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

3

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11

12 **ABSTRACT**

13

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

25

26 **Keywords:** excess commuting, jobs-housing balance, commuting, bus, Beijing

27

28

29

30 **Introduction**

31

32 Car dependency, traffic congestion, long commutes, sprawl and associated air and noise
33 pollution characterise many contemporary cities. They are all challenges that are central to
34 achieving the goal of environmentally sustainable cities (Scott et al., 1997; Marcotullio and Lee,
35 2003; Black, 1997; Litman, 2006). Planners, policy makers and public agencies have advocated,
36 and even incentivised, jobs-housing balance policies as one way to reduce travel demand,
37 increase the efficiency of commuting patterns and improve overall quality of life (California Air
38 Resources Board, 2011; Cervero, 1989, 1991). This is largely because research has shown that
39 there is potential for commuting to be reduced if jobs and housing are carefully arranged to assist
40 with minimisation of actual commuting patterns (Murphy, 2012). Indeed, it has also been shown
41 through simulation that improved jobs-housing balance has the potential to provide for
42 significant reductions in congestion and associated environmental emissions (Scott et al., 1997).

43

44 Unsurprisingly, different factors contribute to the ratio of jobs-housing balance among different
45 social groups and in different locales. In the United States (US) for example, suburbanisation of
46 employment, housing segregation, inefficient public transportation services and race may all
47 (more or less) contribute to jobs-housing balance or otherwise (Bauder, 2000; Horner and
48 Mefford, 2007; Preston and McLafferty, 1999; Taylor and Ong, 1995). In the Chinese context,
49 the idea of the work unit (“Danwei”) in cities represents a very top-down and urban village-like
50 arrangement of jobs, housing and social services which contributes to better jobs-housing
51 balance and shorter commutes (Wang and Chai, 2009). During the socialist period, people
52 residing in Danwei did not even need to exit the compound to meet their daily needs with
53 schools, shops and hospitals located therein (Walder, 1986). The basic planning idea of Danwei
54 was adopted from the former Soviet Union which had a close political relationship with the
55 People’s Republic of China (PRC) during the 1950s. Danwei was designed as a compound that
56 contained both jobs and housing as well as other facilities and was widely adopted as a planning
57 principle across Chinese cities during the first five years of the establishment of the PRC
58 government in 1949 (Li, 1993). One of the advantages of the Danwei planning approach was the
59 belief that it facilitated short commutes and a reduction in travel demand generally (Chai and
60 Zhang, 2009). In the post-socialist period, the dismantling of Danwei, which was accompanied
61 by the suburbanisation of more housing than jobs, has contributed to a widening jobs-housing
62 imbalance and is thought to have contributed to the lengthening of commutes (Yang, 2006;
63 Wang and Chai, 2009). However, despite significant transformations of the built environment in
64 China, the positive impact of Danwei on urban commuting patterns is thought to persist, albeit
65 in a more subtle way, as evidenced in the case of the city of Xi’an (Zhou et al., 2014).

66

67 This manuscript furthers the work of Long et al (2012), which describes how to derive home and
68 workplace locations from smartcard data and quantifies and visualises the existing bus
69 commuting trips in Beijing based on the derived location information. Long et al. (2012) do not
70 investigate (a) how existing bus commuting trips might be optimised; (b) how those trips
71 compare with car commuting trips; and (c) how Beijing’s bus/car commuting efficiency
72 compares to that of other cities. This manuscript examines all of these issues and is organised as
73 follows. The next section discusses the excess commuting framework and associated literature
74 which is central to the overall research objectives (described in the next section). Thereafter, the

75 paper is set within associated research in the Chinese context before the methodology is outlined
76 including the study area, provenance of the smartcard and car data and associated assumptions,
77 as well as the formulations utilised for calculating the theoretical minimum and maximum
78 commutes. The results are then outlined and analysed before some broad-ranging discussion and
79 conclusions are offered.

