The Death of a Transport Regime? The Future of Electric Bicycles and Transportation Pathways for Sustainable Mobility in China

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Abstract

This paper has an empirical and theoretical focus: to empirically assess electric bicycle development in China, and to theoretically test and apply the "Multi-Level Perspective" on transitions and innovation. We examine the electric bicycle (e-bike) sector in China to understand the future prospects for urban mobility and the interaction of e-bikes as a form of vernacular technology within the existing transport regime. For this purpose, we address the following questions: 1) What factors will influence the future adoption of e-bikes? 2) How are alternative travel modes evaluated against e-bikes? 3) Will e-bikes become a popular sustainable mobility mode in the future or only an intermediary mode to cars? To provide answers, we conducted a survey in Nanjing city in order to assess the attitude of e-bike users, and other mode users (e.g. pedestrians; bicycle users). We then analyse responses from this survey through the lens of sociotechnical transitions theory, notably the "Multi-Level Perspective" notions of niches, regimes, and landscape. The paper explores the influential factors underpinning future e-bike adoption and the decision-making calculus behind alternative mode choices. Generalised Linear Models are used to investigate the factors influencing future e-bike adoption and alternative mode choices based on the survey data. We conclude that e-bikes are an intermediary mode on Nanjing's motorisation pathway, and that they therefore may eventually reflect a dying regime.

Keywords: Sustainable mobility; electrification; bicycles; urban transport; modal choice; China.

Highlights:

- Sociotechnical change occurs through the evolutionary interaction of niche, regime, and landscape pressures
- The paper provides survey data from over 1,000 respondents on the future of e-bike use in China
- E-bike use is widespread, but not deeply embedded as a transport mode
- E-bike continued use is vulnerable to policy shifts or increased personal wealth

Nomenclature

ACI	Acoustic complexity Index
GLM	Generalised Linear Models
Pr(>|t|)	*P*-value for that t-test
p-value	Probability for a given statistical model
R^2	The coefficient of determination
Std. Error	Standard Error
VIF	Variance Inflation Factor

1. Introduction

This paper investigates whether electric bicycles, a somewhat neglected but socially important mobility technology, are likely to be an enduring feature of future modal choice for urban transport in China. Drawing from the concept of socio-technical transitions (Geels, 2002), we aim to make empirical and theoretical contributions. Empirically, we ask: 1) What factors will influence the future adoption of e-bikes? 2) How are alternative travel modes evaluated against e-bikes? 3) Will e-bikes become a popular sustainable mobility mode in the future or only an intermediary mode to cars? And theoretically, we ask: 1) Are e-bikes an established or dying transport regime? Such questions require us to examine technologies through a range of possible pathways, and thereby to assess their interaction within "regimes", a term that encompasses a constellation of mutually reinforcing features that becomes the accepted nature of everyday life. These concepts have been applied to the realm of transport (Geels *et al.*, 2012), and underpin the research reported in this paper. Household decisions on mobility choices have long been recognised as a key feature of urbanism in general (Dieleman *et al.*, 2002; Hansen, 2015). Research has identified how urban structures can give rise to certain mobility choices (Shirgaokar, 2015), but there has been less attention on how current and future mobility choices may enable or constrain urbanism typologies. Thus it is proposed here that the uptake of e-bikes in China is reflective of and contributory to a wider process of urban-rural drift (both permanent and temporary) in which such e-bikes may be more of a temporary expedient or 'stepping stone' on the pathway to full (car-based) automobility rather than a laudable 'green mobility' platform.

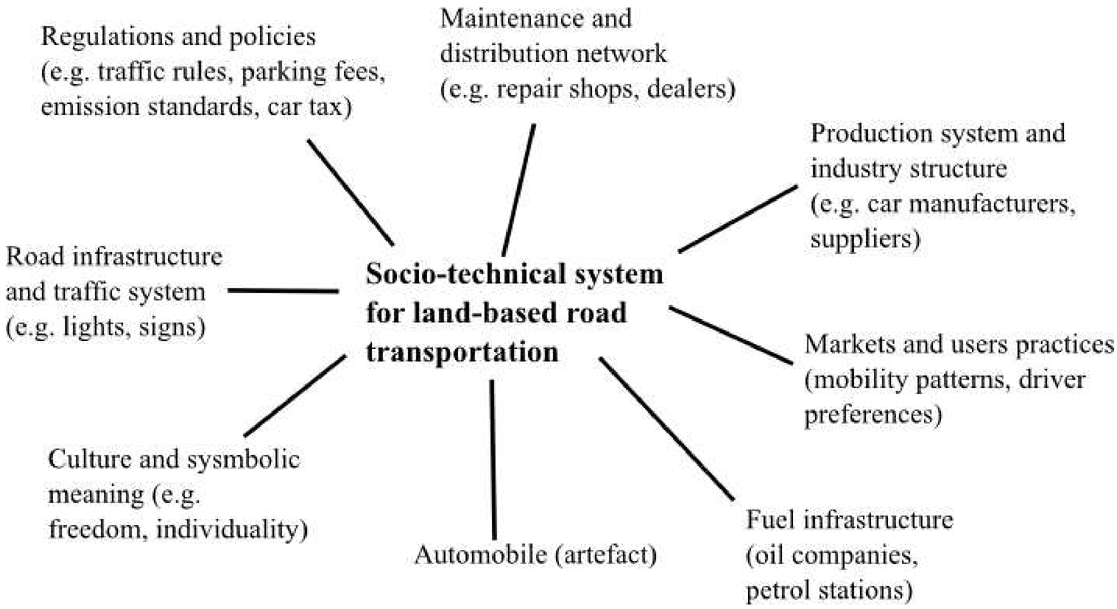
To provide some clarity, the term "electric bicycles" (e-bikes) is generally used to refer to two-wheel transport machines with an electric motor used to power the vehicle, or to assist with pedalling (SBQTS, 1999). Most e-bikes fall into three categories: bicycle style e-bikes (usually termed 'Pedelecs' in Europe), scooter style e-bikes (e-scooters), and something in-between these termed a hybrid style. All e-bikes have three main components: Motors, rechargeable batteries, and controllers, which differentiate an e-bike from other alternative transport modes. Compared with traditional bicycles, e-bikes are faster and require less physical effort. Compared with motorcycles, e-bikes are lightweight and have no exhaust emissions. Compared with buses, e-bikes provide greater accessibility and flexibility of use. Compared with cars, e-bikes are easy to operate, convenient to use, do not require a licence, more affordable, and easier to park. With these advantages, e-bikes have attracted an increasing number of users transferring from walking, bicycles, motorcycles, buses, and cars (Cherry and Cervero, 2007; Weinert *et al.*, 2007; Zhang, 2011; Xu *et al.*, 2014). E-bikes are highly embedded within the regime of mobility in China, being employed for both utility and leisure uses (Cherry, 2007; Cherry and Cervero, 2007; Weinert *et al*., 2007; Zhang, 2011; Ye *et al*, 2014).

Although drawing from socio-technical transitions theory in which niches, regimes, and landscapes are dynamic and always in flux, we treat e-bikes in this paper as a "regime" in their own right, although such a regime also interacts with other regimes (and niches). We consider e-bikes a regime for at least two reasons. Firstly, the annual sales of e-bikes in China are about 30 million units (Jamerson and Benjamin, 2013), meaning they have established economies of scale and also their own supportive policies, stakeholder groups, and industry practices. Nowadays, more than 220 million e-bikes are in use in China (Yang and Yang, 2016). The explosive growth of e-bikes has already attracted the attention of government, and also resulted in consequent supportive government regulations (Rose, 2012). Second, e-bike pathways are, consistent with MLP theory, contested, and generate friction. For instance, Chinese authorities argue that e-bikes cause numerous traffic accidents, and undermined urban road transportation rule compliance due to the traffic violation behaviour of e-bike users - such as running red lights, and overloading (Wang *et al.*, 2011; Du *et al.*, 2013; Lu *et al.*, 2015). In addition, e-bikes have been restricted by some urban authorities because of potential lead pollution created by the use and disposal of lead-acid batteries (Chen *et al.*, 2009). It is a concern that only 33% of lead-acid batteries were properly recycled by official companies in China, while 67% were illegally recycled in hazardous and polluting ways (Chun, 2013). The uncontrolled lead recycling process increases the likelihood of a negative impact on human health, such as developmental disorders and a lower IQ (Sanders *et al.*, 2009).

