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Urban Stud 2014 51: 1019 originally published online 12 July 2013
DOI: 10.1177/0042098013494423

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Urban Studies
51(5) 1019–1037, April 2014

Article

The Impact of the Built Environment on Bicycle Commuting: Evidence from Beijing

Pengjun Zhao

[Paper first received, October 2011; in final form, January 2013]

Abstract

This paper aims to contribute to existing literature on the effects of the built environment on bicycle commuting, examining the case of Beijing. A group of city-wide random samples is analysed. The analysis shows that bicycle commuting is significantly associated with some features of the built environment when many demographic and socioeconomic factors are taken into account. Higher destination accessibility, a higher number of exclusive bicycle lanes, a mixed environment and greater connectivity between local streets tend to increase the use of the bicycle. These effects differ across gender, age and income groups. However, residential density has no significant effects on the use of a bicycle for commuting, while higher levels of public transit services tends to decrease rather than increase bicycle commuting. The results imply that the drastic changes in the built environment are a major reason for the demise of 'the kingdom of bicycles' in China.

1. Introduction

Recent transport policies have paid much attention to promoting cycling as an alternative form of commuting due to an increasing concern about vehicle pollution and public health in the world. In particular, a variety of policy interventions have been considered for the purpose of creating a cycling-friendly built environment; for example, the supply of cycling facilities and spatial policies designed to increase density, diversity and destination accessibility. However, policymakers often face the question of whether such policy interventions efficiently promote commuting by bicycle (Pucher *et al.*, 2010).

Most previous studies have found that the built environment has an effect on bicycle commuting and that some policy interventions into the built environment would encourage an increasing share of bicycle commuting trips (see a review by Heinen *et al.*, 2010). However, the conclusions are still mixed. Some studies have reported that the built environment has no

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0042-0980 Print/1360-063X Online
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DOI: 10.1177/0042098013494423
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significant effects (Moudon *et al.*, 2005) or has only very weak effects (Parkin *et al.*, 2008) on bicycle use for commuting when other factors are taken into account. In addition, previous studies often have limitations with respect to research design, data collection, typicality of cases, mathematical methods and so on (Crane, 2000; Ewing and Cervero, 2010).

This study aims to extend the existing literature by examining the case of Beijing. China has been known as 'the kingdom of bicycles' for decades. The bicycle was even seen as one of the 'must haves' for young people getting married in the 1980s, and in 1999 there were 570 million bicycles in China (CSB, various years). Moreover, the bicycle was once the main travel mode for commuting in China's cities. For example, in Beijing, the share of cycling was 62.6 per cent of all commuting trips in 1986. However, since the 1990s, both the ownership and use of the bicycle for transport have been in dramatic decline in China's cities, particularly for commuting purposes. For example, in Beijing, the share of bicycle use for commuting decreased from 62.6 per cent to 17.9 per cent during the period between 1986 and 2010 (BTC, 1986, 2000, 2005). Meanwhile, the share of travelling by private car increased from 5 per cent to 33.5 per cent. The private car has become a major mode of travel for trips to work. It seems that China's 'bicycle kingdom' is in decline and that it is embracing motorised modes, in particular, cars at a frightening pace.

Halting the decline of cycling has become a key issue in relation to building green transport infrastructure and enhancing air quality in many of China's cities. However, like policy-makers in other countries, the politicians in China's cities often face criticism about the performance of policy interventions in the physical built environment to encourage cycling. Some critics doubt that expensive investment in cycling facilities would have a positive effect on bicycle commuting, as evidence for a relationship between the built environment and bicycle commuting is still scarce in China's cities, not to mention that the findings still remain ambiguous in Western countries.

This paper aims to fill the gap, examining the effects of the built environment on an individual worker's choice of bicycling for their journey to work. This study will contribute to the existing literature in four ways. First, both the scale and speed of the transition in commuting modes and the built environment in Beijing are beyond what has ever been observed in Western countries. Such rapid change can provide more vivid evidence for the links between the built environment and bicycle commuting. Secondly, many of the previous studies used targeted samples of cyclists rather than random samples. In Beijing, both ownership of a bicycle and the use of the bicycle for commuting are still at relatively high levels. A large number of commuters indeed use a bicycle for their trip to work every day. The samples analysed in this study are randomly selected across Beijing. Thirdly, in this study, the built environment will be measured at both the micro level of communities and the macro level of the city. At the macro level, the city size and density will be discussed because these factors make cycling in China's large cities different from Western cities. At the community level, some unique features of the built environment of Beijing will be addressed—for example, the work unit system, block size and street connections. Fourthly, most of the previous studies of bicycle use are concentrated on trip distance, while the effects of travel time on cycling have been overlooked. This study will address the effects of travel time on the mode choice of cycling.

Following this introduction, the analysis will be undertaken in five additional

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sections. Section 2 will present a literature review of studies of the links between the built environment and bicycle commuting. Section 3 will present the research methodology and the commuting data analysed, while section 4 will present the results of the regression analysis. Section 5 will present an elasticity analysis. Finally, section 6 will draw conclusions.

2. Literature Review

There is a vast body of literature on the links between the built environment and bicycle commuting (see reviews in Ewing and Cervero, 2001, 2010; Handy *et al*., 2002; Heinen *et al*., 2010; Krizek *et al*., 2009). This paper will not undertake a comprehensive literature review since many have already been done. Instead, the paper will focus on recent research (published after 2000) on the relationship between bicycle commuting and the built environment, concentrating on three main features of the built environment: urban form, the transport system and design features.