80

81 **The excess commuting framework**

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

90

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

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

101 This relationship implies that careful (re)organisation of jobs and housing in a city-region has the
102 potential to produce more efficient commuting patterns. Under this framework, the minimum
103 commute can be thought of as an indicator of the mean distance or time separation between jobs and
104 housing (i.e. jobs-housing balance) across a city-region. Lower relative average minimum
105 commutes represent a higher degree of jobs-housing balance while higher average minimum
106 commutes represent the opposite.

107

108 At the opposite end of the scale, Horner (2002) introduced the notion of an average maximum
109 commute (T_{max}). It represents a theoretical situation where individuals, on average, commute to the
110 furthest possible workplace destination in a city-region. Together T_{min} and T_{max} represent the lower
111 and upper limit of the theoretical extent to which individuals can minimise or maximise commuting
112 costs within the context of the existing distribution of home-work land use arrangements. Horner
113 (2002) used the addition of T_{max} to develop a measure for what he refers to as capacity utilisation
114 (C_u) - the percentage travel cost capacity of a city-region being consumed by daily commuting:

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

Recent 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 normalised commuting economy (NC_e) where the average random commute (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 influenced to a much lesser extent by MAUP effects than either the EC or C_u measure. However, neither C_e nor NC_e are the focus of the current research. It is also the case that 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, some studies have undertaken modal choice analysis within the framework, including, for instance, Horner and Mefford (2007), Murphy (2009, 2012) and Murphy and Killen (2011).

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 here and within other 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 suburbanisation 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 centres (Li and Li, 2007; Liu et al., 2009; Meng, 2009; Meng et al., 2011); similar trends can 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

158 and Wang (2013). Liu et al. (2008) estimated excess commuting in Guangzhou for 2001 and
159 2005 and found that it had decreased from 58% to 44% over the period. However, they used a
160 small sample of commuters (n=1,500) and a relatively large unit of analysis (zonal units with an
161 average size=12.5 square kilometres) which tends to underestimate real excess commuting
162 because of a greater MAUP effect at larger units of analysis (see Niedzielski et al., 2013).
163 Moreover, Liu et al.'s (2008) study did not differentiate between modes of transport in
164 determining measures of excess commuting. Elsewhere, Liu and Wang (2013) calculated excess
165 commuting for the city of Mianyang, China. Compared to existing studies, Liu and Wang
166 (2013)'s contribution is that they assumed that the number of workers/jobs in each TAZ could
167 grow by up to 30%. The purpose here was to find the number of extra workers and jobs by TAZ
168 where the resultant T_{min} is optimised. Using this model, they found that T_{min} tends to follow a "U"
169 shape as the total number of workers/ jobs increases. Despite these exceptions, there remains a
170 considerable gap in our knowledge of commuting patterns across Chinese cities especially when
171 leading Chinese cities are compared with their European and US counterparts.

172
173 There has also been some research which has examined the related issue of jobs-housing balance.
174 The most notable studies are those undertaken by Wang and Chai (2009) and Zhao et al. (2011).
175 Based on a sample of data (n≤ 750) from the Beijing household travel survey, Wang and Chai
176 (2009) found that Danwei contributes to a better jobs-housing balance and ultimately shorter
177 commutes for Beijing residents. They also found that the relatively recent free-market approach
178 adopted in the housing sector has led to a decline in jobs-housing balance and longer distance
179 commutes on average. Rather importantly, these studies and findings indicate that the
180 mechanisms associated with jobs-housing balance and the resulting commuting patterns in China
181 are considerably different from those found in the western context. In addition, recent research
182 by Li and Li (2007) investigated jobs-housing balance and commuting patterns in two new
183 suburban affordable housing communities in Beijing. They found that the journey times of bus
184 commuters are significantly longer than that of commuters by automobile.

185
186 In Beijing, there existed 184 kilometres of commuter subways (excluding the airport express rail,
187 which was 28.1 kilometres and only served the airport and two stations in the inner city) as of
188 2008. Recent investment has led to an expansion of the subways where subway trips have
189 gradually increased as a proportion of overall trip making. Beijing Metro manages and maintains
190 the subways, which were built and financed by the Beijing Municipal Government and Beijing
191 Public Transportation Company, a state-owned company providing public bus services in the
192 Beijing metropolitan area. As of 2011, the company has 28,343 buses on 948 bus routes with a
193 total length of 187,500 kilometres. In 2011 alone, these buses produced 1.7 billion vehicle
194 kilometres travelled and transported of 4.9 billion passengers¹. These figures indicate that
195 Beijing has one of the most extensive public transportation systems in the world which is heavily
196 bus-based. Indeed, bus trips account for a significant share of total public transportation trips.

