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Commuting efficiency in the Beijing metropolitan area: An exploration combining smartcard and travel survey data

ABSTRACT

Using Beijing as an example, this manuscript demonstrates that smartcard data can be used to (a) assembly the required data for excess commuting studies and (b) visualize related results. Based on both smartcard and household travel survey data, it finds that the theoretical minimum commute is considerably lower for the bus than for the car in Beijing. This suggests that there is a greater inter-mixing of jobs-housing functions (i.e. a better jobs-housing balance) associated with users of that mode compared to the corresponding land use arrangement for car users. Car users locate further from the central area (Tian'anmen) than bus users. The commuting range for car users is 9.4 kms greater than that for bus users. Excess commuting is slightly higher for bus users (69.5%) than for car users (68.8%). Commuting capacity values are slightly lower for car users than for bus users, implying that car users consume less overall of their available commuting resources than bus users, albeit only marginally.

INTRODUCTION

Car dependency, traffic congestion, long commutes, sprawl and associated air and noise pollution characterise many contemporary cities. They are all challenges that are central to achieving the goal of environmentally sustainable cities (Scott et al., 1997; Marcotullio and Lee, 2003; Black, 1997; Litman, 2006). Planners, policy makers and public agencies have advocated, and even incentivized, jobs-housing balance policies as one way to reduce travel demand, increase the efficiency of commuting patterns and overall quality of life (California Air Resources Board, 2011; Cervero, 1989, 1991). This is largely because research has shown that there is potential for commuting to be reduced if jobs and housing are carefully arranged to assist with minimization of actual commuting patterns (Murphy, 2012). Indeed, it has also been shown

through simulation that improved jobs-housing balance has the potential to provide for significant reductions in congestion and associated environmental emissions (Scott et al., 1997).

Unsurprisingly, different factors contribute to the ratio of jobs-housing balance among different social groups and in different locales. In the United States (US) for example, suburbanisation of employment, housing segregation, inefficient public transportation services and race may all (more or less) contribute to jobs-housing balance or otherwise (Bauder, 2000; Horner and Mefford, 2007; Preston and McLafferty, 1999; Taylor and Ong, 1995). In the Chinese context, the idea of the work unit ("Danwei") in cities represents a very top-down and urban village-like arrangement of jobs, housing and social services which contributes to better jobs-housing balance and shorter commutes (Wang and Chai, 2009). During the socialist period, people residing in Danwei did not even need to exit the compound to meet their daily needs such as schooling, shopping and going to hospitals (Walder, 1986). This manuscript is organised as follows. The next section discusses the excess commuting framework and associated literature which is central to the overall research objectives (described in the next section). Thereafter, the paper is set within associated research in the Chinese context. Then, the methodology is outlined including the study area, provenance of the smartcard and car data and associated assumptions, as well as the formulations utilised for calculating the theoretical minimum and maximum commutes. The next section empirically estimates different jobs-housing and commuting related indicators for the different policy scenarios based on the input data and compares those indicators across modes in Beijing and across cities, where possible. The final section concludes and discusses directions of further studies.

The excess commuting framework

In the literature, there have been significant attempts over the last two decades to establish a framework for analysing the efficiency of regional commuting patterns. Central to this has been the notion of jobs-housing balance which has most frequently been studied via the excess commuting framework (Horner 2004). In existing studies, jobs-housing balance concerns "the spatial relation between the number of jobs and housing units within a given geographical area" (Peng, 1997, p.1216) and this is normally represented as a ratio at the level of a zonal unit such as a census tract or TAZ or at the aggregate regional level within the excess commuting framework.

As mentioned already, the excess commuting framework has often been utilised to provide insights into the nature of jobs-housing balance in cities as well as the overall efficiency of trip-making therein. Excess commuting is defined as "the nonoptimal or surplus work travel occurring in cities because people do not minimize their journeys to work" (Horner 2002, p.543). Thus, non-excessive commuting is where the actual travel (T_{act}) is equivalent to the theoretical average minimum commute (T_{min}) in a city where individuals travel to the closest possible workplace on average in terms of some measure of zonal separation (e.g. time, distance). In other words, commuting above what is necessary given the distribution of existing jobs and housing is considered excessive. It is expressed as a percentage of the actual commute as follows:

$$EC= \left(\frac{T_{act} - T_{min}}{T_{act}} \right) *100 \qquad (1)$$

This implies that careful (re)organisation of jobs and housing in a city-region has the potential to produce more efficient commuting patterns. Under this framework, the minimum commute can be thought of as an indicator of the mean distance or time separation between jobs and housing (i.e.

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jobs-housing balance) across a city-region. Lower relative average minimum commutes represent a higher degree of jobs-housing balance while higher average minimum commutes represent the opposite.

By way of contrast, Horner (2002) introduced the notion of an average maximum commute (T_{max}). It represents a theoretical situation where individuals, on average, commute to the furthest possible workplace destination in a city-region. Together T_{min} and T_{max} represent the lower and upper limit of the theoretical extent to which individuals can minimize or maximize commuting costs within the context of the existing distribution of home-work land use arrangements. Horner (2002) used the addition of T_{max} to develop a measure for what he refers to as capacity utilisation (C_u) - the percentage of travel cost capacity of a city-region being consumed by daily commuting:

$$C_u = \left(\frac{T_{act} - T_{min}}{T_{max} - T_{min}} \right) * 100 \qquad (2)$$

