The impact of land-use mix on residents' travel energy consumption: New evidence from Beijing

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ABSTRACT

Policies that encourage mixed land use are widely believed to make transport more energy efficient. However, few studies have directly examined the impacts of land-use heterogeneity on travel energy consumption at the individual level. Moreover, the definition and measures of land-use heterogeneity are debated. This paper aims to fill these gaps using the large city of Beijing, China, as a case study. Three types of land use are examined in terms of their effects on individual residents' travel energy consumption. The results suggest that high land-use diversity and a good jobs-housing balance significantly reduces commuting travel. Interestingly, highly heterogeneous retail and housing areas may have high travel energy use, as residents are more likely to go shopping. There are obvious spatial variations in these effects. Residents of suburban 'newtowns', where the jobs-housing balance is particularly good, consume less travel energy. The results suggest that decreased use of conventional planning patterns, such as the socialist danwei system, and increasing urban sprawl, bring new challenges to achieving transport efficiency. Mixed land-use policies can be an effective solution to these challenges.

1. Introduction

As of 2015, energy used in the transport sector comprised 30% of total global energy consumption (IEA, 2015). Transport energy use is expected to increase by 30% by 2030, particularly in the developing world where continued urbanisation is accompanied by increasing use of automobiles (IEA, 2008). To achieve energy savings, energy reduction targets have been set by many countries, with the transport sector having a key role to play (Loo and Li, 2012). Especially in cities, passengers’ travel energy use has increased consistently along with use of automobiles. In China, car ownership increased 15-fold during the last decade. Meanwhile, the proportion of residential trips taken by automobile has doubled (China National Statistical Bureau, 2015). Hence, changes in people's travel behaviour—from energy-intensive to energy-efficient—can play an important role in saving energy.

The effects of land use and the built environment on travel behaviour and, accordingly, travel energy use, has been a topic of longstanding interest (Newman and Kenworthy, 1989; Cervero, 1988, 1989, 1996; Krizek, 2003; Cao et al., 2009; Ewing and Cervero, 2010; Handy and Xing, 2011; Boarnet et al., 2011a, 2011b; Wang and Lin, 2013; Munishi, 2016). Policymakers and researchers have started to consider land-use planning as a tool for reducing travel energy use. Mixed land use, as a key planning parameter, is considered to be energy efficient. However, due to a lack of data for calculating travel energy use at the individual level, most studies in this field have focused on the effect of mixed land use on changes in passenger travel mode (Cervero and Kockleman 1997; Ewing and Cervero, 2010; Boarnet et al., 2011b; Munishi, 2016) and vehicle miles travelled (VMT; Zegras, 2010; Boarnet et al., 2011a),

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rather than actual energy use. A quantitative study on the direct relationship between mixed land use and individual travel energy use is lacking. This article seeks to build knowledge in this direction.

Although mixed land use has been extensively investigated in transport studies, its definition and measures are still debatable. Numerous studies have taken land-use diversity (Cervero, 1996), or proximity between residences and potential destinations (Cervero and Duncan, 2006), as the true reflection of mixed land use, and use metrics like the entropy index, or the ratio of jobs or shops to households in an area, to measure it (Cervero and Duncan, 2006). However, these measures fail to reveal the matching of employment opportunities and housing affordability at the individual level. Many methods have emerged to assess this issue, such as gauging the “matched accessibility” of jobs and housing affordability to individuals (Cervero and Duncan, 2006; Sultana, 2002; Cao et al., 2009). However, these measures only reflect potential job-housing proximity instead of the actual jobs-housing balance. Moreover, another two questions still confound researchers. Firstly, what types of mixed land use effectively influence travel behaviours—a job-housing mix or a retail-housing mix? Secondly, do different types of mixed land use have different effects? Accordingly, a new method is needed to measure the land-use heterogeneity of an area and reflect the realised proximity of jobs, retailers and other travel destinations to housing at the individual level. Only in this way can the impacts of mixed land use on travel behaviour be completely captured.