Urban form has been found to have effects on travel mode, including cycling to work (Dieleman *et al*., 2002; Litman, 2005; Loo and Chow, 2008). In large cities the share of bicycle commuting trips is smaller than in small cities because in the former the trip distance is usually longer, thus requiring more physical effort (Badland and Schofield, 2006; Rietveld and Daniel, 2004). Urban sprawl increases motorised travel and deters the use of the bicycle for commuting trips (for example, Camagni *et al*., 2002; Cervero and Landis, 1995). Higher population density is found to relate to higher cycling rates and lower car use (Saelens *et al*., 2003; Schwanen *et al*., 2004). However, the direct relationship between density and travel mode is ambiguous. The effects of density on the use of the bicycle might often be indirect. For example, density may affect cycling because a higher density is related to higher destination accessibility (shorter distance) (Parkin *et al*., 2008) and higher levels of obstacles to car use (more traffic congestion and higher parking fees) (Litman, 2007).

Destination accessibility refers to the ease of travel to destinations. It is often measured in terms of the travel time or travel distance to destinations. Many studies have found that an increase in travel distance results in a decrease in cycling (Martens, 2004; Parkin *et al*., 2008; Pucher and Buehler, 2006). One of the main reasons for this is that longer travel distances require more physical effort (van Wee *et al*., 2006). However, few studies have considered the effects of commuting time on bicycle commuting. In some cases, a worker's mode choice of cycling may be more sensitive to increases in commuting time than motorised travel modes (Wardman *et al*., 2007). Theoretically, longer commuting time would relate to a smaller share of bicycling, as most non-cyclists report that the slower speed and longer time needed for cycling are often the main reasons why they do not travel by bicycle (Dickinson *et al*., 2003).

Urban design includes many elements—for example, density of roadways, block size, types of street networks, street connections, footpaths. The studies available suggest that people who live in communities that have been designed to be cycling-friendly—characterised by higher levels of street connectivity, mixed land use and small blocks—are more likely to commute by bicycle (Cervero and Duncan, 2003; Dill and Voros, 2007; Southworth, 2005). However, some studies have reported that there are no significant relationships between bicycle commuting and the density of roadways or block size when socioeconomic and demographic factors are taken into account (Moudon *et al*., 2005).

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Transport infrastructure is a major area on which politicians usually focus in an attempt to encourage cycling. The presence of bicycle infrastructure—for example, off-road paths, on-road lanes and bicycle parking—is often found to relate to a higher share of cycling to work (see a review by Pucher *et al*., 2010). There are differences between the effects of on-road bicycle lanes and off-road bicycle paths on bicycle commuting. It has been reported that potential users prefer off-road bicycle paths to on-road bicycle lanes as they consider the former to be safer (Abraham *et al*., 2002; Hunt and Abraham, 2007). However, not all of the findings of previous studies demonstrate the positive effects of improving bicycle infrastructure on cycling. For example, Parkin *et al*. (2008) conclude that in England and Wales, even though a higher proportion of off-road bicycle routes are related to a higher proportion of bicycle commuting, the elasticity is small (+0.049), which means that major investment in off-road bicycle infrastructure would result in only a modest increase in bicycle use for commuting. Some studies have even reported that improving bicycle infrastructure has no significant relationship with cycling when other factors are taken into account (for example, Moudon *et al*., 2005).

A larger number of main-road crossings tend to reduce bicycle use (Rietveld and Daniel, 2004; Stinson and Bhat, 2003), primarily because this is related to lower traffic safety for cyclists (Shankwiler, 2006). For example, a recent study by Winters *et al*. (2010) using bicycle survey data found that if the road network had a higher percentage of highway or arterial roads there was a lower likelihood of cycling. The distance to public transit stations also has an effect on bicycle use, but these effects are mainly on the bike-and-ride mode which combines cycling with public transport for the journey to work (Martens, 2007). When it comes to other kinds of commuters, the impact of the distance to public transit stations on cycling is still not clear (Lund *et al*., 2004).

There are few studies examining the effects of the built environment on bicycle commuting in China's cities. However, some general conclusions can be drawn from previous studies about the links between urban form and travel mode choice. For example, Kenworthy and Hu (2002) analysed the links between transport and urban form in China at the national level and concluded that the rapid change in urban form is a major factor causing the reduction in bicycle commuting. A survey done by Zacharias (2002) in Shanghai reported that the improvements to public transit for the purposes of freeing more road space for motorised modes and pedestrians in the city centre have decreased both bicycle and car volumes, while the decrease was greater for bicycles in the central areas. In his later study, using travel survey data from four communities in Shanghai, Zacharias (2005) found that higher road density and larger block size were related to a lower share of bicycle use for all trips, including trips to work. Using a longitudinal study method, Cervero and Day (2008) found that residential relocation from the city centre to suburban neighbourhoods is strongly linked with changes in travel mode in Shanghai. Relocating to a suburban area resulted in a dramatic shift away from cycling and walking to transit commuting, mainly due to a decrease in destination accessibility indicated by longer commuting time. At the neighbourhood level, Pan *et al*. (2009) found that the appearance of non-cyclist-friendly urban form, which is characterised by large block size and low destination accessibility, would be one of the reasons for greater car use. Looking at Beijing, recent studies by Zhao and his colleagues (Zhao, 2010; Zhao *et al*., 2010) found that