Recent additional extensions to the framework have also been added including the introduction of the notion of random commuting (T_{rand}) (Charron, 2007; Murphy and Killen, 2011). This metric has led to the development of additional measures of commuting efficiency such as commuting economy (C_e) and normalized commuting economy (NC_e) where T_{rand} is considered to be the more realistic upper bound of commuting capacity (Murphy and Killen, 2011). Indeed, Niedzielski et al (2013) have pointed out that C_e and NC_e are affected to a much lesser extent by MAUP effect than either the EC or C_u measure. However, neither C_e nor NC_e are the focus of the current research. However, few studies have assessed trip efficiency by mode within the excess commuting framework which is likely to be related to the difficulty of acquiring data

disaggregated by mode in most city regions. Nevertheless, there are some studies which have undertaken modal choice analysis within the framework. These include studies by Horner and Mefford (2007), Murphy (2009), Murphy and Killen (2011) and Murphy (2012). Within this context, the current research investigates the trip efficiency of commuters in Beijing, China within the context of the excess commuting framework. The paper contributes to existing studies in three ways. First, it outlines the potential role of and utilises a new data source, namely smartcard data, for outlining patterns of public transport commuting efficiency within the excess commuting framework. The future role of such datasets is important because they are updated daily and therefore have the potential to contribute to more dynamic excess commuting analysis. Thus, they have clear advantages over census data which has tended to be the dataset of choice for excess commuting studies to date. Second, it utilises innovative approaches for mapping not only actual commuting patterns but also minimum commuting patterns within the excess commuting framework. This provides an intuitive way in which to visually explore the geography of flows under the perfect efficiency assumptions of the minimum commute. Finally, the research offers the only analysis to date of commuting efficiency in Beijing within the context of the excess commuting framework. Given the size of Beijing and its role in the Chinese economy, applying the excess commuting framework to Chinese cities is important comparatively given their altogether different historical development outside the typical market-led framework that is seen in many western cities.

The Chinese context

In recent years Chinese cities have undergone significant spatial and social transformation and this has had a considerable impact on land use arrangements (including jobs-housing balance)

and commuting patterns. There has been large-scale urban expansion which has been accompanied by the suburbanization of affordable housing opportunities. This has resulted in an increase in average commuting distances across the city but especially among Beijing's suburban residents who have been forced outwards due to lack of affordable housing closer to employment cents (Li and Li, 2007; Liu et al., 2009; Meng, 2009; Meng et al., 2011); similar trends an also be seen in cities such as Guangzhou (Zhou and Liu, 2010; Liu et al., 2008).).

However, few Chinese studies have analysed commuting patterns within the context of the excess commuting framework. The only two exceptions are the work Liu et al. (2008) and Liu and Wang (2013). Liu et al. (2008) estimated excess commuting in Guangzhou for 2001 and 2005 and found that it had decreased from 58% to 44% over the period. However, they used a small sample of commuters (n=1,500) and a relatively large unit of analysis (zonal units with an average size=12.5 square kilometres) which tends to underestimate real excess commuting because of a greater MAUP effect at larger units of analysis (see Niedzielski et al, 2013). Moreover, Liu et al's (2008) study did not differentiate between modes of transport in determining measures of excess commuting. Liu and Wang (2013) calculated excess commuting for the city of Mianyang, China. Compared to the existing studies, Liu and Wang (2013)'s contribution is that they assumed that the number of workers/jobs in each TAZ can grow between 0 to 30%. The purpose of the model is to find the number of extra workers and jobs by TAZ where the resultant T_{min} is minimized. Using the model, they found that T_{min} tends to follow a "U" shape as the total number of workers/ jobs increases. Despite these exceptions, there remains a considerable gap in our knowledge of commuting patterns across Chinese cities especially when leading Chinese cities are compared with their European and US counterparts.

There has also been some research which has examined the related issue of jobs-housing. The most notable studies are those undertaken by Wang and Chai (2009) and Zhao et al. (2011). Based on a sample of data (n≤ 750) from the Beijing household travel survey, Wang and Chai (2009) found that Danwei contributes to a better jobs-housing balance and ultimately shorter commutes for Beijing residents. They also found that the relatively recent free-market approach in the housing sector has led to a decline in jobs-housing balance and longer distance commutes on average. Rather importantly, these studies and findings indicate that the mechanisms associated with jobs-housing balance and the resultant commuting patterns in China is considerably different from those found in the western context. In addition, recent research by Li and Li (2007) investigated jobs-housing balance and commuting patterns in two new suburban affordable housing communities in Beijing. They found that the journey times of bus commuters are significantly longer than that of commuters by automobile.

In Beijing, there were 184 kilometres of commuter subways (excluding the airport express rail, which was 28.1 kilometres and only served the airport and two stations in the inner city) as of 2008. Recent investment has led to an expansion of the subways where subway trips have gradually increased as a proportion of overall trip making. Beijing Metro manages and maintains the subways, which were built and financed by the Beijing Municipal Government Beijing Public Transportation Company, a state-owned company providing public bus services in the Beijing metropolitan area. As of 2011, the company has 28, 343 buses on 948 bus routes with a total length of 187,500 kilometres. In 2011 alone, these buses produced 1.7 billion vehicle

kilometres travelled and transported total passengers of 4.9 billion[1]. These figures indicate that Beijing has one of the most extensive public transportation systems in the world which is heavily focused on bus-based public transport. Indeed, bus trips account for a significant share of total public transportation trips. Table 1 shows the modal share breakdown of trips for 2008 and 2010. It can be seen that the car is the most dominant mode of travel with its share on the increase. On the other hand, the bus is the most dominant form of public transport and its share has remained more or less constant over the period with a large increase seen in the use of the subway. It is notable also, that contrary to many world cities where the share of biking (see Murphy and Usher, 2013) and walking is increasing, the trend in Beijing is for a decline in the role of these modes.

Table 1: Mode Share of Beijing Residents

Mode	2008 Share (%)	2010 Share (%)
Bus	28.8	28.9
Subway	8.0	10.0
Taxi	7.4	7.1
Car	33.6	34.0
Bike and walking	20.3	18.1
Company shuttle	1.9	1.9
Total	100	100

Source: BTRC, 2011.

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[1] Information based on: http://www.bjbus.com/home/view_content.php?uSec=00000002&uSub=00000012, accessed July 01, 2012.

