Transportation Research Part C 87 (2018) 26–45

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Peer pressure enables actuation of mobility lifestyles☆

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ARTICLE INFO

Keywords:
Games on social networks
Data mining
Machine-learning
Microsimulation
Activity-based models
Network interventions
Climate change policy
Mode shift
Social welfare maximization
Peer-pressure

ABSTRACT

This paper explores the utility of peer pressure as an actionable mechanism to induce socially responsible and environmentally-conscious mobility habits. We adopt a two-stage game theoretic model of peer pressure to investigate feedback between social, geographic, and temporal dimensions of agent choices in a hyper-realistic micro-simulation of travel. The results show that peer pressure helps in achieving desirable equilibrium properties while reducing congestion and emissions due to sustained mode shift. With a way to initiate the required social norming and a proper concern for privacy and ethics, these cost-effective mechanisms may soon begin to find use in improving community welfare.

1. Introduction

Surging interest and political acceptance of behavioral interventions, or *nudges*, have created novel opportunities for transportation planners to strategically structure mobility choice architectures that actuate and stabilize environmentally-beneficial mobility lifestyle changes (Leonard et al., 2008; Avineri, 2012). Voluntary travel behavior change and personal travel planning have been in use since the 1980s to persuade commuters to engage in pro-environmental and pro-social travel behaviors (Fujii and Taniguchi, 2006). More recently, ubiquitous, networked computing technologies and social media channels have provided additional outlets to motivate and sustain behavior change (Jariyasunant et al., 2015; Gaker et al., 2010, 2011). While empirical and theoretical evidence suggests social norms and personalized feedback can reinforce positive attitudes towards sustainable mode choice (Brög et al., 2009), little work has been done to rigorously and independently evaluate the costs and benefits of novel behavioral policy alternatives (te Brömmelstroet, 2014; Bonsall, 2009).

Simulations of cyber-social influence on travel decision-making may help transit agencies quantitatively and transparently justify to stakeholders programs intended to incentivize peer-to-peer influence as a means of encouraging socially cooperative modality lifestyles. Herein, we adapt a two-stage game theoretic model of peer pressure inspired by Mani et al. (2013) to investigate how feedback between social, geographic, and temporal dimensions in agent-based simulations of travel can motivate pro-environmental transportation decisions. This work extends related research on joint-decision making as well as the cost-benefit analysis of policy incentives to internalize the environmental externalities of transportation (Illenberger, 2012; Dubernet and Axhausen, 2013; Axhausen, 2007; Agarwal et al., 2015; Hackney and Marchal, 2011; Kaddoura et al., 2017; Kickhöfer and Kern, 2015). The software implementation of our model is built on top of the open-source microsimulation software, MATSim, which was chosen for its compatibility with behavioral choice theories, modularity, and ability to handle large heterogeneous populations of agents (Horni et al., 2016).

☆ This article belongs to the Virtual Special Issue on “Agent technology”.

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https://doi.org/10.1016/j.trc.2017.12.008
Received 30 January 2017; Received in revised form 11 December 2017; Accepted 11 December 2017

We verify our system on a scenario situated in the San Francisco Bay Area in California. By monetizing reductions in emission and congestion externalities, we evaluate the effect of potential policy instruments intended to motivate agents to influence their peers to use public transit instead of commuting to work alone. While experimental results are focused on public transportation as an alternative mode, the game-theoretic setting and experimental simulation developed by this work covers a wide class of situations characterized by a high price of anarchy (Koutsoupias and Papadimitriou, 2009; O'Hare et al., 2016) where selfish behaviors (such as driving alone) curtail system performance.

2. Related work

By definition, *common pool resources* are freely-available and ungoverned (Ostrom, 2010). *The tragedy of the commons* may occur when a common pool resource is depleted to the extent that each' additional unit of consumption reduces the value of the resource for the entire society (Hardin, 1968). The tragedy of the commons has been frequently studied in the economics, control, and distributed artificial intelligence communities using game theoretic models representing agent decision-making related to the overuse of telecommunication, transportation, wildlife, and global climate resources (Diekert, 2012; Saha and Sen, 2003; Ostrom, 1999; Turner, 1992). In the transportation setting, commons constraint problems occur when users of a road network seek to maximize their expected individual utility without regard for capacity limitations (Saha and Sen, 2003). The resulting costs of congestion and pollution are felt by everyone. Klein et al. (2018) have recently introduced the term *social mobility dilemma* to emphasize the specific challenges faced by transport engineers and urban planners tasked with curbing excessive personal vehicle use on limited road networks.