The paper is organised as follows. The following sections introduces the research methods and theoretical approach of the paper, research design, case and field procedures, and model speicification. Then, the survey results of the future choices of e-bikes users with respect to e-bikes and other alternative travel modes are discussed in Section 6. To further explore the mode choice behaviour. And the factors influencing future modal choices using the Generalised Linear Models (GLM). A further analysis is performed in Section 7. The final section presents the conclusions following the research as well as suggested areas for further development.

2. Research methods and approach

The conceptual framework employed in this study is rooted in the "multilevel perspective on innovation," or MLP, arising from innovation studies, evolutionary economics, and science and technology studies. This approach posits that cars and even electric forms of mobility create part of a socio-technical system, one that involves not only technological "artefacts" (such as the car) but broader social, cultural, economic, and political factors depicted in Figure 1. This requires analysts to focus not only on infrastructure and technical systems, but human users and actors (and their behaviour) as well as the institutionalization of their behavioural patterns. The research reported in this paper relates to some, but not all, of the elements of Figure 1. The paper has a focus on markets and user preferences, the artefact, and culture and symbolic meaning. It also touches upon infrastructure and regulation and policies. It does not relate to the production system, the maintenance system, or the fuel infrastructure.



(Source: van Bree *et al*., 2010)

Figure 1: A socio-technical system of transport

As Geels (2012) indicates, the MLP moves beyond (and in a way, integrates) the conceptual tools utilized by neo-classical economics, psychology, ecology, and political science. Economics helps reveal market failures and the motivating factors of price and affordability; psychology helps reveal attitudes and behaviour of individuals whose aggregated choices result in social outcomes; ecology looks at environmental problems and some of the failures of capitalism. Political science often examines the struggles over policy implementation and the way that global norms interact with the local level in the form of regulations and policy programs.

Applying the MLP to analyse sustainable mobility can help understand the transport system and possible transition pathways towards more sustainable mobility (Geels *et al*., 2012). The MLP has been applied to study niche innovations in green propulsion technologies such as battery electric vehicles and fuel cell vehicles. Orsato *et al.* (2012) suggested that pure battery electric vehicles now were accepted culturally compared with the period of the 1970s to 1990s. Ehret and Dignum (2012) studied fuel cell vehicles in Germany, finding that they were regime-preserving as they fit current driver preferences as well as regime-changing as they are a disruptive innovation in the energy sector. Sovacool *et al*. (2017) draw from the fit-stretch aspects of the MLP to explore how innovations in charging infrastructure and battery swapping being promoted by Better Place, a now bankrupt company, were "contained" by incumbents and user expectations. Other studies have been concerned with human-powered vehicles (Brown *et al.*, 2006), hydrogen and battery electric vehicles (Farla *et al.*, 2010), biofuel vehicles and natural gas vehicles (Van Bree *et al.*, 2010; Berggren *et al.*, 2015), and e-mobility (Tyfield, 2014; Nilsson and Nykvist, 2016).

The MLP has been applied to study niche innovations in low-carbon urban transport system transitions. Spickermann *et al.* (2014) studied possible multimodal mobility solutions in urban transport systems, and designed an integration of individual and public passenger transport systems for future sustainable urban mobility. Parkhurst *et al.* (2012) suggested that intermodal personal mobility promotion would be a possible way to achieve sustainable personal mobility. In addition, innovation in public transport was highlighted by Harman *et al.* (2012), including bus lanes, demand-dependent services, information provision about arrival times and short distance radio systems. Among the various innovations, they found that the tram-train concept was a better solution to attract more commuters and widen access to cities. Pel *et al.* (2012) and Lyons *et al.* (2012) investigated the role of traffic information in the transport regime transition, such as "Intelligent Transport Systems". Other ongoing niche developments in low-carbon urban transport transition include mobility management (Nykvist and Whitmarsh, 2008) car-sharing (Marx *et al*., 2015), and telework (Hynes, 2016).

Sustainable mobility governance was proposed by Auvinen *et al.* (2015) to support strategic decision-making and policy planning by simulation and modelling with impact assessment based on the MLP framework. Another study (Upham *et al.*, 2015) focused on the current climate-related transport policies in three countries, namely, Finland, Sweden, and the UK. They found that the climate-related transport policy supported by regime actors in these three countries mainly concentrated on technological substitution and incremental changes rather than path-breaking innovations (Upham *et al.*, 2015).

The MLP approach is premised on the view that all of these different dimensions are important, and it offers three core conceptual units to reveal the complex interplay among them: niche, regime, and landscape (Grin *et al.*, 2010). Niches refer to "protective spaces" from which new, promising innovations can emerge. Niche actors hope that through learning and continued innovation their breakthroughs can come to be more widely accepted in the form of a regime. E-bikes would have begun, as most technologies do, as a niche.

Novelties and niches must compete with technologies that are already part of the existing socio-technical system around them, and here we have the idea of a regime, which aligns "existing technologies, regulations, user patterns, infrastructures, and cultural discourses" (Geels, 2004). Within this environment, innovation is usually incremental and non-radical due to the influence of path dependence and lock-in. Change can occur, but it is usually managed and predictable, giving rise to stable trajectories. As Geels (2012) notes, the notion of a regime introduces a structuralist element in our analysis, by assuming that actor behaviour is constrained by rules located at the collective level of a regime. As previously intimated, we would maintain that e-bikes in China currently serve as such a regime.

Finally, a socio-technical landscape is the wider macro context operating in the background (but still important), one that can exert influence over the dynamics of regimes and landscapes. It therefore includes "spatial structures (e.g. urban layouts), political ideologies, societal values, beliefs, concerns, the media landscape and macro-economic trends" (Geels 2012).

Our theoretical utilization of "regime" results in two key insights. The first is that it views change within a transport regime as a highly uneven, unpredictable, and at times even disruptive process. Put another way, the MLP rejects linear causality, and notes that there is no simple cause or driver (Grin *et al.*, 2010). The second is the notion of co-evolution and learning; new niches and existing regimes do not exist in a vacuum, they interact with each other and co-evolution occurs within and between different levels. It thus goes far beyond the usual "S-curves" presented in diffusion theories and adoption models. Thus, socio-technical trajectories can co-evolve along different dimensions and that in this complex process multiple feedback loops between state, market, science, and civil society exist.

3. Research Design

To explore the unique and dynamic socio-technical transition of e-bikes, the survey variables were designed to be closely connected to the elements of socio-technical system of transport illustrated in Figure 1: Markets and user practices; culture and symbolic meaning; regulations and policies, the underlying technology of the artefact itself; and the road infrastructure and traffic system. The survey did not so deeply address the fuel infrastructure, the maintenance and distribution network, the production system or the industrial structure, but certain important elements were explored. The details of the survey variables designed for the study are discussed below.

In terms of markets and user practices, market-related variables included e-bike prices, e-bike types, and the factors influencing e-bike purchase. As main regime actors, the choices of e-bike users are key to transition pathways. Only with the increase of e-bike users, is it possible for e-bikes to break out of their niche level. Therefore, it is significant to understand why e-bike users spontaneously chose e-bikes as their daily vehicles to achieve the personal mobility and to what extent e-bikes were embedded in their lifestyles and social practice. In this case, we particularly paid attention to the user practices and individual behaviours related to e-bike usage. For example, to explore the socio-demographic variables influencing individual behaviours, we collected the information such as age, gender, and income of the participants. In terms of the effect of psycho-social variables, we incorporated the trip purpose, the feeling associated with using e-bikes, and the attitudes towards e-bikes. In addition, considering the value of travel time and travel time reliability, we asked the questions such as which travel mode will be used in an urgent trip and how the trip time accuracy requirement determined the travel mode to understand the driving preferences.

One of the main aspects of MLP studies is transition management which emphasises the role of policy and tends to suggest that distinct policy intervention is fundamental to turning unsustainable practices into sustainable ones. This is because it stimulates and nurtures new production-consumption modes in the following aspects: distributing fiscal and other incentives, providing Research and Development (R&D) support, formulating regulatory frameworks, and taking charge of infrastructure development (Schot *et al.*, 1994; Hoogma *et al.*, 2002, Kemp and Loorbach, 2006). The requirement of policy interventions in different contexts is highlighted to steer a radical transition (Smith *et al.*, 2005; Smith, 2007; Genus and Coles, 2008). To extend the understanding of the role of regulations and policies in e-bike transition process, e-bike users were consulted whether e-bike restriction policies (e.g. restricting e-bike travel on main roads, and restricting e-bike travel in the city at specific times) had impact on their future travel mode choice and which regulations and policies would govern the e-bike towards a positive development, such as banning fast speed e-bikes, and requiring driving licences. In addition, we asked whether road condition was an important factor in terms of e-bike adoption and which suggestions on road infrastructure and traffic system change would improve e-bike development, including widening bicycle lanes, building e-bike lanes, and increasing e-bike parking places. Then, we investigated the fuel infrastructure, including home charging points, public charging points, and workplace charging points.