197
198 Table 1 shows the modal share breakdown of trips for 2008 and 2010. It can be seen that the car
199 is the most dominant mode of travel with its share on the increase. On the other hand, the bus is
200 the most dominant form of public transport and its share has remained more or less constant over

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

201 the period with a large increase seen in the use of the subway. It is notable also, that contrary to
 202 many world cities where the share of biking (see Murphy and Usher, 2015) and walking is
 203 increasing, the trend in Beijing is for a decline in the role of these modes.

204
 205

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

206 Source: BTRC, 2011.

207

208 Methodology

209

210 *Data origins and zonal system*

211 As the capital of China, Beijing has now over 20 million residents and is one of the most
 212 populous cities in the world. The land area of the Beijing metropolitan area is c.16,410 Km².
 213 Beijing Transport Public Transportation Company (BTRC) is the local transportation planning
 214 agency and is charged with collecting local travel survey data as well as developing and
 215 maintaining local travel demand models. Unlike its US counterpart, BTRC does not integrate
 216 data from the China Census Transportation Planning Packages into its models and, instead,
 217 assembles its travel demand model from data collected through separate surveys. Indeed, it is
 218 not easy to gain access to transportation data in China and acquiring data for research purposes
 219 requires special permission which is granted at the discretion of BTRC. Often, data that is
 220 acquired for research purposes is done so via personal connections to high-level individuals
 221 within these organisations as is the case with the data being utilised for this paper. The 2008
 222 smartcard data and the 2010 Beijing Household Survey data are the primary data used in this
 223 manuscript and have been provided by the Beijing Institute of City Planning (BICP). This data
 224 has not been utilised previously in other studies of Beijing’s transportation patterns.

225

226 In excess commuting studies, interzonal flow (in terms of trip volumes) and cost matrix (in terms
 227 of some measure of zonal separation such as distance, time etc.) data are required for the
 228 calculation of T_{min} and T_{max} . In the case of our study, we were able to acquire comparable data
 229 only for bus and car modes for 2008 and 2010 respectively. Due to institutional constraints, data
 230 hoarding and the difficulty of acquiring data for research purposes in China, it was not possible
 231 to get a complete public transport flow matrix broken down by bus and rail modes (c.f., Zhou,
 232 2012).