Methodology

Data

As the capital of China, Beijing has now over 20 million residents and is one of the most populous cities in the world. The land area of the Beijing metropolitan area is c.16, 410 Km^2. Beijing Transport Public Transportation Company (BTRC) is the local transportation planning agency and is charged with collecting local travel survey data as well as developing and maintaining local travel demand models. Unlike its US counterparts, BTRC does not have the Census Transportation Planning Packages from the China Census and thus it assembles its travel demand model from data collected through separate surveys. It is not easy to gain access to transportation data in China; acquiring data for research purposes requires special permission which can be granted or otherwise at the discretion of the agency. Often, data that is acquired for research purposes is achieved as a result of personal connections to high-level individuals within these organizations as is the case with the data being utilised for this paper. The 2008 smartcard data and the 2010 Beijing Household Survey data are the primary data used in this manuscript and have been provided by the Beijing Institute of City Planning (BICP). As the local urban planning agency, BICP does not collect all the data it needs to develop various local urban plans. But for the sake of developing local urban plans, it can ask other local governmental entities such as BTRC and Beijing Metro for data it requires. This data has not been utilised previously in other studies of Beijing's transportation patterns.

In excess commuting studies interzonal flow (in terms of trip volumes) and cost matrix (in terms of some measure of zonal separation such as distance, time etc.) data are required for the calculation of T_{min} and T_{max}. In the case of our study, we were able to acquire comparable data only for bus and car modes. Due to institutional constraints, data hoarding and the difficulty of acquiring data for research purposes in China, it was not possible to get a complete public transport flow matrix broken down by bus and rail modes (c.f., Zhou, 2012).

In the case of the car data, we acquired the car commuter data of the 2010 Beijing Household Travel Survey (BHTS). This data that is the closest data available to 2008 because Beijing only conducts large-scale Household Travel Surveys in years ending with "0" or "5". To protect privacy, the data are aggregated by the local traffic analysis zones (TAZs) for 2010. There are 1911 TAZs in Beijing in 2010. The TAZs are different from those 1118 TAZs in 2008. Figure 1 is the map of the 2008 TAZs. On average, each TAZ in 2008 is about 14 square kilometres. But for inner city, TAZs are much smaller than the global average, as shown in Figure 1. The average size of TAZs in Beijing's core is comparable to or even smaller than that of the TAZs or sub-divisions used in existing studies. For instance, in Small and Song (1992), the 3,341-square-kiliometer Southern California Region was divided into 706 TAZs. In Murphy (2009) and Murphy and Killen (2011), the Great Dublin Region consists of 463 sub-divisions and covers 6,982 square kilometers. Tian'an Men Square is also shown in Figure 1. Geometrically speaking, the square is not the centroid of Beijing, but widely thought of as the centre of Beijing. Venues of national significance such as Zhong Nan Hai, the National Historical Museum, the Forbidden City, The State Council and The People's Great Hall are all within a walking distance to the square.
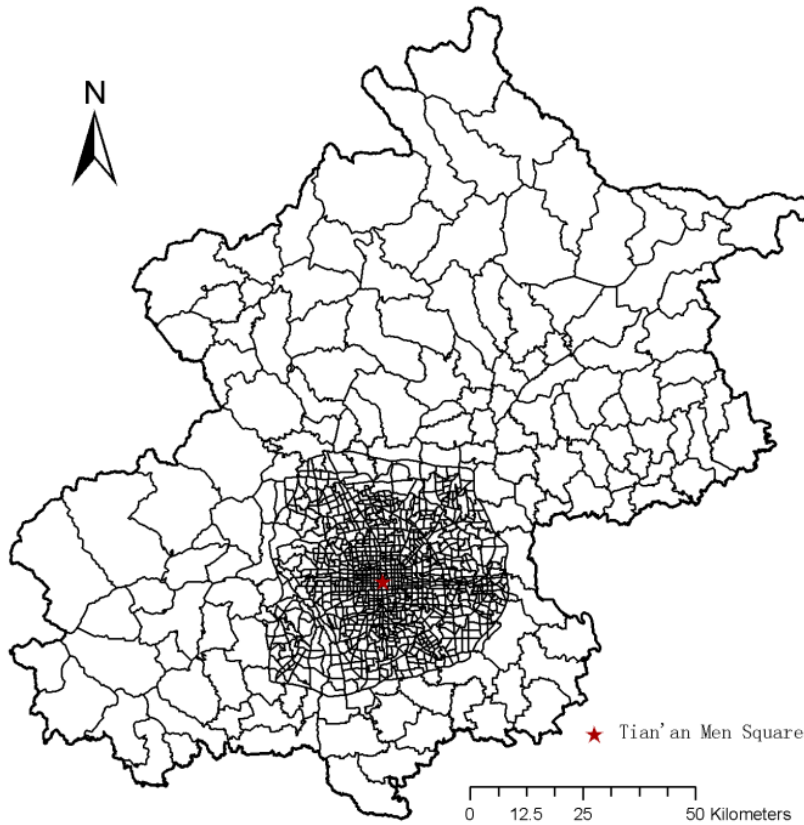
Figure 1: 1,118 TAZs in Beijing and the study area

In order to make useful comparisons between the car and bus commuting trips, we needed to convert either the car data into the 2008 TAZs or the bus data into the 2010 TAZs. Given that we have much large sample of bus commuters in 2008, we decided to do the former. When making the conversion, we assumed the following. First, at the TAZ level, car commuters are evenly distributed across the space and so if we know the total area of any TAZ and a subarea of the same TAZ, we can use the percentage of the subarea to determine the number of car commuters in that subarea. Second, the ratio of the car commuter to all the car commuters in different TAZs is a constant. Actually, this is also the goal that BHTS expects to achieve: a 5% response rate across TAZs. Third, the underlying mechanism (e.g. the gravity model) that governs the spatial

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distribution of car commuters has not changed between 2008 and 2010. Fourth, the jobs-housing distribution of the car commuter sample is representative of the broader population of car commuters. Because of these assumptions, we were able to convert the 2010 car commuter samples (N=37,837, approximately 7% of the universe) into 532,722 car commuters, the estimated car commuter universe in 2008 we obtained based on BTRC (2009).

More specifically, the procedures for the translation were as follows. First, we performed an overlay analysis of the 2010 and 2008 TAZs in *TransCAD*, which generates 6,757 distinct smaller "TAZs". These TAZs have a one-to-one or one-to-many relation to the 2010 and 2008 TAZs. *TransCAD* automatically produces a relationship table of three sets of TAZs: their TAZ IDs and the respective percentage of the 2010 and 2008 TAZ areas fall into the smaller one. Second, using the relation table, we disaggregate the 2010 sample into the smaller TAZs with the known area percentage and then aggregate the samples of the smaller TAZs into the 2008 sample. Third, we scaled up the 2008 sample up to the car user universe of the same year.