In terms of maintenance and distribution network, e-bike users were asked whether they were worried about the maintenance difficulties encountered for e-bikes. To investigate the production system and industry structure of e-bikes, we focused on innovations which would enhance e-bike performance, including speed, motor power, grade ability, battery life, appearance, weight, and the anti-theft system. In the transport domain, the automobile is not the only regime which co-exists with other regimes (e.g. bus, bicycle, metro, and e-bike). In order to explore the interactions among these regimes, e-bike users were asked whether the changes in other regimes had impact on their future travel mode choice, such as new bus routes added, and new metro stations added. In addition, e-bike users were consulted whether they would shift to cars once their income were increased. Apart from that, the survey variables were designed with a deliberate on the past, present, and future of e-bike transition. We explored the e-bike users' previous travel mode choices, present e-bike adoption behaviour, and future e-bike adoption to understand where e-bike users were from, the reasons of e-bike adoption, what the factors influence the future adoption of e-bikes, and how alternative travel modes were evaluated against e-bikes.

4. Case and Field Procedures

With our theoretical framework laid out, we sought to test the durability of the e-bike regime in China through primary data gleaned from surveys, which were conducted in

Nanjing City. The reasons why we chose Nanjing for performing surveys included: 1) As the capital of Jiangsu province, Nanjing is an important city in China with developed economics; 2) Nanjing is a base for e-bike industry in China, concentrated with a large number of e-bike manufactures and retailers; 3) E-bikes are widely used in Nanjing; 4) The authors have many friends in Nanjing who can help distributing and collecting questionnaires. The selected sample groups are e-bike users and non-e-bike users (bicycle users, private car users, and pedestrians). Moreover, Nanjing is widely representative of the mobility challenges and contradictions faced by populations in the major cities of China (Feng *et al.*, 2017).

The process of delivering and collecting questionnaires is mainly completed by residential community workers, and office workers. Firstly, the residential community workers are very familiar with the citizens who live in the communities and have a good relationship with them. Consequently, residential community workers can easily identify those who are e-bike users or non-e-bike users, and communicate with citizens and the government. When the potential participants passed by the neighbourhood committees, the community workers sent them questionnaires and asked them to return them after they were completed. If citizens refused to participate, the community workers simply asked others. Questionnaires were also sent to office workers and collected. Once the questionnaires were completed, they were collected and returned to the researcher.

Secondly, community works and office workers asked citizens in the city commercial centre which vehicle they were adopted and invited them to participate the survey. The advantages of choosing commercial centre are: 1) commercial centre usually have a large flow of visitors with different age groups, education backgrounds, and occupations, which maximises the diversities of the sample; and 2) with the large stream of citizens and the high density of populations, we can find more potential survey participants and also increase the number of accomplished surveys. Thirdly, when the e-bike users were waiting for e-bike maintenance in e-bike retail shop, the researchers asked them to participate in the survey.

The participants were therefore selected in a wide range of locations, including the residential communities, commercial centre, e-bike repair shops and e-bike communities throughout the urban areas. These locations are selected arising from a consideration of convenience. However, a certain degree of bias is unavoidable. A further effort is needed to ensure a diverse and unbiased sample through a larger scale sample selection approach. One challenge of the Nanjing case study was low response rate. Many people simply refused to participate in the survey, and some abandoned the survey after answering two or three questions. If citizens refused to participate, the community workers simply asked others. The low response rate made it time-consuming to achieve a large sample size. The target sample population and sample size consisted of: e-bike users (600); bicycle users (200); car drivers (200); and pedestrians (200). In total 1,003 responses were collected. The achieved number of responses for each group is: e-bike (403), bicycle users (200), car drivers (200), and pedestrians (200).

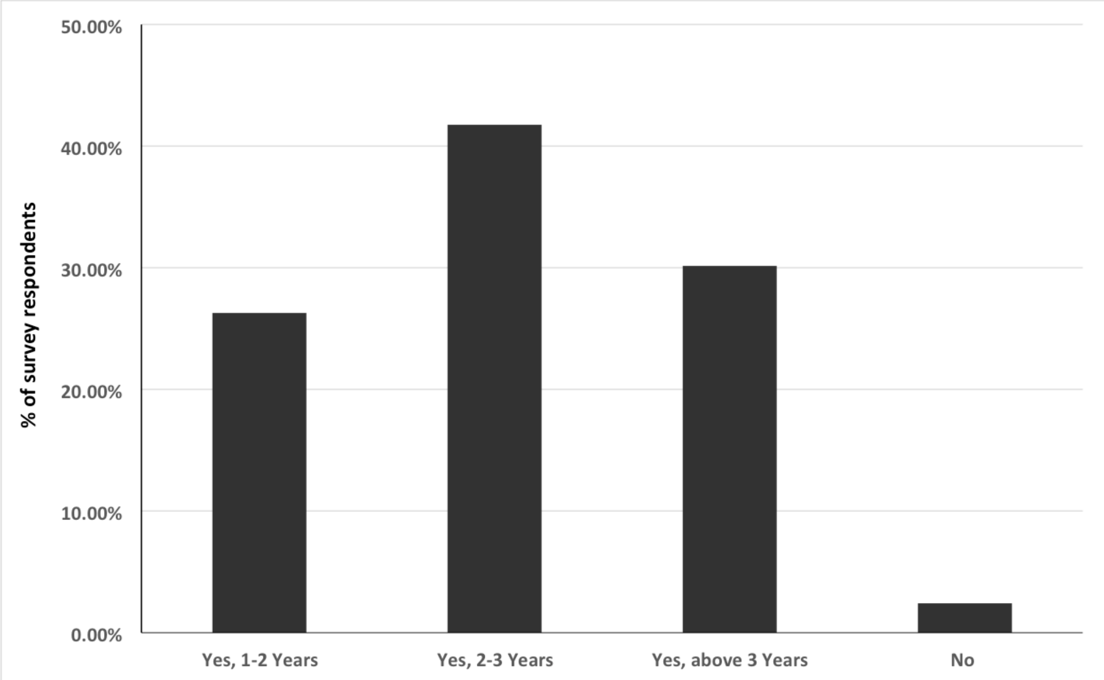
5. Model Specification

The survey data were used to develop a GLM with Gaussian distribution to predict e-bike usage in the future. The dependent variable is the years of future e-bike adoption. The data of the dependent variables are based on responding answers of the survey question “expected future use of e-bikes” (Figure 2). The reason for incorporating time dimensions into the dependent variable is that it helps the respondents to provide an overall consideration and rational estimation of their future choices, which mitigates the effect the value-action gap (Anable *et al*., 2006). The independent variables entering the model include user demographics, previous experience, and positive and negative associations and attitudes. In the regression analysis of the previous study by Cherry and Cervero (2007), the tested independent variables included user demographics, pro-e-bike attitudes, reasons for e-bike adoption, and e-bike travel time. Inspired by the study, we also chose user demographics, pro-e-bike attitudes, reasons for e-bike adoption, and e-bike travel time as independent variables. In addition, we introduced many new independent variables because they were thought to be potentially related to e-bike future adoption, including previously used travel modes, e-bike price, safety issues, e-bike user anxiety, and travel purposes.

In our sample, five alternative travel modes were chosen, including buses (39.2%), metro (37.3%), private cars (29%), walking (24.9%) and bicycles (22.9%), because they are the most popular ones. To understand the factors influencing the aforementioned alternative travel mode choices, each alternative mode was tested by a GLM with binomial distribution to examine the relationship with the potential influence factors. The initial factors (independent variables) entering the models include demographics, previous travel mode, attitude to e-bike adoption, and the reasons for transferring to alternative modes, because these factors were thought to have impact on mode choices according to individual behaviour literatures (Handy, 1996; Hiscock *et al*., 2002; Srinivasan and Rogers, 2005; Devarasetty *et al*., 2012; Boschmann and Brady, 2013; Bahamonde-Birke *et al*., 2017).

6. Results: Unveiling survey results

In our survey of e-bike users, more than 40% of participants expected to continue using e-bikes in the following two to three years, 30% of participants expected above three years, and 28% of participants in the following two years (Figure 2). The percentage of people expecting to transfer to other travel modes is only 2%. This suggests that e-bikes have satisfied the current travel demand of travellers to a great extent.