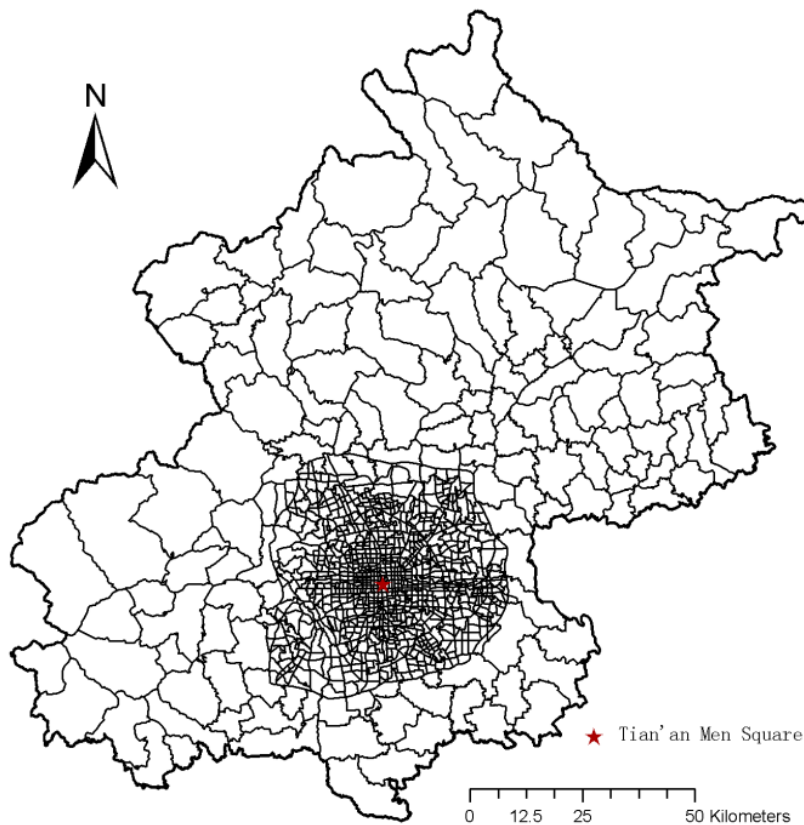
233

234 While we had bus data for 2008, we acquired car commuter data from the 2010 Beijing
 235 Household Travel Survey (BHTS) because this data was the closest available in chronology to
 236 the 2008 bus data. The reason for this is due to the fact that the Beijing authorities only conduct
 237 large-scale Household Travel Surveys in years ending with “0” or “5”. To protect personal

238 privacy, the data were aggregated on the basis of the local TAZs for 2010. However, there are
239 1911 TAZs for 2010 but only 1118 for 2008 (see Figure 1). On average, each TAZ in 2008 is
240 about 14 square kilometres but TAZ's tend to decline in size from the periphery to the core of the
241 city. The average size of TAZs in Beijing's core is comparable to or even smaller than that of the
242 TAZs or sub-divisions used in existing studies. For instance, in Small and Song (1992), the
243 3,341-square-kilometer Southern California Region was divided into 706 TAZs. In Murphy
244 (2009) and Murphy and Killen (2011), the Great Dublin Region consists of 463 sub-divisions
245 and covers 6,982 square kilometers.

246
247 Tian'an Men Square is also shown in Figure 1. Geometrically speaking, the square is not the
248 centroid of Beijing, but is widely thought of as the centre of the city. Venues of national
249 significance such as Zhong Nan Hai, the National Historical Museum, the Forbidden City, The
250 State Council and The People's Great Hall are all within a walking distance of the square and,
251 therefore, our analysis considers this to be the city centre.

252



253
254 **Figure 1: 1,118 TAZs in the 2008 Beijing zonal system**

255
256 *Allocating individuals to TAZs*

257 In order to make useful comparisons between the car and bus commuting trips, we needed to
258 convert either the car data to the 2008 TAZs or the bus data to the 2010 TAZs. Given that we had
259 a much large sample of bus commuters for 2008, we decided to do the former. When making the
260 conversion, we assumed the following. First, at the TAZ level, we assumed that car commuters

261 were evenly distributed across space and because we knew the area of each TAZ and a subarea
262 of the same TAZ, we were able use a percentage of the subarea to determine the number of car
263 commuters in that subarea. Second, we assumed that the ratio of the sample of car commuter to
264 all the car commuters in different TAZs was a constant (7%). Actually, this is similar to what
265 BHTS expects to achieve: a 5% response rate across TAZs. Third, we assumed that the
266 underlying mechanism (e.g. the gravity model) governing the spatial distribution of car
267 commuters was unchanged between 2008 and 2010. Fourth, we assumed that the jobs-housing
268 distribution of the car commuter sample was representative of the broader population of car
269 commuters. Using these assumptions, we were able to upscale the 2010 car commuter sample
270 (N=37,837) to 532,722 car commuters (approx.. 7% of daily car commuters).

271
272 More specifically, the procedures for the translation were as follows. First, we performed an
273 overlay analysis of the 2010 and 2008 TAZs in *TransCAD*, which generates 6,757 distinct
274 smaller TAZ's. These TAZ's have a one-to-one or one-to-many relation to the 2010 and 2008
275 TAZs. *TransCAD* automatically produces a relationship table of three sets of TAZs: their TAZ
276 IDs and the respective percentage of the 2010 and 2008 TAZ areas that fall into the smaller one.
277 Second, using the relation table, we disaggregated the 2010 sample into the smaller TAZ's with
278 the known area percentage and then aggregated the samples of the smaller TAZ's into the 2008
279 sample. Third, we scaled up the 2008 sample to represent the larger sample of daily car
280 commuters for the same year.