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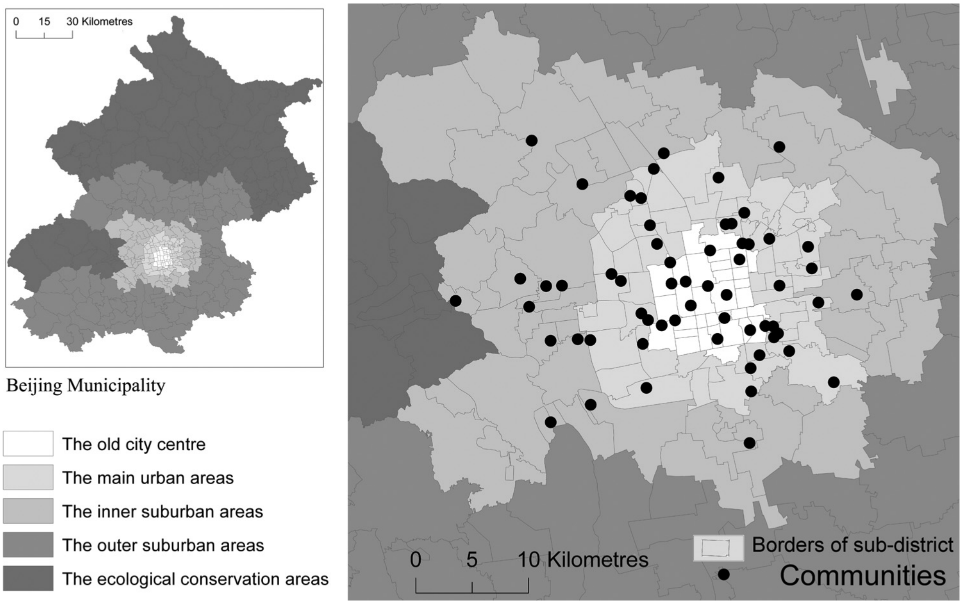

Figure 1. The sample communities.

sprawling land use is significantly related to a higher share of motorised travel and a low share of non-motorised travel on the urban fringe of Beijing. A recent survey about bike-sharing programme in Hangzhou (Shaheen *et al.*, 2011) reported that more docking stations and parking sites for bikesharing may promote use of share bike for commuting.

3. Method

3.1 Travel Data

The commuting data used in this study are derived from a household interview survey conducted in Beijing in 2006 by an international housing research group from Hong Kong and the US. Among other questions, employed respondents were asked to state their major travel mode for trips to work. During the data-collection process, a multilevel probability proportional-to-size sampling strategy (PPS) was used to provide a sample of all urban districts in the central and intersuburban areas of Beijing. A number of communities were selected from each district according to the distribution of urban residents in Beijing, calculated on the basis of the *Beijing Statistical Yearbook 2005* (BSB, various years). Sixty communities were selected (Figure 1) and 25 local households were randomly selected in each of the 60 communities. Face-to-face interviews were conducted, with the survey successfully interviewing 1500 residents. Of those residents, there were 742 employed people from 615 households. The detailed data from each household were checked and if too much was missing they were also excluded. As a result, 613 household heads of 613 households were used in the analysis for this study (Table 1). It should be noted that no multimodal options were reported by the respondents as they were asked to only report their major travel mode for daily commuting.

The data sample analysed in this study is representative (see Table 1). Table 1

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Table 1. Data summary of the sample analysed in the study and its comparision with the city-level data

Classification	*The sample*		*The city level*[a]
	Cases	*Percentage*	*Percentage*
Work trip transport mode			
Walking	84	13.7	–
Bicycling	234	38.2	35.6
Public transit (road bus, metro, bus provided by employers)	201	32.8	34.1
Car	84	13.7	15.5
Others	10	1.6	9.8[b]
Worker demographic characteristics			
Gender			
Male	391	63.8	49
Female	222	36.2	51
Age			
< 30	50	8.2	11.9
30–60	557	90.8	75.6
> 60	6	1.0	12.5
Features of worker's household			
Household family type			
Single member family	47	7.7	10.7[c]
Core family without children	91	14.8	17.1[c]
Core family with children	405	66.1	53.9[c]
Others	70	11.4	18.3[c]
Household annual income			
< 20,000 (RMB)	79	12.9	19.6
20,000–39,999 (RMB)	275	44.8	36.1
40,000–59,999 (RMB)	142	23.2	25.3
> 60,000 (RMB)	117	19.1	19
Household car ownership			
Private car owned	106	17.3	14.7
No car	507	82.7	85.3
Total	613	100	100

[a]The city-level commuting data came from the Beijing Travel Survey 2005 (BTC, 2005).
[b]The percentage of walking was included into 'other' modes.
[c]There was no information on household family type in the travel survey data. The information on household family type comes from the Beijing Census (2000).

compares the sample data with the city-level data gathered by the Beijing Travel Survey 2005 and Beijing census data from 2000. The share of cycling for commuting is 38.2 per cent in the sample data, which is close to the 35.6 per cent reported by the city-level travel survey data. The share of public transport is 32.8 per cent in the sample data, which is also close to the 34.1 per cent observed in the travel survey data. It should be acknowledged that there are some differences in travellers' socioeconomic features between the data sample and the travel survey data. For example, 90.8 per cent of the total respondents in the sample data were between 30 and 60 years

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old, while they accounted for only 75.6 per cent of the respondents in the travel survey data at the city level. One of the major reasons for this is that the sample data presented information provided by household heads, who were usually of working age (younger than 60 years old) in Beijing.