Economic incentives and behavior change strategies aimed at encouraging socially cooperative alternatives to driving alone often require an accounting of the marginal external costs (MECs) of transport on the environment. An *externality* is defined as an experienced cost or benefit due to the failure of a rational economic actor to take into account the consequences of their behavior on others (Verhoef, 1994; Rothengatter, 1994). Externalities can be characterized as *positive* or *negative* depending on whether they benefit or harm parties external to the action in question.[1]

Transportation externalities may exhibit significant spatiotemporal variability, requiring policy planners to carefully delineate the affected population (Mayeres et al., 1996; Parry et al., 2007; Delucchi, 2000). For example, the cost of noise pollution due to transport may be indirectly quantified by observing the relationship between housing prices and traffic flow rates and proximity to motorways (Mayeres et al., 1996; Subramani et al., 2012). In contrast, the CO_2 emissions from the exhaust of a fossil-fuel powered automobile contribute to global climate change, which has a more diffuse, long-term marginal social cost (MSC) (Small and Kazimi, 1995). External costs need not be directly monetary in nature. For example, reductions in social welfare due to regularly congested road networks may be quantified according to the value that commuters place on travel time (VOT) (Small, 2012). An independent measure of the desire for reliable commute times (value of travel time variability, VTTV) can measure the impact of more sporadic events such as adverse weather conditions on social welfare (Coulombel and de Palma, 2014).

Reducing externalities by requiring individuals to compensate for the costs that their actions impose on others is known as *internalization*. *Pigouvian mechanisms* are market-based approaches that attempt to internalize externalities by taxing goods resulting in net disbenefits or subsidizing goods that result in net benefits (Pigou, 1920). However, as the spatial scope of external effects increases, Pigouvian schemes become more politically contentious, since attributing effects to their sources becomes less precise. Pigouvian mechanisms also fail to take advantage of the social effects that often shape individual behavior and preferences.

Game theoretic models of externalities assume that, at user equilibrium, individuals lack the incentive to take actions that improve social welfare if they believe that others will profit from their efforts without making a similar sacrifice in utility (Eriksson et al., 2006). However, in many cities, a growing concern over the contribution of fossil fuel emissions to climate change and increasing access to low-cost, alternative-energy transportation modes, has resulted in commuters switching to public transit, electric vehicles, and ridesharing services at rising rates (Biel and Thøgersen, 2007; SFCTA, 2010). For example, recent work studying automobile purchase decisions shows to what extent adoption of a new technology (such as electric vehicles) is driven by the spread of attitudes and behaviors (e.g., pro-environmental mode choice) as they become social norms (Gaker et al., 2011).

Traditional, consequentialist views of travel behavior have failed to explain these preferences, inspiring modern studies of transportation behavior to investigate bounded rationality, observer bias, and, increasingly, the impact of social influence on human reasoning (Grabowicz et al., 2014; Verplanken et al., 0000; Axhausen, 2007; Páez et al., 2008; Abou-Zeid et al., 2013; El Zarwi et al., 2017). Complicating claims of causality made by these experiments is the difficulty in accounting for endogeneity in explanatory variables (Dugundji and Walker, 2005). Distinguishing social influence from homophily, which is defined as the tendency for individuals with similar characteristics and behaviors to form clusters in social networks is currently a growing area of research and debate.[2]

In contrast to the passive processes governing diffusion of social influence, individuals can, at some cost in utility to themselves, actively influence each others' choices through *peer pressure* (Pentland and Reid, 2013; Calvó-Armengol and Jackson, 2010; Mani et al., 2013). In particular, when one person's choices result in visible negative externalities for his community, his peers may

[1] The reader is referred to Mas-Collel and Green (1995) for more detail and background on the concepts from neoclassical game theory used in this text. Shoham and Leyton-Brown (2008) is also a good reference with particular emphasis on the use of game theory in multiagent systems.

[2] See Christakis and Fowler (2013) and Shalizi and Thomas (2011) for a recent exploration of the *identification problem* in the econometric analysis of diffusive processes in social networks, as first characterized in Manski (1993).