(Sample size: 403 e-bike users)

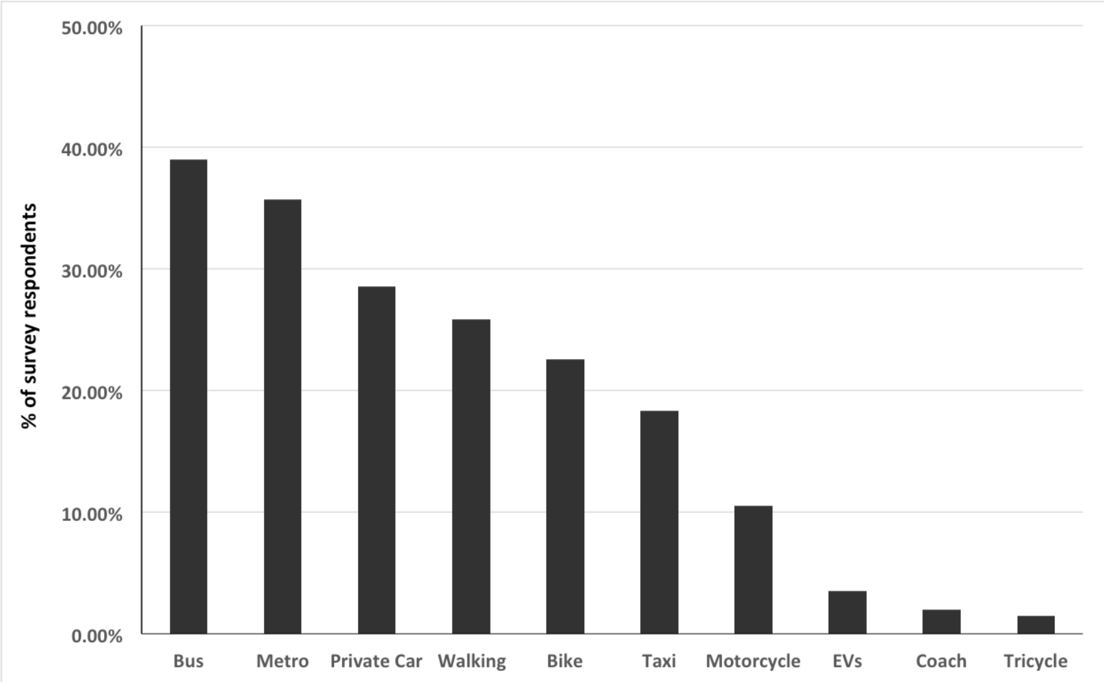
Figure 2 Expected future use of e-bikes: Nanjing survey

These results, interestingly, reinforce our idea of the contested nature of transport regimes. The e-bike regime does have a strong degree of path dependency, yet it is also one in tension with other transport regimes. For instance, those in favour of e-bikes argue that an "e-bike bans" policy will induce a significant increase in the use of private cars, which will place a higher burden on the traffic system and produce more pollution. If e-bikes are banned, it will cause a significantly higher demand for buses and the metro. On the other hand, if urban governments can allow for the development of e-bikes, traffic congestion will be lower than would otherwise be the case, and at very low cost. The travellers also will retain an additional choice to achieve personal mobility. Hence, e-bikes serve as a source of tension within and between different transport modalities.

This section presents and discusses which travel modes could be the alternatives to e-bikes in the future (Section 6.1). In order to identify the influential factors of future e-bike adoption, GLM with Gaussian distribution is adopted. As previously summarized, the initial independent variables entering the model include user demographics, previous experience, safety issues, reasons for e-bike adoption, travel purposes, e-bike travel time, e-bike price, and e-bike user anxiety (Section 6.2). The factors influencing alternative mode choice are examined by GLM with Binomial distribution (Section 6.3). The initial factors entering the models include demographics, previous travel mode, attitudes to e-bike adoption, and the reasons for transferring to alternative modes. It is also noted that in the questionnaire, the respondents are allowed to select more than one items from the given alternatives. Hence, a series of binomial logits are used instead of the multinomial logits or nested logit because the latter are suitable for a single choice from the alternatives.

6.1 Alternative travel mode choices

Concerning the possible alternative travel modes in the future if e-bikes are unavailable, for example due to e-bike policy, public transport is the primary choice (buses are 38.96% and the metro is 36.72% respectively), followed by private cars with 28.54% of responses (Figure 3).



(Sample size: 403 e-bike users)

Figure 3 Alternative mode choices in the absence of e-bikes: Nanjing survey

In comparison, fewer than 25% of e-bike users expecting to be using bicycles or walking in the future. This may indicate that the travellers have an increasing requirement for travel speed, so bicycles are not attractive to them. One of the reasons could be that the travel distances have grown due to the separation of housing, working, and other activities in a growing urban area, which results in a requirement for faster vehicles. In addition, when e-bike users were asked whether they would transfer to motorcycles if e-bikes were to be banned in the future, only 10.53% of them responded that they would consider it in the future. The reasons could be the high purchase cost, heavy weight and high operation cost of motorcycles. Very few people expected to adopt electric vehicles, coaches, and tricycles, which only occupy a very tiny share of the market.

In the surveys in other cities, buses are the most popular alternative travel mode as in Nanjing (this study), Shanghai, Kunming, and Shijiazhuang (Cherry and Cervero, 2007; Weinert *et al.*, 2008), whereas private cars are the most popular alternative mode in Xi'an (Xu *et al.*, 2014). The alternative mode choice may vary with the cities due to the difference of city scales, the household income and the level of the development of public transport system.

6.2 The factors influencing e-bike use

Number of observations=403, ACI=824.91, R^2: 0.6633, Adjusted R^2: 0.6515					
Variable	Estimate	Std. Error	*t* value	Pr(>|t|)	VIF
(Intercept)	0.988470	0.071616	13.802	< 2e-16***	
Age	0.002105	0.009710	0.217	0.828478	1.021218
E-bike price	0.034761	0.008491	4.094	5.2e-05***	1.106262
Number of e-bikes in household	0.064732	0.022823	2.836	0.004813**	1. 064900
Number of bicycles in household	0.039486	0.014690	2.688	0.007512**	1.088284
Number of cars in household	-0.028584	0.019114	-1.495	0.135640	1.029476
Walking (previous travel mode)	0.049217	0.026286	1.872	0.061943.	1.080514
Bus (previous travel mode)	0.063649	0.025489	2.497	0.012950*	1.175079
Metro (previous travel mode)	-0.072159	0.036267	-1.990	0.047360*	1.063229
Have accidents (1 if have accident, 0 otherwise)	-0.061511	0.024368	-2.524	0.012009*	1.033830
Flexible time (reason of e-bike adoption)	0.051698	0.025046	2.064	0.039694*	1.146073
Pro-e-bike attitude (1 if pro-e-bike, 0 otherwise)	0.056270	0.032612	1.725	0.085278.	1.089731
E-bike tends to be out of work during use (user anxiety)	-0.038360	0.011145	-3.442	0.000643***	1.051031
Commute (travel purpose)	-0.073896	0.024766	-2.984	0.003034**	1.056441

Significant. Codes : 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

Table 1 Results of predicting e-bike use choice model

The results of the GLM are shown in Table 1. The regression analysis is performed in the similar way to Cherry and Cervero (2007), Cherry *et al.*, (2016) and Campbell *et al.*, (2016), but more independent variables are introduced in our model, as mentioned in Section 2. The data were coded to represent the attitudes to e-bike development: supportive or opposing (1 if it is supportive, 0 otherwise). The independent variables are closely related to markets and user practices, culture and symbolic meaning, and maintenance and distribution network. The results of the GLM show that e-bike prices were positively associated with e-bike adoption. One explanation may be that the expensive e-bikes are normally of a better quality and exhibit better performance which fully satisfies the desires of consumers. For example, the scooter style e-bikes, the most expensive type, have a strong frame, a robust brake system, high speed and long battery life. Another reason may be that the respondents plan to use e-bikes for a long period of time, and therefore are motivated to invest in expensive e-bikes.

The model shows that future e-bike adoption is significantly associated with the household ownership of e-bikes and bicycles. E-bike ownership has the greatest influence and plays a positive role. The ownership of bicycles also increases the probability of future e-bike adoption in the following years. By contrast, future e-bike adoption is not closely related to household ownership of cars, which reinforces the survey results that the people who have owned cars in the family are not precluding the possibility of purchasing e-bikes.

Concerning the effect of previously used travel modes, the respondents who previously adopted walking or buses tend to expect to transfer to e-bikes in the following years, which is possibly due to a larger demand for personal motorised vehicles than before. In contrast, the e-bike users who previously travelled by metro are less likely to use e-bikes in the future. This could indicate that consumers are more satisfied with the service of the metro than buses. It is not surprising because the metro timetable is highly reliable and generally waiting time is also much less than buses. Therefore, if e-bikes are no longer used, it is more likely that e-bike users transfer to using the metro instead of the bus.