3.2 Measurement of the Built Environment

In this study, the features of the built environment are measured by several types of indicators: urban design indicators, urban form indicators and transport infrastructure indicators (see Table 2). These indicators are measured at two levels: the community level and the sub-district level. A sub-district is known as a Street Area (*jiedao*) or Township (*xiangzhen*) and is a basic administrative unit in Beijing. Most land use and transport planning policies are implemented at the level of sub-districts. The boundaries of the sub-districts are presented in Figure 1. Each sub-district includes dozens of communities.

This study measures population density, employment density and the jobs–housing balance at the sub-district level. The jobs–housing balance is indicated by an index which reflects the ratio between the number of jobs and residents. It is calculated as

$$JH_k = \left| \ln\left(\frac{J_k}{H_k}\right) \right|$$

where, JH_k is the jobs–housing balance index of sub-district k; J_k is the number of jobs; and H_k is the number of households. The lower the value of the jobs–housing balance index, the higher the degree of jobs–housing balance.

The local impact range of the built environment on bicycling is defined at the community level. Some empirical research which has explored the relationship between distance and the transport mode has found that the bicycle is most often used for distances between 0.5 and 3.5 km (Keijer and Rietveld, 2000; Martens, 2004). In Beijing, trips of less than 3.5 km accounted for 82 per cent of bicycle commuting trips. Therefore, this study defines a circle with a 3.5 km radius from the centroid of a community as the local impact range of the built environment on the use of a bicycle.

The diversity of land use at the community level is indicated by a diversity index which is measured by a normalised entropy method. This method has been widely used to measure diversity in previous studies which explored the effects of land use mix on travel (for example, Cervero, 2002; Frank *et al.*, 2004). The value of a diversity index can be calculated as

$$H_k = \frac{-\sum_{l=1}^{s} (p_l)\ln(p_l)}{\ln(s)}$$

where, H_k is the diversity index for community k; p_l is the proportion of land use type l within the local impact range of the built environment of community k; and s is the number of land use types.

This study examines four land use types: residential, industrial, commercial and public services use of land. The value of the land use diversity index varies from 0 (homogeneous land use) to 1 (most mixed land use). The higher the value of the diversity index, the higher the diversity of land use.

Destination accessibility is measured by a worker's actual one-way commuting time from home to work. The pattern of local streets is measured by the density of local streets and connections between local streets. The number of crossings is used to indicate the degree of connection of local streets. The more crossings, the higher the

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Table 2. Indicators and measures analysed in the study

Indicators	*Measure*
Built environment	
Urban form	
Net density of population	Residents per hectare in built-up area (at the sub-district level) (100 persons/ha)
Net density of employment	Jobs per hectare in built-up area (at the sub-district level) (100 jobs/ha)
Jobs–housing balance	A jobs–housing balance index measured at the sub-district level
Location of community	Distance to the old city centre (Tiananmen square) from the centroid of community (km)
Destination accessibility	One-way commuting time (minutes)
Urban design	
Diversity of land use	A diversity index measured by entropy method
Density of local streets	Length of local streets per square km in built-up area within the local impact range (km/square km)
Connection of local streets	Number of crossings of streets within the local impact range (unit)
Infrastructure characteristics	
Density of main road and expressways	Length of main road and expressways per km in built-up area within the local impact range (km/square km)
Crossings of main road and expressways	Number of crossings of main road and expressways within the local impact range (unit)
Exclusive bicycle lanes	Length of bicycle lanes separated from motorised traffic per km in built-up area within the local impact range (km)
Proximity to transit	Distance to closest metro station from the centroid of community (km)
Worker demographic characteristics	
Male	= 1 if worker is male
Age	Worker's age
Features of worker's household	
Family with children	= 1 if family with children
Low-income household	= 1 if a household has annual income equal to or less than 39,999 (RBM)
Middle-income household	= 1 if a household has annual income between 40,000 and 59,999 (RBM)
High-income household	A household has annual income above 60,000 (RBM) (Reference variable for household income)
Car ownership	= 1 if household has car

connection between local streets. This study also uses two indicators to reflect traffic safety in relation to the built environment: the density and the number of main-road and expressway crossings.

Table 3 shows that there are obvious variations in the built environment between different areas in Beijing. In particular, the jobs–housing balance, the length of exclusive bicycle lanes, the crossings of local streets,

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Table 3. Descriptive statistics for the variables analysed

Variable	*Mean*	*S.D.*
Age	42.6	13.4
Household annual income of low-income workers (10,000 RMB)	2.7	3.1
Household annual income of middle-income workers (10,000 RMB)	4.4	7.9
Household annual income of high-income workers (10,000 RMB)	7.3	10.5
Net density of population (100 persons/ha.)	1.39	0.91
Net density of employment (100 jobs/ha.)	0.84	3.47
Jobs–housing balance	0.7	1.6
Distance to the old city centre (km)	16.3	23.1
Destination accessibility (minutes)	19.5	26.3
Diversity of land use	0.6	0.5
Density of local streets (km/square km)	8.7	13.2
Crossings of local streets (units)	14.6	20.3
Density of main road and expressways (km/ square km)	4.2	5.9
Crossings of main road and expressways (units)	4.5	10.8
Exclusive bicycle lanes (km)	6.1	12.5
Proximity to transit (km)	3.9	11.4

proximity to transit and the net density of employment vary greatly according to the value of the standard deviation. It should also be noted that there are slight differences in the net density of the population between the areas.