For the bus data, we utilised smartcard data of bus users which is a potentially rich source of information; similar data has not been used previously in excess commuting studies. Since 2005, over 90% of bus riders in Beijing have swiped an anonymous smart card when boarding and alighting (for suburban routes) or when boarding (for inner-city routes) to pay for their fare. The high rate of smart card usage among bus riders is largely due to a significant government subsidy for smartcard users. Those users avail of 60% discounts on any routes in the local bus system; the smartcards are also integrated with other services and can pay taxi, electricity and sewage services that are offered by BMG and associated companies. In this manuscript, we assume that

the bus commuters we identified through the smartcard data are representative of all bus commuters.

When holders use their smart card for paying bus services, the card reader installed on the bus automatically generates the following information:

(a) Bus trip origin and destination stop (if the holder on a suburban route) or bus trip origin only(if the holder is on an inner-city route). For those inner-city routes, the cardholder only swipes his/her card when boarding the bus. In this case, we deduced the cardholder's trip origin and destination based on all swipes during five consecutive weekdays. An origin or destination and all bus stops within 500 meters of them that is associated with recurring swipes would be estimated as "home" and "workplace". Later, home and workplace are differentiated using the local parcel-level land use information. More technical details can be found in Long, Y. Zhang, Y. and Cui, C. (2012).

(b) Boarding and alighting time (if the holder is on a suburban route) or boarding time only (if the holder is on an inner-city route).

(c) Unique card number and card type (student card or regular card).

The above information is instantly sent to a central server where it is stored. For this study, we were granted access to a full week's historical data from the server administrator, which contains 77,976,010 bus trips of 8,549,072 non-distinct cardholder records between April 7 and April 13, 2008. To identify a cardholder's workplace, we queried one-day data on a MS SQL Server and repeated the work for seven days based on the following rules:

(a) The card type is not a student card. Students were excluded on the basis that they are not commuters;

(b) $R_j \geq 6$ hours, where R_j is the time that a cardholder stays at place j, which is associated with all bus stops within 500 meters of one another;

(c) $j <> 1$, which means that j is not the first place in a weekday that the server records;

where the land use associated with T_j is identified as non-residential (based on the local parcel-level land use map).Thus, the final workplace of each bus user include in our flow matrix was defined by utilizing these criteria..

Similarly, a cardholder's home (origin) was identified if it adhered to the following criteria:

(a) The cardholder already has an identified workplace;

(b) The card type is not a student card;

(c) $R_i \geq 6$ hours, where R_i is the duration that a cardholder stays at place i, which is associated with all bus stops within 500 meters of one another;

(d) $F_h >= F_j$, where F_h is the first and the most frequent place a cardholder starts a bus trip of a day within the week; F_j is a cardholder's trip frequency to or from j.

In addition, to ensure that we singled out commuters solely by bus, we only selected cardholders that had continuous bus swipes. That is, our study excludes multimodal public transport users (i.e. bus and subway). It is possible to get a breakdown of the swipe card data by mode (subway and bus) but unfortunately we were not permitted to access such information for this study. In total, we ended up with 216,844 distinct cardholders/workers commuting solely by bus within the study boundary (see Long et al., 2012 for more details). We then geocoded and aggregated

cardholders' homes and workplaces by TAZ of 2008. This is also the data that we were allowed to use for research and publishing.

As with numerous other studies, we used the Euclidean distance between zone centroids as a measure of zonal separation. For all trips (bus and car), intra-zonal travel distances were estimated by assuming that each zonal unit is approximately circular in shape (see Frost et al, 1998). In a similar manner to other studies, we also excluded those trips originating and destined for locations outside the study boundary (see Frost et al, 1998; Horner, 2002; Murphy, 2009).

Formulations

From the preceding discussion, it should be clear that a necessary prerequisite for attaining values associated with the efficiency indicators described in Equations 1-2, is the calculation of T_{min}, T_{max}, and T_{act}. T_{act} was calculated from empirical data. For T_{min}, the TPLP was used to determine the assignment of trips from origin to destination that minimized mean commuting cost. The objective function and constraints of the TPLP are given by:

$$\text{Min: } Z = \frac{1}{N} \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} X_{ij} \qquad (3)$$

$$\text{s.t.} \quad \sum_{i=1}^{n} X_{ij} = D_j \qquad \forall j = 1,...,m \qquad (4)$$

$$\sum_{j=1}^{m} X_{ij} = O_i \qquad \forall i = 1,...,n \qquad (5)$$

$$X_{ij} \geq 0 \qquad \forall i, j \qquad (6)$$

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where, m = number of origins; n = number of destinations; O_i = trips beginning at zone i; D_j = trips destined for zone j; cij = travel cost from zone i to zone j; X_{ij} = number of trips from zone i to zone j, and N = total number of trips. The objective function (2) minimizes average transport costs. Constraint (3) ensures that trip demand at each destination zone is satisfied while constraint (4) limits the number of trips leaving each origin zone to the number of trips originating there. Constraint (5) restricts the decision variables, X_{ij}, to non-negative values. It should be noted that travel costs, c_{ij}, may be expressed in terms of any measure of zonal separation, for example travel distance, travel time or indeed a generalized cost measure.