Now we investigate how future e-bike adoption expectations were affected by the time flexibility when riding e-bikes. Flexible travel time is an essential characteristic of personal motorized mobility, which produces “personalized, and subjective temporalities” (Urry, 2007), and allows motorized vehicle users to travel spontaneously rather than following the official timetable of buses and trains. Compared with cars, e-bikes have lower requirements on the infrastructure conditions and do not need specific parking facilities as cars do, and more importantly, can be used during traffic jams at peak times. The importance of travel time flexibility is also reflected in our survey: the respondents who agreed that e-bikes provide flexibility are more likely to continue to use e-bikes in the future.

As expected, the participants who held the opinion that e-bike development benefits the urban transport system are more likely to choose e-bikes as their future travel mode. In contrast, user anxiety is negatively associated with e-bike usage. The e-bike users who had accidents with other vehicles are especially unwilling to use e-bikes in the future. It is commented that the positive associations with usage are more individual and internal; for example, the feelings associated with e-bike usage. On the other hand, negative associations are more external and can be influenced through contextual change; for example, improving e-bike performance, and enhancing traffic safety awareness.

The trip purpose of e-bikes has a negative relationship with e-bike future adoption. If e-bikes are used mainly for commuting, the possibility of adopting e-bikes in the future is relatively small, probably because e-bikes confront the competition from other travel modes when commuting.

Without statistical significance, the factors such as gender, income, education, and trip time are precluded in the final model. That is, the future of e-bike adoption does not depend on the gender, income, or the educational level of the person.

6.3 The factors influencing travel mode choice

It is important to understand the impact on alternative travel modes if e-bikes were to be banned, as the transfer of modes will incur environmental costs and have mobility impacts in the urban transport system. The relationship between each mode and these influencing factors are discussed below.

6.3.1 Bus

Number of observations = 403, ACI = 480.96, Likelihood Ratio=70.75, Pseudo R^2=0.218				
Variable	Estimate	Std. Error	*t* value	Pr(>|t|)
(Intercept)	-1.22001	0.24334	-5.014	5.34e-07***
Income	-0.15946	0.07737	-2.061	0.039312*
Long trip distance	0.38240	0.17034	2.245	0.024771*
Previously used travel mode (bus)	0.79132	0.17230	4.593	4.37e-06***
Road condition is not suitable for e-bike	0.72400	0.19768	3.662	0.000250***
Request an accuracy of time	0.81026	0.21053	3.849	0.000119***
Demand of high accessibility	0.59011	0.17902	3.296	0.000979***

Significant. Codes : 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

Table 2 Predicting the likelihood that current e-bike users will transfer to bus usage if e-bikes are unavailable

The dependent variable in this binomial model is whether buses are the alternative choice (1=Yes, 0=No), when e-bikes are unavailable. Income is negatively associated with bus usage (Table 2). That is, the low cost of travelling with buses is a critical factor attracting lower income travellers, so the travellers with higher income are less likely to choose buses and are willing to pay more for a better transport service instead. Road conditions also have an influence on choosing buses. The worse the road condition is, the more likely it is that a consumer will choose to use the bus. Other factors positively associated with bus adoption include long trips, previous travelling experiences by bus, and a high demand of time requirement and accessibility.

6.3.2 Metro

The dependent variable for this binomial model is whether the metro is the alternative choice (1=Yes, 0=No), when e-bikes are unavailable. The independent variables mainly belong to markets and user practices element and road infrastructure and traffic system element in the regime. The relationship between income and the probability of metro adoption is positive (Table 3), indicating that the travellers with a higher income tend to choose the metro. Consistent with this, the travellers who use e-bikes mainly due to their low cost are less likely to use the metro in the future.

Number of observations = 400, ACI = 448.15, Likelihood Ratio=100.56, Pseudo R^2=0.304				
Variable	Estimate	Std. Error	*t* value	Pr(>|t|)
(Intercept)	-0.44456	0.26865	-1.655	0.097967.
Income	0.12452	0.06944	1.793	0.072922.
Demand of low operation cost	-0.31813	0.16140	-1.971	0.048723*
Request an accuracy of time	0.49310	0.19662	2.508	0.012146*
No time requirement	-0.73227	0.27305	-2.682	0.007323**
New metro stations added	0.54511	0.18336	2.973	0.002951**
Previously used travel mode (bus)	0.78801	0.14326	5.500	3.79e-08***
Previously used travel mode (car)	-0.74032	0.27575	-2.685	0.007258**
E-bike price	-0.20961	0.05403	-3.879	0.000105***
Household ownership of bicycles	0.20827	0.09187	2.267	0.023389*
Physical discomfort	0.65347	0.21059	3.103	0.001915**

Significant. Codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1

Table 3 Predicting the likelihood that current e-bike users will transfer to metro use if e-bikes are unavailable

The requirement of time accuracy also plays an important role in metro adoption. If a trip has a strict requirement on time accuracy, travellers are more likely to use the metro. Consequently, if there are more new metro stations built, the travellers are more likely to use the metro. So increasing the number of metro stations is an effective method for attracting prospective metro riders.

The e-bike users who previously used buses are more likely to transfer to using the metro. This could be an indicator that the metro better fits travellers' demands than buses. In contrast, the respondents who previously used private cars are less likely to transfer to the metro, because the respondents who are accustomed to personal motorised vehicles have no preference for travel modes without travel flexibility. For the same reason, respondents with expensive e-bikes have fewer chances to transfer to metro. By contrast, the travellers who have bikes in their households are more likely to adopt metro use, especially when e-bikes are unavailable, indicating that the motorised transport is a future tendency. Furthermore, if respondents are physically uncomfortable, the probability of choosing the metro will increase. This could be because metro facilities better suit their needs.

6.3.3 Private cars

Number of observations = 396, ACI = 418.51, Likelihood Ratio=81.582, Pseudo R^2=0.171				
Variable	Estimate	Std. Error	*t* value	Pr(>|t|)
(Intercept)	-3.511111	0.510365	-6.880	2.41e-11***
Gender (Female)	0.637487	0.250658	2.543	0.01137*
Household ownership of cars	0.674912	0.193139	3.494	0.00053***
Previously used travel mode (walking)	0.504620	0.269605	1.872	0.06200.
Previously used travel mode (car)	0.795335	0.390759	2.035	0.04249*
Income increase	0.766780	0.267546	2.866	0.00438**
Trip time	0.012819	0.004519	2.837	0.00480**
Trip distance (short)	-1.152717	0.405715	-2.841	0.00473**
E-bike restriction policy	0.784523	0.363037	2.161	0.03130*
Safety issues	1.596260	0.405356	3.938	9.74e-05***
Demand of high accessibility	0.529472	0.267232	1.981	0.04826*

Significant. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

Table 4 Predicting the likelihood that current e-bike users will use private cars if e-bikes are unavailable

The dependent variable for this binomial model is whether using a private car is the alternative choice (1=Yes, 0=No), when e-bikes are unavailable. The independent variables mainly have connection with markets and user practice element, regulations and policies element and automobile regime. The positive relationship with car usage is found in female e-bike users (Table 4), meaning that female travellers have stronger intentions to transfer to using private cars.

It is noted that although female travellers presented a strong willingness to transfer to private car use, they may not actually take it into action, because there is a so-called value-action gap between the attitude and corresponding behaviour (Lane and Potter 2007; Olson 2013). In the model, the use of private cars is closely correlated with the safety issues regarding e-bikes. E-bike users with greater safety concerns about e-bike are more likely to transfer to cars, meaning that they perceive that private cars are safer.

As expected, the household ownership of cars is positively associated with car usage. Consistent with the effect of household ownership of cars, the travellers who previously adopted cars are more likely to use private cars, if e-bikes become unavailable. The result may indicate that private cars are the “expensive dream travel vehicle” for travellers.

Trip time is significantly positively related to private car adoption, indicating that the longer trip times or distances lead to a higher probability of choosing private cars. Other potential groups of e-bike uses inclined to transfer to car use are: 1) The respondents choosing e-bikes for high accessibility and 2) the ones who are worried about the future release of an e-bike restriction policy.