4. Regression Analysis

The multinomial logit (MNL) model was applied to estimate individual workers' travel mode choice of bicycle for their journey to work. Motorised travel mode, including car, public transport and taxi, was the reference category. A multinomial logit model needs to meet the independence from irrelevant alternatives (IIA) requirement, which means all of the variables included in the model must be independent of each other (McFadden *et al.*, 1978). In this study, prior to estimating the models, a Pearson correlation analysis was used to check the autocorrelation between the independent variables before a MNL regression was applied. A correlation coefficient less than –0.8 or more than 0.8 is usually seen as strong correlation (Freedman *et al.*, 1991).

The results of the correlation analysis show that the commuting distance has a 0.919 correlation coefficient when compared with commuting time. Since previous studies have focused on travel distance, overlooking the effects of commuting time on the mode choice of bicycling, this study uses commuting time to indicate destination accessibility. The variable of distance to the old city centre has a –0.650 correlation coefficient when compared with the employment density variable and a –0.314 correlation coefficient when compared with the variable of net density of population. The variable of jobs–housing balance has a 0.672 correlation coefficient when compared with the land use diversity variable. Household income shows no strong correlation with commuting time. However, household income has a 0.810 correlation coefficient when compared with car ownership. This means either the household income variable or the car ownership variable should not be entered into the

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regression to avoid autocorrelation issues. However, both household income and car ownership have been found to affect workers' mode choice for commuting by many previous studies (for example, Moudon *et al.*, 2005; Winters *et al.*, 2010). The absence of one of these two variables would create the disadvantage of not being able to compare the findings of this study with previous studies. In addition, the growth rate of car ownership has declined dramatically in Beijing since 2010 when a quota policy for car licences was implemented to limit car ownership. That means the changes in the amount of car ownership will be smaller in future than household income. Therefore, both the household income variable and the car ownership variable were entered into the regression in this study. However, the household income variable is indicated by three dummy variables: low income, middle income and high income.

Table 4 presents the results of two models of the regression analysis. Model 1 only includes the dependent variables for the built environment. Model 2 includes dependent variables for both the built environment and workers' socioeconomic characteristics. The results of model 2 suggest that the built environment is still associated with individual workers' mode choice when socioeconomic factors are controlled. The results of model 2 will be discussed in detail as the model takes more potential factors into account and has higher fit than model 1.

The results of model 2 show that the exp(B) value is 0.3023 for the jobs–housing balance index, which means that the odds of choosing to commute by bicycle is 0.3 times higher than the odds of choosing to commute by motorised mode. In other words, for a one-unit decrease in the jobs–housing balance index (namely, a one-unit *increase* in the degree of jobs–housing balance) there will be an increase of 1.5 times ($e^{0.3023}$) of the odds of choosing to commute by bicycle, holding other variables at a fixed value. The results suggest that policies designed to create more job opportunities in a residential area or more housing opportunities in an employment area would increase the share of bicycle commuting.

As to the jobs–housing balance, Beijing has a unique feature: urban form in the central urban areas (the old city centre and the main urban areas) is composed of thousands of self-contained work units, known as *danwei*. *Danweis* are socialist-developed work units which, since the 1950s, organised all aspects of urban life (Bray, 2005; Lü and Perry, 1997). In most cases, *danweis* integrate urban productive activities and social life into the same location, combining housing, jobs, hospitals, schools and other urban services. With respect to urban function, *danweis* can be seen as "self-sufficient subcities" (Xie and Costa, 1993, p. 106). The jobs–housing balance in *danweis* started to decline in the 1980s when market-oriented housing reforms were implemented. In the meantime, urban sprawl led to a decrease in the jobs–housing balance in the suburbs of Beijing after the 1990s (Deng and Huang, 2004; Zhao, 2011). Nevertheless, due to the remaining *danwei* system, a high level of jobs–housing balance will persist in the central urban areas for some time.

Destination accessibility, which is measured by individual workers' one-way commuting time, has very significant effects on the use of a bicycle for commuting (see Table 4). A longer commuting time is related to less likelihood of cycling. The exp(B) value suggests that, when commuting time increases from 19.5 minutes (mean value of the sample) to 29.5 minutes, the odds of bicycling will only be 0.16 ($e^{-10\times0.1806}$) per cent of the average odds, all things being equal. This is consistent with findings reported by previous studies

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Table 4. Multinomial logit (MNL) model analysis for workers' travel mode ($n = 613$) (the reference category is 'commute by motorised mode')