T_{max} was also determined using the TPLP where the objective function is the inverse of the minimization problem discussed previously (5) and is given by:

$$\text{Max} \, Z = \frac{1}{N} \sum_{i=1}^{m} \sum_{j=1}^{n} CijXij \qquad (9)$$

Results

Table 3 show and Figure 2 the results emerging for the values associated with the travel scale T_{min}, T_{max} and/or T_{act}. They also show the commuting range (T_{max}-T_{min}) as well as the efficiency indicators EC and C_u. It can be seen that T_{min} is considerably lower for the bus than for the car. What this suggests is that there is a greater inter-mixing of jobs-housing functions (i.e. a better jobs-housing balance) associated with users of that mode compared to the corresponding land use arrangement for car users. The lower value of T_{min} for bus user suggests that, on average,

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users of that mode have easier access (in terms of commuting distance) to job opportunities than car users. However, this greater juxtaposition between origins and destinations for bus users may simply be a reflection of the fact that those commuters who cannot get easy access to their job destination via the bus simply switch to the car (if possible); those who can access destination opportunities relatively easily via the bus network continue with that mode for their commute. Overall, these findings echo those of Wang and Chai (2009) and Zhao et al. (2011) which show that Danwei is associated with a better jobs-housing balance and ultimately shorter commutes for Beijing residents.

To some degree, this phenomenon might explain why the modal results for T_{min} in Beijing are in contrast to other cities where similar analysis has been undertaken. For example, the general trend in the results are in contrast to those emerging for the case of Dublin, Ireland (see Murphy, 2009) where T_{min} values for public transport were consistently lower for car users than for public transport users. Murphy's (2009) public transport data included bus and train data rather than just bus data (as in this study) but because train commutes tend to be longer, the T_{min} results from Beijing would likely be even higher than at present if rail data were to be included. Quite why this trend is different in the case of Beijing is open for debate but there would seem to be little doubt that it is related to differences in the overall urban spatial organization of Beijing relative to Dublin. Beijing is a much more monocentric city than Dublin (which is highly polycentric) and thus has witnessed much less decentralisation of employment than not only Dublin but many western cities in a more general sense. The decentralisation of employment functions allows car users, in particular, to access job opportunities closer to residential locations beyond the central area thereby reducing the value of T_{min} to a considerably greater extent for users of that mode.

The fact that this has not happened to the same extent in Beijing suggests that the maintenance of a monocentric city (and thereby a maintenance of a largely centralised employment and decentralised residential structure) has not afforded car users the same opportunities to access job opportunities closer to peripheral residential locations. Moreover, if it was assumed that all workers in Beijing were to commute to the city centre (i.e. Tian'anmen square) where most employment opportunities are located we found that the mean commuting distance by car is considerably longer (27.7km) than by bus (14.8km). This supports the previous assertion that car commuters tend to locate further from the central area (Tian'anmen) whereas bus commuters locate closer to the centre.
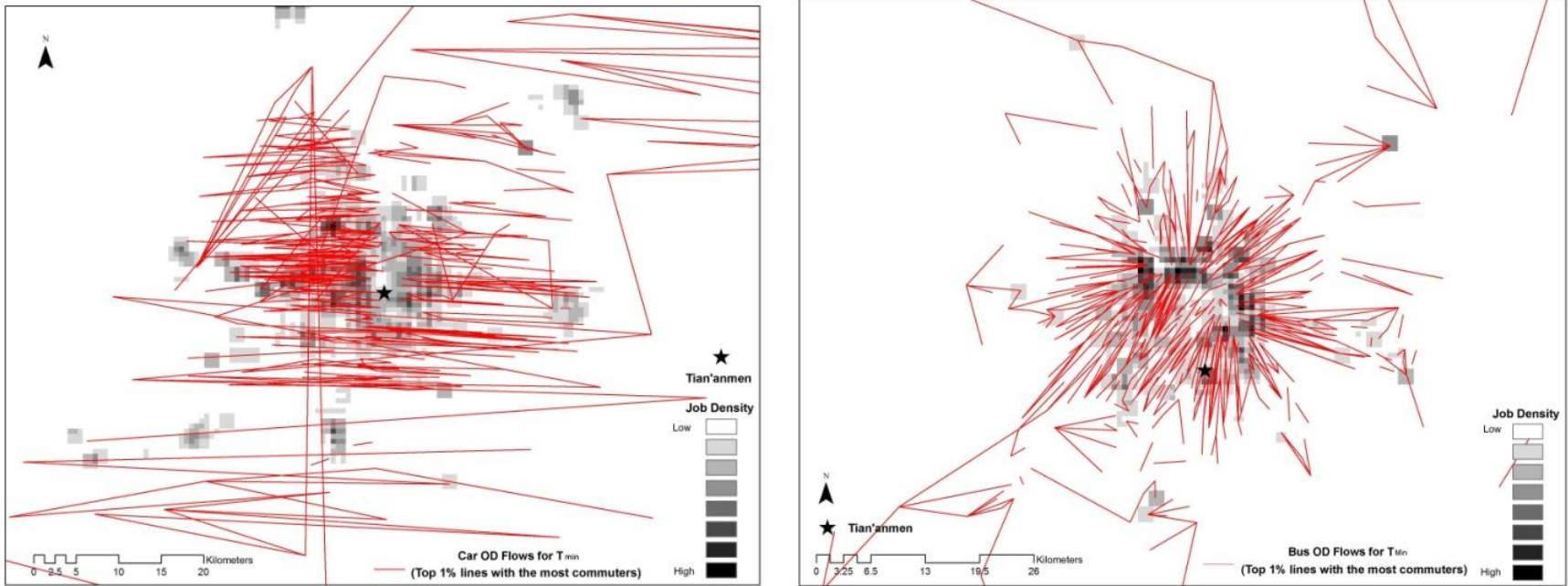
Figure 2. Top one per cent of origin-destination flows for the minimum solution (T_{min}) by car and public transport

Figure 2 shows a graphical display of the top one per cent of OD flows associated with the minimum solution (T_{min}) for car and bus. The results are interesting in that they demonstrate graphically the difference in the complexity of origins and destinations associated with the two modes of transport. For the car, origin and destination flows are much more dispersed and complex whereas for the bus flows are remarkably radial in nature and are oriented towards flows along radial routes converging in the centre. For the car, they highlight that even under the perfect efficiency assumptions of the minimum solution, origin and destination flows associated with the existing distribution of car users are highly dispersed and more random in nature. This suggests that in the specific case of Beijing, the primary role of the car is to accommodate more complex trips that, in the main, are inter-suburban or cross-commuting trips not oriented towards the centre.