281
282 For the bus data, we utilised smartcard data of bus users which is a potentially rich source of
283 information; similar data has not been used previously in excess commuting studies. Since 2005,
284 over 90% of bus riders in Beijing have swiped an anonymous smart card when boarding and
285 alighting (for suburban routes) or when boarding (for inner-city routes) to pay for their fare. The
286 high rate of smart card usage among bus riders is largely due to a significant government subsidy
287 for smartcard users. Those users avail of 60% discounts on any routes in the local bus system;
288 the smartcards are also integrated with other services and can pay taxi, electricity and sewage
289 services that are offered by BMG and associated companies. In this manuscript, we assume that
290 the bus commuters we identified through the smartcard data are representative of all bus
291 commuters.

292
293 When cardholders use their smartcard to pay for bus services, the card reader installed on the bus
294 automatically generates the following information:

- 295 (a) Bus trip origin and destination stop (if the cardholder is on a suburban route) or bus trip
296 origin only (if the cardholder is on an inner-city route). For inner-city routes, the cardholder
297 only swipes his/her card when boarding the bus. In this case, we deduced the cardholder's
298 trip origin and destination based on all swipes during five consecutive weekdays. An origin
299 or destination and all bus stops within 500 meters of them that is associated with recurring
300 swipes were estimated as "home" and "workplace". This allowed home and workplace data
301 to be differentiated using the local parcel-level land use information. More technical details
302 can be found in Long et al (2012);
- 303 (b) Boarding and alighting time (if the holder is on a suburban route) or boarding time only (if
304 the holder is on an inner-city route);
- 305 (c) Unique card number and card type (student card or regular card).

306

307 The above information is instantly sent to a central server where it is stored. For this study, we
308 were granted access to a full week's historical data from the server administrator, which contains
309 77,976,010 bus trips of 8,549,072 non-distinct cardholder records between April 7 and April 13,
310 2008. Given that 95 per cent of bus users are smartcard holders (Long et al., 2012), the one
311 week sample is representative of all bus users in Beijing. To identify a cardholder's workplace,
312 we queried one-day data on a MS SQL Server and repeated the process for seven days based on
313 the following rules:

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

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

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

319 We also ensure that the land use associated with j is non-residential based on the local parcel-
320 level land use map.

321

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

323 (a) The cardholder already has an identified workplace;

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

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

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

329 In addition, to ensure that we singled out commuters solely by bus, we only selected cardholders
330 that had continuous bus swipes. That is, our study excludes multimodal public transport users (i.e.
331 bus and subway). It is possible to get a breakdown of the swipe card data by mode (subway and
332 bus) but unfortunately we were not permitted to access such information for this study. In total,
333 we ended up with 216,844 distinct cardholders/workers commuting solely by bus within the
334 study boundary (see Long et al., 2012 for more details). We then geocoded and aggregated
335 cardholders' home and workplace information by TAZ for 2008.

336

337 *Inferring a cost matrix*

338 As with numerous other studies (see Horner, 2002; O'Kelly and Lee, 2005), we used the
339 Euclidean distance between zone centroids as a measure of inter-zonal cost for both bus and car.
340 However, recent research by Shen et al. (2013) found that commuting routes between zonal units
341 in Beijing deviate significantly from straight-line distances. Indeed, Shen et al.'s work questions
342 the conventional assumptions that commuting is relatively stable and fixed. Nevertheless,
343 Murphy and Killen (2012) have pointed out that Euclidean distance is a useful proxy for
344 calculating EC and C_u in particular when compared with the results using network distance.
345 While Euclidean distance underestimates the actual distances travelled between zones, it
346 underestimates them roughly equally across all routes in the network implying that the measure
347 is a good proxy for measuring relative commuting cost between zonal units.