6.3.4 Walking

Number of observations = 397, ACI =399.53, Likelihood Ratio=75.13, Pseudo R^2=0.254				
Variable	Estimate	Std. Error	*t* value	Pr(>|t|)
(Intercept)	-0.871374.	0.501176	-1.739	0.082095
Income	-0.230349	0.099483	-2.315	0.020587*
Income increase	-0.511154	0.244762	-2.088	0.036764*
Walking (previously used travel mode)	0.421115	0.226280	1.861	0.062740.
Road condition is not suitable for e-bike	0.947014	0.235090	4.028	5.62e-05***
E-bike price	0.246562	0.070663	3.489	0.000484***
Trip time	-0.023572	0.007059	-3.339	0.000840***
Request an accuracy of time	-0.774549	0.349270	-2.218	0.026581*

No time requirement	0.969219	0.330402	2.933	0.003352**
New bus routes added	0.633668	0.224947	2.817	0.004848**
Pro-e-bike attitude	-0.561309	0.244391	-2.297	0.021632*
Have traffic accidents using e-bikes	0.512976	0.207033	2.478	0.013221*

Significant. Codes : 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1

Table 5 Predicting the likelihood that current e-bike users will transfer to walking if e-bikes are unavailable

The dependent variable for this binomial model is whether walking is the alternative choice (1=Yes, 0=No) if e-bikes are unavailable. The independent variables are closely related to markets and user practices, road infrastructure and traffic system and automobile regime. Income enters the model with a negative sign, suggesting that the survey participants with higher incomes or high expectations for future income are less likely to choose walking as an alternative mode (Table 5). This may be because walking is the cheapest way to travel. It is also possible that these respondents with higher income are able to locate further from city centres in new housing developments, so walking ceases to be a viable option. So the respondents who previously travelled by walking are more likely to walk when e-bikes become unavailable.

If the respondents show a positive attitude towards e-bike development, they are less likely to choose walking. It is interesting that the participants who have more expensive e-bikes are more likely to transfer to walking in the future. A possible explanation is that the e-bikes with good performance satisfy users’ travel demands, so they have no interest in other vehicles. But walking is a complement to e-bikes.

It is not surprising that trip time is negatively associated with walking, indicating that the shorter the trip time the more likely it is that respondents will choose to walk. But if the trip has a high requirement on the accuracy of time, the respondents are less likely to choose walking.

The result also shows that respondents are more likely to choose walking when new bus routes are added. This could be because respondents need to walk to bus stations. The result could be an indicator that urban transport mobility tends to be multimode.

However, taking into account the safety issues of using e-bikes, walking is more likely to be chosen. That is, if the respondents experience accidents when using e-bikes, they are more likely to choose walking. If road conditions are not suitable for e-bike travelling, this can also increase the number of people willing to transfer to walking.

6.3.5 Bicycle

The dependent variable for this binomial model is whether bicycles are the alternative choice (1=Yes, 0=No), when e-bikes are unavailable. The independent variables mainly have connections with markets and user practice, production system and industry structure, and automobile regime. The e-bike users who previously adopted bicycles are more likely to transfer back to bicycles if e-bikes are unavailable (Table 6). From our model, the household ownership of bicycles enters the model with a positive sign, suggesting that the more bicycles owned by the household, the more likely it is that consumers will choose bicycles.

Number of observations = 397, ACI = 408.39, Likelihood Ratio=35.64, Pseudo R^2=0.130				
Variable	Estimate	Std. Error	*t* value	Pr(>|t|)
(Intercept)	-1.5548	0.3524	-4.412	1.02e-05***
Household ownership of bicycles	0.2437	0.1152	2.115	0.03441*
Household ownership of cars	-0.3946	0.1984	-1.989	0.04673*
E-bike performance	0.6609	0.2481	2.664	0.00772**
E-bike price	-0.1284	0.0776	-1.654	0.09805.
Safety issues	0.6384	0.2304	2.771	0.00559**
New metro stations added	0.4960	0.2580	1.922	0.05460.
Bicycle (previously used travel mode)	0.5581	0.2137	2.612	0.00901**

Significant. Codes : 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

Table 6 Predicting the likelihood that current e-bike users will transfer to bicycle use if e-bikes are unavailable

By contrast, the households who own more cars are less likely to use bicycles, which agrees with our previous discussion that car users will continue to use cars in the future.

As expected, if the respondents are not satisfied with the e-bike performance, they tend to transfer to bicycle use. A parallel finding is that the more expensive e-bikes the respondents have, the less likely they are shift to bicycle use, because expensive e-bikes normally perform better and can satisfy users' requirements.

Interestingly, additional metro stations can promote bicycle use, indicating that they may be used to transfer to metro stations. So similar to walking, bicycles can also be a complement to public transport. Finally, safety concerns regarding e-bikes is positively associated with bicycle usage, which suggests that respondents believe that bicycles are safer than e-bikes.

7. Discussion: Comparative factors and travel mode transitions

In this section an analysis is offered of the factors likely to be of influence in travel mode transitions, and the role of gender issues in those factors. Put another way, we connect the survey results back to our theory of sociotechnical transitions and the MLP.

7.1 Comparison of influencing factors

Table 7 lists the factors which can influence mode choices.

	E-bike	Bus	Metro	Car	Walking	Bicycle
Gender (Female)	N	N	N	+	N	N
Age	N	N	N	+	N	N
Income	N	-	+	N	-	N
Income increase	N	N	N	+	-	N
Household ownership of e-bikes	+	N	N	N	N	N
Household ownership of bicycles	+	N	+	N	N	+
Household ownership of cars	N	N	N	+	N	-
Safety consideration	N	N	N	+	N	+
Long trip distance	N	+	N	N	N	N
Short trip distance	N	N	N	-	N	N
Trip time	N	N	N	+	N	N
Request an accuracy of time	N	+	+	N	-	N
No time requirement	N	N	-	N	+	N
New metro stations added	N	N	+	N	N	+
New bus routes added	N	N	N	N	+	N

“+”: positive sign, “-”: negative sign, “N”: no significant relationship

Table 7 The influence factors of travel mode choice behaviour

Income seems to influence the travel mode choice significantly. Income is significantly related to travel mode choices in our model. Travellers with higher income tend to use more expensive travel modes, such as metro and cars. Our conclusion is also supported by the travel behaviour research of Dieleman *et al.* (2002), who has a similar finding that the higher the household income, the more likely it is that respondents use cars. However, the statistically significant relationship between income and mode choice was not found by Cherry and Cervero (2007). Our study further revealed that people with high expectations for future income tend to buy private cars. The result reinforces the automobility culture of China in which the car is a symbol of wealth, whereas other vehicle users are identified as less wealthy or from a poor educational background.

Households in China tend to have more than one type of vehicle. In our sample, nearly 50% of e-bike users have both e-bikes and cars in their households, and nearly 80% of car drivers have e-bikes in their households. This may indicate that the respondents who have both e-bikes and cars are likely to adopt e-bikes. Hence, e-bikes and cars can complement each other for a better motorised mobility.

According to previous research (Handy, 1996; Cervero, 2002; Naess, 2003; Naess and Jensen, 2004; Srinivasan and Rogers, 2005), the infrastructure construction of public transport has a significant impact on mode choice behaviour. Our research results also fit their observations – and in doing so, lends support to the obduracy of transport regime infrastructure. In our research, newly added metro or bus routes do not only increase the probability of using public transport, but also increase the chances of bicycle adoption and walking. This result may suggest that the door-to-door service of e-bikes could be partly replaced by the combined use of bicycles and metro routes. However, in the bike future use predictive model by Cherry and Cervero (2007), the factor of infrastructure construction of public transport was not considered.

Also, we find that trip time requirement has an extensive influence on travel behaviour. For the same trip length, if an accurate time is required, buses and the metro are more likely to be chosen. In the opposite situation, walking is more likely. In addition, if a trip is not urgent, travellers tend to choose a slow speed transport mode. If it is an urgent trip, travellers tend to choose a faster transport mode. This finding is different from Cherry and Cervero (2007) who used a Logit model to examine the factors which have an impact on the mode choice. Their model did not consider the trip time accuracy requirement, but only took into account the travel time gap between e-bikes and bicycles as the independent variable. They suggested that the wider the travel time gap between e-bikes and bicycles, the more likely it is that people will choose e-bikes (Cherry and Cervero, 2007). In addition, the longer the travel time of a particular mode, the lower the probability of choosing that mode is (Cherry and Cervero, 2007). However, the trip time requirements affect the mode choice to a greater degree than actual trip time. This understanding also contributes to the MLP by indicating the temporality of transitions – that transport regimes are fluid, and the timing of the service demanded can implicate how or why particular modes are favoured. The co-evolution of urban structures and mobility possibilities in specific spatial and temporal settings therefore results in distinct trajectories for regimes and niches that can only be uncovered empirically, as we demonstrate here.