The results for T_{max} are considerably higher for car users than for public transport users. This is consistent with literature which has calculated these values by different mode (see Murphy, 2009). This demonstrates that, in the case of Beijing, the private transport network facilitates the possibility of longer trips than those afforded by the bus network. Thus, individuals who have longer commuting distances to their workplace are more likely to use the car over the bus than for shorter journeys. In effect, the T_{max} results for the bus (24.7 kms) show that individuals commuting more than c.24 kms to work simply cannot use the bus network and must transfer to the car in order to reach their destination. This result has significant policy implications for Beijing because it suggests that any moves towards decentralisation of employment would

undermine the role of the bus network in serving commuting trips and would likely lead to considerable modal shift towards the car.

The foregoing result is also highlighted by the respective travel ranges for the two modes (Table 3). They show that the commuting range for car users is 9.4 kms greater than that for bus users. This reinforces the previous point emerging from the T_{max} results and ultimately highlights the possibility for car users to live further from employment destinations than bus users. Thus, the results suggest, quite concretely, that the car facilitates a greater separation between home and work land uses than the bus. Moreover, it suggests that the greater intermixing of jobs-housing associated with the bus (i.e., T_{min}) has not facilitated an improvement in the range of commuting possibilities for bus users.[2]

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[2] In similar studies, a lower T_{min} normally translates into a higher T_{max} but this is not the case for our results.
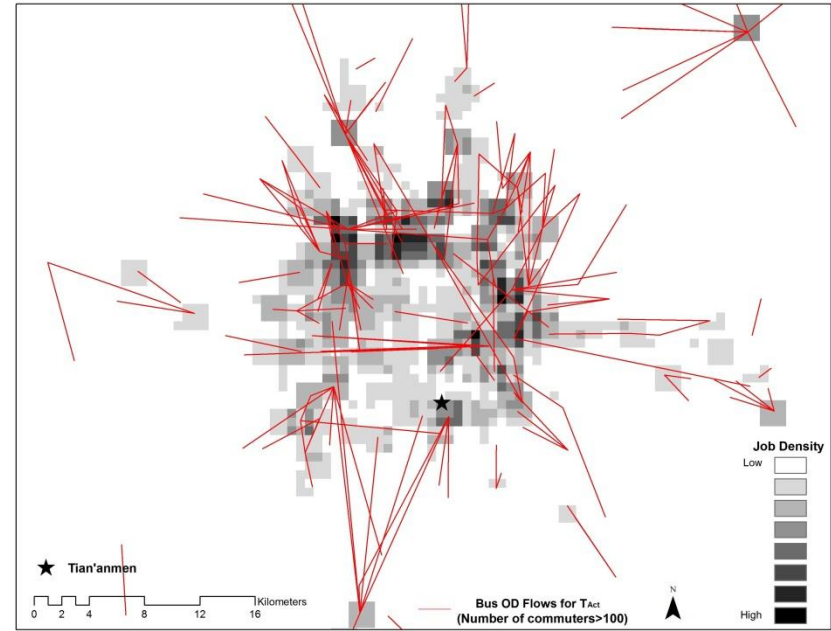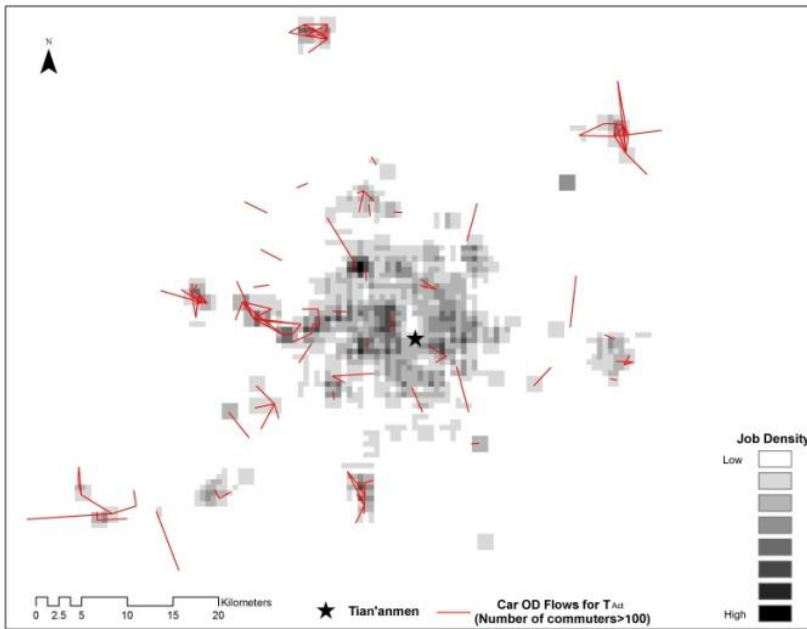
Figure 3: Origin-destination flows for the actual pattern of trip making (Tact) by car and public transport

Unlike Figure 2, Figure 3 shows a graphical display of all OD pairs with greater than 100 commuters for car and bus for the actual pattern of trip making (T_{act})[3]. The results show that more red lines are visible for bus than for car users indicating more highly concentrated flows for the bus network; by way of contrast, the considerably lower number of red lines for the car network indicates that there are less OD pairs associated with concentrated flows. Given that public transport systems generally work best with high volumes of users along a limited number of routes, it is hardly surprising that the bus is associated with greater concentration of flows. Nevertheless, it does demonstrate the extent to which car flows are characterised by low volume, dispersed and complex patterns of flow associated with the OD flows compared those for the bus.

All of these assertions are consistent with the observed values of T_{act}. Given the lower values of T_{min} for bus users over car users, one would expect T_{act} to be lower for that mode. The results show that this is indeed the case (Table 3). T_{act} for bus users (8.2 kms) is 3 kms lower on average than for car users. Indeed, T_{min} is 40.0% larger for car users than for bus users and similarly T_{act} is 36.6% larger for car users than for bus users. This implies a close correlation between T_{min} and T_{act} indicating that the greater intermixing of jobs-housing functions associated with bus users allows individuals who use that mode to reduce their observed commuting costs to a greater extent than car users.

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[3] We choose this because using a similar approach to that adopted for the minimum solution (Figure 2) would have yielded unreadable maps.

