the decision making of individuals makes a group converges to all defection, while the existence of the optimistic type is very important to pioneer cooperation within a group. If another type of expectations, the opportunistic type, is allowed to exist inside a group, then it will spread, dominate and thus prevent the group members from becoming more cooperative.

In a social dilemma situation of travel mode choice, there are three conditions that may favour cooperation of travellers on choosing bus as a transport mode of commuting. The first is related to the existence of expectations as guidance for individuals’ decision making. The existence of optimistic bandwagon expectations in some individuals may pioneer and

Fig. 10. Dynamics of cooperation level (a = 0.4) with three bandwagon types and one opportunistic type.
encourage other individuals to cooperate. The second is group-based interactions. Grouping among travellers limits travellers’ knowledge about behaviours of other groups’ members. Also, it makes the actions of others more influential on an individual. The third is the conformist transmission. When travellers do not feel economic rationality (via the payoff-biased transmission) as a must, they would observe other types of social learning process such as the conformist transmission which gives cooperation a chance to spread in the population. This kind of social learning mechanism must be strong enough to give cooperation a chance to spread in the population.

References