	Model 1						*Model 2*					
	Bicycling			*Walking*			*Bicycling*			*Walking*		
Independent variables	*B*	*Wald*	*Exp(B)*	*B*	*Wald*	*Exp(B)*	*B*	*Wald*	*Exp(B)*	*B*	*Wald*	*Exp(B)*
Intercept	0.1171	1.1537*		0.1266	0.2914		0.0824	1.0367		0.0329	0.5501	
Built environment												
Urban form												
Net density of population	0.0127	0.0089	1.0128	0.0044	0.0693	1.0044	0.0475	0.0112	1.0486	0.0031	0.0405	1.0031
Jobs-housing balance	–1.3561	2.1492**	0.2577	–1.1237	1.3150**	0.3251	–1.1964	1.8305**	0.3023	–0.9462	1.1997**	0.3882
Net density of employment	0.4289	1.9214**	1.5356	0.5143	1.9587**	1.6725	0.6531	1.7997*	1.9215	0.9635	1.5312*	2.6209
Distance to the old city centre	–1.9126	1.1265*	0.1477	–1.3912	1.1645*	0.2488	–1.8748	2.1053**	0.1534	–1.1571	2.6279***	0.3144
Destination accessibility	–1.8014	2.1613**	0.1651	–1.0090	2.2124**	0.3646	–1.7112	2.7254***	0.1806	–0.8255	3.5081***	0.4380
Urban Design												
Diversity of land use	0.1223	1.6225**	1.1301	0.1571	1.6462**	1.1701	0.1064	0.8756**	1.1123	0.1429	1.7001**	0.1536
Density of local streets	0.0617	1.3748*	1.0636	0.0394	0.7535	1.4020	0.0463	1.1492*	1.0474	0.0947	1.5174*	1.0993
Connections of local streets	0.0979	1.2831*	1.1029	–0.0123	0.0278	0.9878	0.1157	1.3165*	1.1227	–0.0046	0.0101	0.9954
Infrastructure characteristics												
Exclusive bicycle lanes	0.4174	1.5061**	1.5180	0.0014	0.0045	1.0014	0.1376	1.4293**	1.1475	0.0026	0.0095	1.0026
Proximity to transit	0.6438	1.3472**	1.9037	0.4315	1.2934*	1.5396	0.4365	1.6585**	1.5472	0.2463	1.4777*	1.2792
Crossings of main road and expressways	–1.2017	1.9053*	0.3007	–0.9083	1.6245*	0.4032	–1.1486	2.3971**	0.3171	–0.7158	1.8100**	0.4888
Density of main road and expressways	–0.0115	0.0059	0.9886	–0.0757	0.7942	0.9271	–0.0083	0.0076	0.9917	–0.0634	0.5509	0.9386
Worker demographic characteristics												
Male							0.4935	1.8205*	1.6380	0.3181	1.7213*	1.3745
Age							0.1782	1.4991**	1.1951	0.2294	1.7576*	1.2578

(continued)

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Table 4. (Continued)

	Model 1						Model 2					
	Bicycling			Walking			Bicycling			Walking		
Independent variables	*B*	*Wald*	*Exp(B)*	*B*	*Wald*	*Exp(B)*	*B*	*Wald*	*Exp(B)*	*B*	*Wald*	*Exp(B)*
Features of worker's household												
Family with children							–0.6131	1.3616*	0.5417	0.1075	0.6003	1.1135
Low income							0.4673	1.6237**	1.5957	0.6834	1.8506**	1.9806
Middle income							–0.1283	0.4920	0.8796	0.2029	0.7485	1.2249
Car ownership							–2.3927	2.5331***	0.0914	–2.5365	2.4346**	0.0791
Model fit information												
–2LL (-2 times log likelihood)	172.1						319.2					
Chi-squared	408.3						561.7					
Significance	p < 0.01						p < 0.01					
PCP (percentage correctly predicted)	53.2						74.5					

Notes: *indicates significance at 0.1 level; ** indicates significance at 0.05 level; ***indicates significance at 0.01 level.

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(van Wee *et al.*, 2006). One of the major reasons for this is for travel time disutility to be minimised mainly through faster travel modes (cars or metro) according to travel behaviour theory. Another reason is that longer travel requires more physical effort. In fact, a slower speed and longer ride times for bicycling are the two main factors associated with a reduction in the use of a bicycle (Dickinson *et al.*, 2003). The findings also imply that increasing commuting times due to the growth of the city would further reduce bicycle use in Beijing.

The results of model 2 in Table 4 also show that when workers live within a subdistrict with a higher employment density there is a higher likelihood that they will choose to commute by bicycle rather than by motorised mode. There is no significant relationship between population density and cycling to work (see Table 4). This is inconsistent with many previous studies (Parkin *et al.*, 2008; Saelens *et al.*, 2003). One of the major reasons for this is that Beijing is traditionally a dense city. There are slight differences in population density across different zones in the central urban areas. As a result, bicycle commuting has no significant relationship with population density. Similar findings have been reported in Bogotá, Colombia, by Cervero *et al.* (2009). Bogotá is also a densely populated city and this density is uniform across communities.

Urban design at the community level has a significant relationship with individual workers' mode choice of cycling (see Table 4). The value of exp(B) indicates that the odds of travel by bicycle will increase three times when the number of local street crossings increases by one unit, holding other variables at a fixed value. Similarly, when the overall length of local streets increases, there will be increases in the odds of travel by bicycle. In particular, in the city centre of Beijing, the street pattern is dominated by thousands of *hutongs*, which are small and narrow alleys. The *hutongs* create obstacles to driving but make cycling easy. Diversity of land use has significant effects on the use of a bicycle for the journey to work. An increase in the land use diversity index is related to increases in the odds of choosing to commute by bicycle. This is consistent with many previous studies (Cervero and Duncan, 2003; Pucher and Buehler, 2006).