The results for the commuting efficiency indicator - excess commuting (EC) – also reinforce this relationship between T_{min} and T_{act} for bus and car users in that they show that excess commuting is similar for both modes. However, despite bus users having a lower T_{min} and T_{act}, they show that excess commuting is slightly higher for bus users (69.5%) than for car users (68.8%). This implies that relative to the existing distribution of home-work land use arrangements for each mode (i.e., T_{min}), there is little difference in the commuting efficiency between modes as evidenced by the EC statistic. For the case of Dublin, EC for public and private transport was 59.8% and 78.4% respectively. It is clear then that excess commuting for bus in Beijing is considerably higher than the corresponding results for public transport in Dublin; for car they are considerable lower. However, when compared with other Chinese cities, Beijing exhibits relatively high levels of excess commuting. Liu et al's (2008) 2005 analysis of excess commuting in Guangzhou found (for all trips) only 44.7% of commuting to be excessive. While they used simulated data and relatively small samples which might undermine the strength of the results, the difference, nevertheless, is remarkably large and implies that commuting patterns in Beijing are more inefficient than those in Guangzhou.

Turning to the C_u statistic which highlights the extent to which a city's existing commuting capacity is being utilised, it is clear that the differences are also only marginal between car and bus modes (Table 3). However, the results show that the C_u values are slightly lower for car users than for bus users implying that car users consume less overall of their available commuting resources than bus users, albeit only marginally. This general trend is similar to the results emerging from Murphy's (2009) research on Dublin. However, the magnitude of the difference in the modal results is quite different between Dublin and Beijing. In Dublin the

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difference in car and public transport C_u values was almost 7.0% whereas in Beijing the difference is only 1.4%. Taken together, the results for EC and C_u for Beijing highlight that within the context of the existing distribution of jobs and housing functions, bus use is associated with slightly more inefficient commuting patterns than car use. However, this must be viewed within the context of the T_{min} and T_{act} values which demonstrate a better jobs-housing balance for bus users and also that bus users commute, on average, 3 kms less per trip than car users in Beijing.

Table 3. Excess commuting and related results for the Beijing metropolitan area

	T_{min}	T_{act}	T_{max}	Range (T_{max}-T_{min})	EC	CU
Car	3.5	11.2	35.1	31.6	68.8%	24.3%
Bus	2.5	8.2	24.7	22.2	69.5%	25.7%

Conclusions

Contemporary Chinese cities are highly dynamic. The rapidity of urban transformation right across the country is quite remarkable with transport infrastructure and land use functions witnessing rapid change over the last two decades in particular. In Beijing for instance, the subway network length has more than doubled from 184 kms to 465 kms between 2008 and 2013 alone. Thus, the geography of transport patterns is changing rapidly over much shorter periods of time than we have traditionally become accustomed to. This means that for excess commuting and related transport studies dynamic input data is needed to more quickly assess the nature of

change. While our study only provides a snapshot of transport patterns in a Chinese city, our approach which uses Smartcard data as input for analysing the efficiency of trip patterns along the bus network has the potential to be a much more dynamic source of data for input into transport studies than traditional survey data. Indeed, this study has demonstrated how this data can be manipulated and utilised for assessing very recent public transport patterns.

Our results show that T_{min} is lower for the bus than for the car indicating a better jobs-housing balance associated with the former mode. However, it is possible (although further research would be needed to gain more certainty) that this is related to the residential self-selection (RSS) phenomena and less due to the deliberate efficiency choices of bus users. This phenomenon refers to situations where individuals choose their residence based on their travel needs, abilities and preferences that are constrained by an individual's place in the socio-economic hierarchy modified by the opportunities and constraints provided by society (Van Wee, 2009). In the context of our results, this may suggest that those commuters who cannot gain easy access to their employment destination via the bus simply switch to the car or alternatively choose an alternative origin (home location) that allows them the opportunity to commute by car rather than by bus.

The results also highlight that Beijing is a considerably more monocentric city than many western cities. The upshot of this is that modal shifts from bus to car does not confer huge efficiency benefits upon car users relative to bus users due to the fact that employment has not been decentralised to anywhere near the same extent as in many western cities and this is

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evidenced by the relative T_{min} values for both modes. Where employment is decentralised, it clearly confers significant additional benefits on car users relative to public transport users (see Murphy, 2012). The fact that Beijing has not gone down this route and has maintained a more monocentric-like urban structure has actually allowed the bus to increase its modal share in recent years and this is contrary to what has happened in most western cities that have pursued decentralisation strategies via polycentric urban models. In terms of efficiency indicators such as excess commuting and capacity utilisation, our study shows that Beijing's excess commuting is high for bus and low for car relative to other cities that have assessed these indicators by mode. Quite why this is the case would require more detailed research with a temporal component to map changes in commuting efficiency onto changes in land use arrangements.

More broadly, the generally lower values of T_{min} for Beijing relative to other cities of a similar size, suggests that the legacy/impacts of the Danwei phenomenon persists in Chinese cities. However, as shown in other studies, the dismantlement of Danwei, rapidly changing residential preferences, broader motorisation and suburbanisation can undermine the potential positive efficiency impacts of Danwei. In our view, there are lots of uncertainties in terms of the phenomena's impacts on jobs-housing balance and commuting patterns. However, this also means that rich opportunities exist for further research on the issue which, to some extent at least, our study provides insights into even if they are somewhat indirect.

Our graphical maps of key origin-destination flows are an innovative approach to demonstrating flows of actual travel patterns as well as those associated with the minimum solution of the TPLP.

In this sense they are a useful addition to aid with the interpretation of results emerging via the excess commuting framework. They demonstrate spatial variations in flow patterns associated with T_{min} and T_{act} and provide useful insights into the geography of transport flows associated with these solutions which are otherwise lost in previous studies of the same nature.