Our study also fits the idea that users rely on utility-maximising rules. Generally, a traveller chooses the suitable travel mode according to the opportunity cost of the time that was spent on the journey. In our models, when the trip has no time requirement, a traveller is more likely to walk to the destination. If the trip is urgent, a traveller has a strong desire to save time and thus will choose a more expensive but faster travel mode. In addition, our model also fits the income effect, which is defined as a common phenomenon that the price change in consumption results in the change of the consumer's real income, and then the consumer purchases more or less products until a new equilibrium is reached again for the real income (Deaton and Muellbauer, 1980). In our study, the lower the income of the traveller, the more likely he or she is to use buses or to walk rather than using a car, which suggests that they are sensitive to price and will choose basic travel services which match their income level. As income grows, a traveller will pay more for the travel service with better quality; for example, the metro or a car. This underscores the dynamism of users and flexibility of regimes, namely that creative users will consider multiple regimes as they decide about particular modes. Hence part of the trajectory of regime stability or instability is tied to market and technological possibilities: the emergence of e-bikes as a technology package coincided with urbanization but also with a growth in personal or household income that resulted in e-bike adoption on a large scale. With further personal or household income growth there may be a further shift into cars.

Safety issues influence travel mode choice behaviour as an important psycho-social factor. If e-bike users are sensitive to traffic safety problems, or experienced accidents before, they are less likely to use e-bikes, and are more likely to travel by walking, bicycles and cars. Sönmez and Graefe (1998) found that perceptions of risk and safety from past travel experience are significantly associated with future travel behaviour by applying information integration theory (it explores how individuals form and change their psychophysical and value judgments through the integration of a number of information sources), protection motivation theory (it investigates how a person process threats and stress and how to cope with them), and logit regression. Their result concluded that perceptions of safety from past travel experience increased the probability to travel there again, while the perceptions of risk from past travel experience decreased the probability to travel (Sönmez and Graefe, 1998). Compared to the previous literature, which performed qualitative analysis on safety issues, our study incorporated the safety factor to GLM with Gaussian distribution and GLM with Binomial distribution of e-bike mode choice for quantitative analysis.

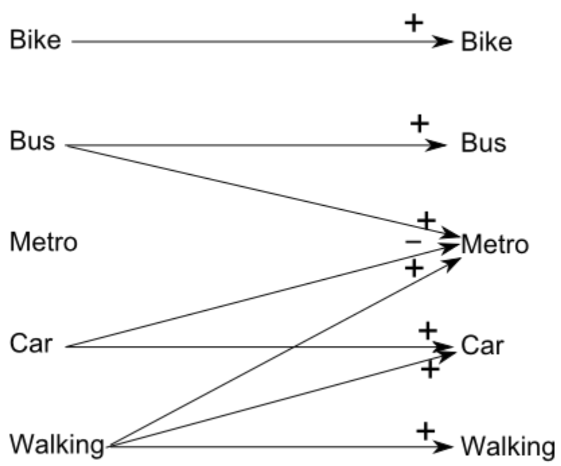


Figure 4 Travel mode transition flow when e-bikes are unavailable

In addition, it is found that the e-bike experience can change people's inclination for using alternative modes, as illustrated in Figure 4. One is a positive relationship between the previous and future travel mode choices. The travellers who previously travelled by bicycle are more likely to shift to bicycle use in the absence of e-bikes. The similar trends are also found in e-bike users who previously used buses, cars and walking. The other one is the tendency to transfer to metro and private car use. Pedestrians and those who previously travelled by bus are more likely to transfer to the metro use. In addition, the travellers who previously walked exhibited a great demand for car adoption. The result implies an increasing demand for faster speed vehicles. The experience of e-bike adoption partly changed the future choice of travel modes.

7.2 Gender differences in future mode choices

The future travel model choices of female and male e-bike users are influenced by different e-bike usage experiences—emphasizing the heterogeneity of users. This gender difference is embodied in the future adoption of motorcycles and private cars, but not found in the future choices of buses, walking, bicycles, and metro (Table 8).

	Bicycle		*p*-value		Motorcycle*		*p*-value
	Yes	No			Yes	No	
Male	43(21.9%)	168(78.1%)	0.6757	Male	28(13.1%)	215(86.9%)	0.0928
Female	43(24.2%)	175(75.8%)		Female	13(7.4%)	165(92.6%)	
	Bus		*p*-value		Metro		*p*-value
	Yes	No			Yes	No	
Male	86(40.0%)	129(60.0%)	0.79579	Male	73(34.0%)	142(66.0%)	0.14963
Female	68(38.3%)	110(61.7%)		Female	73(41.1%)	105(58.9%)	
	Walking		*p*-value		Private cars※		*p*-value
	Yes	No			Yes	No	
Male	51(23.8%)	164(76.2%)	0.540	Male	51(23.8%)	164(76.2%)	0.0111
Female	47(26.6%)	131(73.5%)		Female	63(35.4%)	115(64.4%)	

※*p*-value <0.05; *: *p*-value<0.1

Table 8 Chi-squared test results of alternative travel modes

The significant difference between female and male e-bike users in terms of future motorcycle choice is similar to the gender differences in the previous motorcycle adoption: the percentage of male respondents (13.1%) is more than female respondents (7.4%).

The gender differences in future private car choice are especially significant. 35.4% of female e-bike users are willing to shift to using private cars in the absence of e-bikes, while only 10.7% of them previously travelled by private cars. In comparison, fewer male e-bike users (23.8%) will shift to private cars in the future. The result is also supported by the prediction of our that female respondents are significantly positively related to private car use. An explanation is that females are more concerned about the physical safety issues compared to males. Moreover, women in the family in China are normally responsible for dropping off/picking up children at/from school, which is also a possible reason for the fact that women are more willing to shift from e-bikes to private cars.

7.3 Future transitions of e-bikes

The successful e-bike transition from niche to regime was not the direct result of positive, purposive policy interventions at national or sub-national level, nor the result of nurturing niches (Wells and Lin, 2015). Moreover, landscape and regime actors restrained the e-bike's ascent to regime status by banning them. Due to the pressures arising from outside criticism and the increasing demand for personal motorised mobility, the government acquiesced to the reality and relaxed the e-bike restrictions, which allowed e-bikes' further permeation. E-bikes well satisfied the current travel demands for personal mobility with the advantages of affordable price, effort saving, flexibility, high accessibility, and saving time in traffic jams (Lin *et al*., 2017). This is also supported by our survey results. That is, 98% of the e-bike users would like to continue to use e-bikes in the future, suggesting that e-bikes did not only meet their current travel demands, but also were predicted to satisfy their future personal mobility. In addition, the survey variables which have significantly positive relationship with e-bike future adoption, including e-bike price, commute (travel purpose), flexible time (reason of e-bike adoption), bus (previous travel mode), walking (previous travel mode), were closely related to markets and user practices element in the regime. Therefore, the spontaneous e-bike transition was mainly triggered and propelled by the markets and users. As a result, e-bikes seem to be well embedded in the current transport regime.

Although e-bikes are an existing transport regime, our analysis suggests that they are the one in decline, or, in other words, an intermediary regime. The first reason is that e-bikes are subject to the adverse effect from landscape and regime. "Public Transport Priority Development" policy is widely implemented across China (Quan *et al*., 2006). This landscape pressure forced the regime actors to re-structure urban transport systems, and especially strongly promoted public transport development, such as reducing ticket prices, adding more buses and bus routes, and even building an entirely new metro system, which had great impact on citizens' travel mode choices. In our survey results, new added metro stations and new added bus stations were significantly positively associated with other travel mode adoption, such as metro, bicycles, and walking. These actions tightened the living space of e-bikes, which might lead to the de-alignment transition process of e-bikes.