The results of model 2 in Table 4 shows that when a worker lives in a community with a larger number of main-road crossings, there is less likelihood that she or he will choose to commute by bicycle than by motorised mode. One of the major reasons for this is that there is a higher risk of traffic accidents between bicycles and motorised vehicles (in particular, cars) at these intersections. In fact, nearly 47 per cent of all 983 bicycle-related traffic accidents in Beijing in 2008 occurred between cars and bicycles at main-road or expressway intersections (BSB, various years). A recent survey undertaken by Beijing Transport Research Centre reported that 39 per cent of respondents thought traffic safety issues related to cars was the most important factor preventing them from bicycling (Yang, 2010).

Another reason why main-road crossings may affect cycling is that a larger number of crossings may increase the level of exposure to traffic pollution. There are no studies showing the effects of traffic pollution on bicycle use in Beijing. However, a recent survey conducted in Guangzhou shows that 32 per cent of respondents thought that high exposure to traffic pollution was a major reason why they chose to commute by car or public transport rather than by bicycle (Baike, 2011). Since Beijing has similar problems with traffic pollution, it can be argued that pollution may also be a barrier to cycling in Beijing.

The number of exclusive bicycle lanes is significantly related to the use of the bicycle (the coefficient is + 0.1376). The odds of a

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worker choosing to cycle will increase when the length of exclusive bicycle lanes in the community where the worker lives increases. This is consistent with some previous studies (Barnes and Thompson, 2006; Krizek *et al*., 2007; Merom *et al*., 2003). The results support the argument for bicycle infrastructure (Dill and Carr, 2003). However, it should be recognised that even if bicycle infrastructure increases the levels of bicycle commuting, it is by no means certain that this is an efficient or effective policy measure to achieve such an increase. Several questions need to be addressed. First, how frequently do commuters use the bicycle facilities? It would be difficult to conclude that the supply of bicycle facilities is effective and efficient if commuters only use the facilities once a week or once a month (Moudon *et al*., 2005). Secondly, with respect to the goal of increasing bicycle commuting, how effective is a supply of exclusive cycling lanes compared with other policies? Thirdly, what are the co-benefits or costs of traffic safety and transport fairness between cyclists and car users, even if bicycling does increase after exclusive bicycle lanes are built? These questions will be discussed in the next section.

Unexpectedly, the results of the analysis suggest that closer proximity to public transport facilities tends to decrease rather than increase the use of the bicycle as a major mode for commuting (see Table 4). The results show that the odds of travel by bicycle will decrease by 54 per cent for every kilometre closer to a metro station that a worker lives. Clearly, proximity to public transport has a substitutive effect with respect to the bicycle. This is even more likely to occur when public transit charges are low and/or subsidised by the government (Bamberg and Schmidt, 2003). In Beijing, a metro ticket was RMB 3—namely, USD37 cents in 2006. The improvement of the public transit network and low charges for services is one of the 'pull' factors in the reduction of bicycle use in Beijing. Similar findings have been reported in Shanghai: the improvements to public transport system in the city centre have decreased bicycling dramatically (Zacharias, 2002). It needs to be acknowledged that a high density of public transit network may encourage bike-and-ride mode in which the bicycle is used as a transfer mode to access the public transport rather than a major mode for commuting in Beijing. The bike-and-ride mode will not be discussed in this study.

5. Elasticity Analysis

Usually it is not easy to judge the relative importance of particular explanatory variables from MNL model results. This study conducts elasticity estimation for the explanatory variables of the built environment to address this issue. A 'representative individual' approach is used to estimate point elasticities (Richards and Ben-Akiva, 1975). These can be measured by increasing one built-environment variable at a time by 1 per cent, and applying an MNL regression model to measure the corresponding percentage change in mode-choice probabilities, setting values for all other variables in the utility function at their statistical means (Cervero, 2002). This is calculated as follows

$$E_{X_{ikn}}^{P_{in}} = \frac{\partial P_{in}}{\partial X_{ikn}} \cdot \frac{X_{ikn}}{P_{in}}$$

where, $E_{X_{ikn}}^{P_{in}}$ is mode-choice point elasticities of the probability (P_{in}) of person n choosing mode i with respect to a change in the value of kth variable X_{ikn}, with all other variables set at their mean value.

As for dummy variables, the mean values here are replaced by their modal values. Since the approach is a 'representative individual' approach, modal values of individuals' socioeconomic features should be representative of the most common

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Table 5. Point elasticity estimates calculated from mode-choice model

	Bicycling	*Walking*	*Motorised mode*
Net density of population	0.0034	0.0013	–0.0014
Jobs–housing balance	–0.4911	–0.4075	0.2162
Net density of employment	0.1265	0.0418	–0.1725
Distance to the old city centre	–0.2494	–0.1941	0.4538
Destination accessibility	–0.3629	–0.3750	0.2906
Diversity of land use	0.3012	0.1017	–0.1783
Density of local streets	0.0926	0.0535	–0.0132
Crossings of local streets	0.1387	0.0187	–0.0394
Exclusive bicycle lanes	0.1909	0.1250	–0.0137
Proximity to transit	–0.1137	–0.1261	0.5115
Crossings of main road and expressways	–0.2155	–0.1161	0.2679
Density of main road and expressways	–0.0218	–0.0128	0.3214

socioeconomic features of a population. Table 1 shows that 63.8 per cent of respondents were male, 66.1 per cent of families had children and 82.7 per cent of families had no car. Therefore, in this study, the modal values for the analysis of travel-mode choice in estimating elasticities are male = 1, core family with children = 1 and car ownership = 0.