Finally, despite the merits of this work, it can still be improved in the future in. First, it would be beneficial to link smartcard data to local household travel survey data. This would provide much richer information on various socio-economic variables which could help explain commuting behaviour more concretely. However, in the Chinese context this is a key barrier to be overcome because there is, generally speaking, a tradition among local agencies of withholding data from scholars. Second, the data and our understanding of public transport trip making would be greatly improved if smartcard data was also available for subway users. While the addition of this data would certainly make smartcard data processing and validation more complicated, it would likely be worth the effort as it would enable us to better understand the efficiency of a broader range of commuters but would also provide important insights about the relative efficiency of that mode relative to others.

REFERENCES

Bauder, H., 2000. Reflections on the spatial mismatch debate. Journal of Planning Education and Research 19, 316-320.

Beijing Transportation Research Centre (BTRC), 2009, 2011. Annual report of Beijing's transportation development (In Chinese), available at: http://www.bjtrc.org.cn/JGJS.aspx?id=5.2&Menu=GZCG. Accessed on February 2012.

Black, W. R., 1997. North American transportation: Perspectives on research needs and sustainable transportation. Journal of Transport Geography 5, 12-19.

California Air Resources Board, 2011. Draft policy brief: Impact of jobs-housing balance on passenger vehicle use and greenhouse gas emissions based on a review of the empirical literature Sacramento, CA.

Cervero, R., 1989. Jobs-housing balance and regional mobility. Journal of the American Planning Association 55, 136-150.

Cervero, R., 1991. Jobs-housing balance as public policy. Urban Land 10, 14.

Charron, M., 2007. From excess commuting to commuting possibilities: more extension to the concept of excess commuting. Environment and Planning A 39(5), 1238-1254.

Frost, M., Linneker, B., Spence, N., 1998. Excess or wasteful commuting in a selection of british cities. Transportation Research Part A: Policy and Practice 32, 529-538.

Horner, M.W., 2002. Extensions to the concept of excess commuting. Environment and Planning A 34, 543-566.

Horner, M.W., 2004. Spatial dimensions of urban commuting: a review of major issues and their implications for future geographic research. The Professional Geographer 56, 160-173.

Horner, M.W., Mefford, J.N., 2007. Investigating urban spatial mismatch using job-housing indicators to model home-work separation. Environment and Planning A 39, 1420-1440.

Li, Q., Li, X., 2007. The characteristics of resident's working-trip in inner-suburb of Beijing (In Chinese). Urban Problems, 55-59.

Litman, T., Burwell, D, 2006. Issues in sustainable transportation. International Journal of Environmental Issue 6(4),331-347.

Liu, W., Yan, X., Fang, Y., Cao, X., 2008. Related characteristics and mechanisms for excess commuting in Guangzhou (In Chinese). Acta Geographica Sinica, 63, 1085-1096.

Liu, Z., Zhang, Y., Chai, Y.W., 2009. Home-work separation in the context of institutional and spatial transformation in urban china: Evidence from Beijing household survey data (In Chinese). Urban Studies (China), (9), 110-117.

Long, Y., Zhang, Y., Cui, C. Y., 2012. Analysing jobs-housing relationship and commuting pattern of Beijing using bus smart card data (In Chinese). Acta Geographica Sinica, 67, 1339-1352.

Marcotullio, P. J., Lee, Y. S. F., 2003. Urban environmental transitions and urban transportation systems - A comparison of the North American and Asian experiences. International Development Planning Review 25(4): 325-354.

Meng, B., 2009. The spatial organization of the separation between jobs and residential locations in Beijing (In Chinese). Acta Geographica Sinica 64, 1457-1466.

Meng, B., Zheng, L., Yu, H., 2011. Commuting time change and its influencing factors in Beijing(In Chinese). Progress in Geography 30, 1218-1224.

Murphy, E., Killen, J. E., 2011. Commuting economy: An alternative approach for assessing regional commuting efficiency. Urban Studies 48(6), 1255-1272.

Murphy, E. and Usher, J. (2013) The role of bicycle-sharing in the city: Analysis of the Irish experience, International Journal of Sustainable Transportation. http://dx.doi.org/10.1080/15568318.2012.748855.

Murphy, E., 2009. Excess commuting and modal choice. Transportation Research Part A: Policy and Practice 43, 735-743.

Murphy, E. 2012. Urban spatial location advantage: the dual of the transportation problem and its implications for land-use and transport planning. Transportation Research Part A: Policy and Practice 46, 91-101.

Niedzielski, MA, Horner MW, Xiao N (2013) Analyzing scale independence in jobs-housing and commute efficiency metrics, Transportation Research A, 58, 129-143.

Peng, Z.R., 1997. The jobs-housing balance and urban commuting. Urban Studies 34, 1215-1235.

Preston, V., McLafferty, S.,1999. Spatial mismatch research in the 1990s: progress and potential. Papers in Regional Science 78, 387-402.

Scott, D. M., P. S. Kanaroglou, Anderson, W. P., 1997. Impacts of commuting efficiency on congestion and emissions: case of the Hamilton CMA, Canada. Transportation Research Part D: Transport and Environment 2(4),245-257.

Small, K. A., Song, S., 1992. Wasteful" commuting: A resolution. Journal of Political Economy 100(4), 888-898.

Walder, A. 1986.Communist Neo-Traditionalism: Work and Authority in Chinese Industry, Berkeley, CA: University of California Press.

Wang, D., Chai, Y.W., 2009. The jobs–housing relationship and commuting in Beijing, China: The legacy of Danwei. Journal of Transport Geography 17, 30-38.

Yang, C. and Wang, C. 2013. Excess commuting and jobs-housing balance model(In Chinese). Journal of Tongji University (Nature Science) 41, 1712-1716.

Zhao, P.J., Lu, B., de Roo, G., 2011. Impact of the jobs-housing balance on urban commuting in Beijing in the transformation era. Journal of Transport Geography 19, 59-69.

Zhou, J., 2012. Transportation models and their mobile-source GHG modules in Chinese Cities. Paper presented at The 91th Transportation Research Board Meeting, Washington, D.C., available at: http://amonline.trb.org/1so6ug/1so6ug/1, accessed on February 22, 2013.

Zhou, S., Liu, Y., 2010. The situation and transition of jobs-housing relocation in Guangzhou, China (In Chinese). Acta Geographica Sinica 65, 191-201.