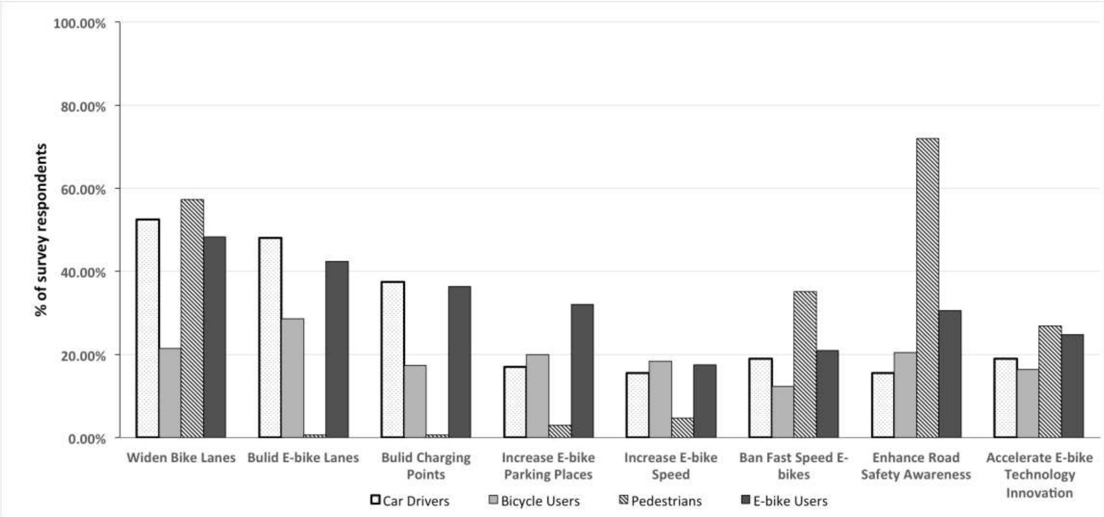
Secondly, e-bikes have to cope with the fierce competition from automobile regime and receive lock-in mechanisms (culture and symbolic meaning) in the complex socio-technical regimes. Many respondents are willing to shift to private cars with an increase in income according to our survey results. In addition to practical usage considerations, this is also closely related to automobility culture in China. A car user is normally viewed as a person with wealth and a well-educated background. In contrast, the current symbolism and social connotation of e-bikes is that e-bikes users are identified as "poor, not well-educated" (Tyfield, 2014). However, it should be pointed out that the above negative opinions on e-bike users are not completely consistent with the facts. For example, our survey reveals that the average education and income level of the e-bike users is much higher than the overall average level of Nanjing City. 63.57% of e-bike users have obtained a college degree or above, and 45.23% of e-bike users have completed a university degree. 87.6% of the e-bike users are employed and their income is in a higher-middle range. Nevertheless, such a negative impression of e-bikes in the public domain is hard to change in a short time, so it will be likely to influence the future choice of e-bikes and profoundly shape the trajectory of socio-technical transition.

Thirdly, e-bikes still confront the high possibility of e-bike restrictions and bans policy from landscape and regime, bringing more uncertainties to the future development of e-bike transition. As mentioned previously, in the early stage of e-bike transition, landscape developers and regime actors issued e-bike bans, but then revoked the policy due to the pressures from outside criticism and the increasing demand for personal motorised mobility. Since then, the number of e-bikes skyrocketed, accompanied with exponentially increasing traffic accidents and severe lead pollution, which highlighted the negative impacts of e-bikes. Out of the concern of the transport safety and environmental protection, a new round of e-bike restriction and ban policies were issued by landscape developers and regime actors in 2011 in

Beijing, Tianjin, Guangdong Province, Yunnan Province, and Zhejiang Province, seriously hindering the e-bike development. These policies were strongly opposed by outside criticism (e.g. journalists, scholars, and public intellectuals) and e-bike users, who suggested the government to draft new e-bike national standard and regulate e-bike rather than simply banning them. However, the suggestions were not adopted in the above-mentioned cities or provinces. Even worse, Guangzhou city went further in the direction of restricting e-bike usage, which started to completely ban e-bikes in 2017. In our survey result, the e-bike restriction policy is a key influential factor, which discouraged the desire of future e-bike adoption. If the landscape developers and regime actors stubbornly and arbitrarily implement e-bike restriction and ban policies, it will be highly possible that e-bikes can only serve as an intermediary regime.

7.4 Perspectives on regimes in tension

Future suggestions for e-bike development are revealed by different groups, as shown in Figure 5, and they confirm our notion that regimes are currently competing and co-evolving in China. A Chi-squared test of independence was performed to examine whether there were statistically significant differences amongst different traveller groups in relation to their suggestions for e-bike development. After the test, statistically significant differences were found in the suggestions such as widening bike lanes, building e-bike lanes, building charging points, increasing parking places, increasing e-bike speed, banning high-speed e-bikes, and enhancing road safety awareness. On the other hand, no statistically significant differences exist when the suggestion is accelerating e-bike innovations.



(Sample size: 200 car drivers; 200 bicycle users; 200 pedestrians; 393 e-bike users)

Figure 5 Future suggestions for e-bike development: Nanjing survey

Approximately 60% of pedestrians suggested that bicycle lanes should be widened, which is also advocated by 55% of car drivers and 50% of e-bike users. However, bicycle users prefer building separate e-bike lanes, implying that the existing bicycle lanes are too narrow to satisfy the mixed use of both bicycles and e-bikes, which could cause traffic conflicts between them.

More than 70% of pedestrians thought that e-bike users should enhance road safety awareness. The result indicates that pedestrians feel that their own safety has been threatened seriously by the e-bike users riding without sufficient safety awareness. Even 30% of e-bike users also held the same opinion as pedestrians, which further exposed the traffic safety problems caused by e-bikes.

It is not surprising that different groups interpreted the road situations and gave suggestions from their own standpoints and experiences. For example, car drivers thought that the speed of e-bikes was acceptable, while nearly 40% of pedestrians suggested banning high-speed e-bikes. Another example is the fact that e-bike users, car drivers and pedestrians suggested widening bicycle lanes. Yet from the perspective of bicycle users, the introduction of separate e-bike lanes is more reasonable, which implies that e-bikes were viewed as a threat to the safety of bicycle users when sharing the same lane. However, the overall attitudes of all groups of respondents to e-bike development are positive. They agreed that e-bikes have contributed to personal mobility and are very environmentally friendly.

Bringing this back to our theoretical perspective, these results about future e-bike development are closely related to the landscape and regime change (see Geels, 2002). In terms of the suggestions for improving bicycle lanes, if a great number of vehicle users have this requirement it will give rise to an intensive pressure on the regime, which will potentially destabilise the existing mobility regime. Subject to this pressure, policymakers could take measures to improve transport infrastructures in favour of e-bikes. Suggestions regarding the enhancing of road safety awareness may be understood as a form of socio-cultural process, occurring at the landscape level. It is noted that the low response rates of “accelerate e-bike technology innovation” indicated that the current e-bike technology well satisfied the needs of majorities, which further supported that e-bikes have already reached the ‘regime’ level and the public concern mainly arised from the safety problems that induced “e-bike ban policy”.

8. Conclusion and implications

Based on original data collected from the survey in Nanjing city, this study has explored how far the e-bike regime is likely to continue to be embedded in transport choices. It therefore presents a novel, and rare, utilization of quantitative methods used to test the validity and application of sociotechnical transitions theory, and the Multi-Level Perspective on innovation. Our GLM predicts the choices with respect to future e-bike adoption. User attitudes, demographics, safety issues, and user anxiety about battery performance are all significant factors that influence travel mode choice in the GLM. The probability of choosing e-bikes is positively associated with the household ownership of e-bikes, the household ownership of bicycles, the cost of e-bikes, pro-e-bike attitudes, and the demand for flexible trip times, while the negative factors are user anxiety about e-bike performance, and experience of accidents.

If an "e-bike ban policy" is issued, the possible alternative modes are ranked as follows: buses, the metro, private cars, walking and bicycles. Hence, public transportation will be subject to a great transportation pressure. The binomial models show that the alternative mode choice is significantly related to income. The lower income respondents tend to use buses or will walk, while higher income respondents prefer to use the metro and private cars. If the trip requires an accuracy of time, the respondents are more likely to choose motorised vehicles. If the trip has no time requirement, the respondents are more likely to choose slower and cheaper travel modes, such as walking. New metro stations will increase the likelihood of choosing to use the metro and bicycles. New bus routes will increase the chances of adopting walking as a mode of transport. Participants with high expectations for future income increase tend to buy private cars, which suggests that the e-bike is highly possible to become an intermediate mode to cars in terms of personal mobility vehicle choice.

Through the lens of the MLP, we can find that e-bikes are a regime in decline. This is due to the above mentioned gradual changes of regulations, use patterns, infrastructures, cultural discourse and travel preferences. These changes lead to de-alignment of e-bike markets, production systems and industry structures in the existing regime. As a result, e-bikes may only serve as intermediate transport modes on Nanjing's motorisation pathway – and they remind us that regimes have often overlooked spatial and temporal attributes.

The future work is to conduct the survey in a great variety of locations with a larger scale of sample selection. Moreover, the latent variables, such as perceptions and attitudes, will be investigated systematically in the framework of Hybrid Discrete Choice models (Bahamonde-Birke *et al*., 2017).

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