Table 5 presents the point elasticity estimates. Consistent with the logit model results, cycling is found to be most sensitive to changes in the jobs–housing balance. A 1 per cent decrease in the jobs–housing balance index (namely, an increase in the degree of jobs–housing balance) is related to a 0.49 per cent growth in the probability of choosing to cycle. Diversity of land use has an elasticity of 0.3012, which is the third-most-powerful factor influencing bicycle commuting of all the built environment variables.

Destination accessibility is the second-most-important variable, as a 1 per cent decrease in destination accessibility (namely, a 1 per cent increase in commuting time) reveals a 0.36 per cent reduction in the probability of choosing the bicycle. Previous studies have focused on travel distance (Martens, 2004; Parkin *et al*., 2008; Pucher and Buehler, 2006), while the effects of commuting time on the mode choice of cycling are usually overlooked. However, travel time can be more than a mere representative of travel distance if a time-budget mechanism and the value of time are also considered (Cirillo and Axhausen, 2002; Fosgerau *et al*., 2010). For example, a recent study by Wardman *et al*. (2007) using travel survey data from the UK, showed that the time spent cycling is valued almost three times more highly than travel time using other modes. Table 5 shows that cycling is more sensitive to changes in commuting time than a motorised travel mode, as destination accessibility only has an elasticity of 0.2906 for motorised mode.

Table 5 also shows that the variable of exclusive bicycle lanes has an elasticity of 0.1909, which is lower than the elasticity for destination accessibility and traffic safety factors. Both residential density and employment density have lower elasticities compared with other variables of the built environment. This is consistent with the MNL regression. However, distance to the old city centre has a relatively high elasticity of –0.2494. The results suggest that the

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expansion of the city and residential suburbanisation would be important factors in the reduction of bicycle commuting. This finding is consistent with results from previous studies conducted in other large Chinese cities, for example Shanghai (Cervero and Day, 2008; Pan *et al*., 2009).

It is interesting that the number of street crossings has more significant effects on cycling than street density. One major reason might be that the number of local crossings is more directly related to street connections, which have significant effects on distance and the time costs of cycling for utilitarian trips (Dill and Voros, 2007). In particular, in Beijing, as already mentioned, urban form has been largely dominated by *danweis*, separated from each other and the rest of the city by walls and guarded gates. As a result, the degree of route connections between urban areas in the city is low.

6. Conclusion

Policies designed to create a bicycling-friendly environment have been seen as one of the major ways to increase the use of the bicycle and reduce vehicle traffic pollution in many countries. However, previous empirical analyses of the links between the built environment and the use of the bicycle for trips to work are dominated by cases from North America and Europe. This paper extends the existing literature on the effects of the built environment on bicycle commuting, examining the case of Beijing. Consistent with previous studies, the paper found that a lower jobs–housing balance and less diversity of land use tend to decrease the use of the bicycle. Lower destination accessibility, which is indicated by longer commuting time, is associated with less likelihood of cycling. More main-road or expressway crossings are significantly related to less cycling.

However, the study found that residential density, which has been believed to be one of the most important factors affecting bicycling in Europe and North America, has no significant effects in Beijing. Residential density policies may not be an effective way of increasing cycling in already densely populated areas. A higher level of public transit services tends to decrease the use of the bicycle as a major mode for commuting due to its substitutive effects in Beijing, although it may encourage bicycling for a bike-and-ride purpose in some cases. This 'pull' effect will be strengthened in the near future due to two factors. First, according to the city's master plan, over 100 km of new metro lines will be built in Beijing before 2020. Secondly, public transit is heavily subsidised, meaning low fares, due to the socialist tradition in Beijing.

The elasticities analysis suggests that, even though a higher level of exclusive bicycle lanes is related to a higher probability of bicycle commuting, its elasticity (+0.1909) is smaller than the variable of mixed environment (the jobs–housing balance index was –0.4911 and the diversity of land use +0.3012). This implies that the most effective way of encouraging cycling for commuting would be to combine improvements in bicycle facilities with urban design. Particularly, the policies designed to shape a mixed environment may be especially important to China's large cities, as the traditional form of mixed use of land has been declining at a rapid speed. The current market-oriented reform in housing tends to break down jobs–housing balance in the *danwei* system. In the process of rapid suburban sprawl, large tracts of land are devoted to a single use and segregated from one another. In addition, the ever-increasing growth of the city is another challenge to the promotion of bicycle commuting in China's large cities. Since it is impossible to stop future urban expansion in

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the context of rapid urbanisation, urban policies which encourage the development self-sufficient areas in the suburbs, similar to the *danwei* system, would be helpful.

Traffic safety and air pollution due to increasing vehicle flows are two of the most important ‘push’ factors reducing the use of the bicycle for commuting. Bicycle facility policies must also be integrated with traffic management policies for vehicles; for example, setting speed limits, traffic calming and the encouragement of low pollution vehicles. Bicycle facility policies are also greatly related to social fairness and environmental justice. The existing policies favouring economic growth and huge investment highways need to be rethought. Long-term policies designed to build bicycle-friendly cities are urgently required in China’s cities, before they become permanently dominated by motorised forms of travel.

Funding

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

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