This article directly examines the quantitative relationship between mixed land use at the neighbourhood level and residents’ travel energy consumption, using Beijing, China, as a case study. We consider mixed land use to have the potential for bringing origins and destinations in close proximity to each other so that residents require less energy for travel. Three different types of mixed land use indexes are hence classified and measured: (1) spatial land use diversity, which indicates the general proximity between potential destinations and origins in an area; (2) job-housing balance; and (3) retail-housing balance, since workplaces and shops are the major destinations of urban trips. Furthermore, the effects of institutional contexts on individual travel energy use will also be discussed, as government interventions are claimed to be important in influencing land use arrangements that might cause social-spatial variations in travel energy consumption.

2. Previous research

2.1. A review of mixed land-use: concept and measurement

The notion of land-use diversity has been widely used to understand mixed land use at neighbourhood scales. Scholars have adapted indexes of inequality, concentration and segregation to measure the degree of land-use diversity within a limited range. The entropy index is the most prevalent one used for gauging land-use diversity (Cervero, 1989, 1996; Munishi, 2016). It quantifies the degree of mixing across land-use categories (i.e. residential, commercial and industrial) according to the proportion of area taken up by each. However, as the entropy index fails to indicate the inter-mixing of different land-use categories, a host of more complex indexes for gauging land-use diversity have been developed, including the dissimilarity index, the Simpson index, the inclustering index and the exposure index (Song et al., 2013).

However, existing measures of land-use diversity have been criticised as giving an incomplete picture, since they fail to indicate the proximity of travel destinations to residences, which is what largely determines urban traffic. For instance, the floor area of a business building cannot accurately reflect its capability of providing employment to nearby residents. Instead, the number of jobs in a neighbourhood is a more useful indicator of the proximity of employment to residences (Cervero, 1989). In this light, the notion of jobs-housing balance was developed and has enriched the concept of mixed land use (Cervero, 1989; Peng, 1997). It is argued that an area with similar numbers of residents and jobs is balanced, as all residents can potentially work in the local area, hence minimising traffic. To measure the jobs-housing balance, the ratio of jobs to households (the J/H ratio) in an area has been extensively applied (Cervero, 1989; 2006; Peng, 1997). Frank and Pivo (1994) found that a census area with a J/H ratio of 0.8–1.2 had the shortest commuting trips and hence was most “balanced”.

However, the J/H ratio has limitations in reflecting the jobs-housing balance. It ignores whether local jobs are actually occupied by local residents. For instance, in an area with sufficient low-paid jobs but high-priced houses, workers still need to live elsewhere and thus have long-distance commutes. Therefore, the J/H ratio only indicates the potential of an area to achieve jobs-housing balance, rather than its actual occurrence (Cervero, 1989). Also, job accessibility varies from individual to individual due to differences in education, skills, experience and occupation.

Improved indicators of jobs-housing balance that measure the accessibility of job opportunities with respect to occupational types and housing affordability have emerged to fill this gap. For instance, Cervero and Duncan (2006) developed an index called “occupationally-matched accessibility” that counts the number of jobs within four miles of each resident’s home. The counted jobs must be in the same occupational category as that held by the resident. Sultana (2002) tried to classify the affordability of housing to local workers at the regional level by using indexes such as the ratio of the median house price to the median income.

However, the above measures still only represent the potential of an area to achieve balance, rather than its actual state of balance (Cervero, 1996). In practice, though planners can plan to have equal numbers of residents and suitable jobs in an area, ultimately it is market forces that distribute jobs and houses to individuals and determine the degree of job-housing balance. Accordingly, the degree of realised jobs-housing balance should be a more accurate indicator of job-housing proximity in an area. Cervero, (1996) used the share of local jobs actually filled by local residents to measure the realised jobs-housing balance. This measure is also called the “self-containment” index. It uses the percentage of workers that reside locally, or the percentage of residents that work locally, to measure the extent to which an area is “self-contained” (Cervero, 1996).

Nevertheless, all the above measures face a key challenge. That is—to what geographic extent should an area be considered to be
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