348 Moreover, for all trips (bus and car), intra-zonal travel distances were estimated by
349 assuming that each zonal unit is approximately circular in shape as has been undertaken in other
350 studies (see Frost et al., 1998). Also similar to other studies, we excluded those trips originating
351 and destined for locations outside the study boundary (see Frost et al., 1998; Horner, 2002;
352 Murphy, 2009).

353

354 *Formulations*

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

$$360 \quad \text{Min: } Z = \frac{1}{N} \sum_{i=1}^m \sum_{j=1}^n c_{ij} X_{ij} \quad (3)$$

$$361 \quad \text{s.t.} \quad \sum_{i=1}^n X_{ij} = D_j \quad \forall j = 1, \dots, m \quad (4)$$

$$362 \quad \sum_{j=1}^m X_{ij} = O_i \quad \forall i = 1, \dots, n \quad (5)$$

$$363 \quad X_{ij} \geq 0 \quad \forall i, j \quad (6)$$

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

372

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

$$375 \quad \text{Max } Z = \frac{1}{N} \sum_{i=1}^m \sum_{j=1}^n C_{ij} X_{ij} \quad (9)$$

376

377 **Results**

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

383 use arrangement for car users. The lower value of T_{\min} for bus users suggests that, on average,
384 users of that mode have easier access (in terms of commuting distance) to job opportunities than
385 car users. However, this greater juxtaposition between origins and destinations for bus users may
386 simply be a reflection of the fact that those commuters who cannot get easy access to their job
387 destination via the bus simply switch to the car (if possible); those who can access destination
388 opportunities relatively easily via the bus network continue with that mode for their commute.
389 Overall, these findings echo those of Wang and Chai (2009) and Zhao et al. (2011) which show
390 that Danwei is associated with a better jobs-housing balance and ultimately shorter commutes for
391 Beijing residents.

392

393 To some degree, this phenomenon might explain why the modal results for T_{\min} in Beijing are in
394 contrast to other cities where similar analysis has been undertaken. For example, the general
395 trend in the results are in contrast to those emerging for the case of Dublin, Ireland (see Murphy,
396 2009) where T_{\min} values were consistently lower for car users than for public transport users.
397 Murphy's (2009) public transport data included bus and train data rather than just bus data (as in
398 this study) but because train commutes tend to have longer average distances, the T_{\min} results
399 from Beijing would be even higher than at present if rail data were to be included. Thus, it is
400 likely that the results for T_{\min} would be higher if data on train trips were to be included and this is
401 a caveat associated with the results emerging from this study.

402 There is also another explanation as to why this trend is different in the case of Beijing
403 and it relates to differences in the overall urban spatial organisation of the city relative to Dublin.
404 Beijing is a much more monocentric city than Dublin (which is highly polycentric) and has
405 witnessed much less decentralisation of employment than not only Dublin but many western
406 cities in a more general sense. The decentralisation of employment functions allows car users, in
407 particular, to access job opportunities closer to residential locations beyond the central area
408 thereby reducing the value of T_{\min} to a considerably greater extent for users of that mode. The
409 fact that this has not happened to the same extent in Beijing suggests that the maintenance of a
410 monocentric city (and thereby a maintenance of a largely centralised employment and
411 decentralised residential structure) has not afforded car users the same opportunities to access job
412 opportunities closer to peripheral residential locations as has occurred in other world cities.
413 Moreover, if it was assumed that all workers in Beijing were to commute to the city centre (i.e.
414 Tian'anmen square) where most employment opportunities are located we found that the mean
415 commuting distance by car is considerably longer (27.7km) than by bus (14.8km). This supports
416 the previous assertion that car commuters tend to locate further from the central area
417 (Tian'anmen) whereas bus commuters locate closer to the centre. In policy terms, it may be
418 difficult to implement a zone-based jobs-housing balance in Beijing given the current orientation
419 towards market-based development. However, a corridor-based jobs-housing balance approach
420 would, perhaps, be most appropriate for Beijing because that would facilitate public transport to
421 a greater extent than a zone-based jobs-housing balance approach which tends to facilitate more
422 favourable commutes for car users to a greater extent. Indeed, the introduction of a BRT line and
423 the no. 6 metro line has already improved the jobs-housing balance along Beijing's west-east
424 axis.

425

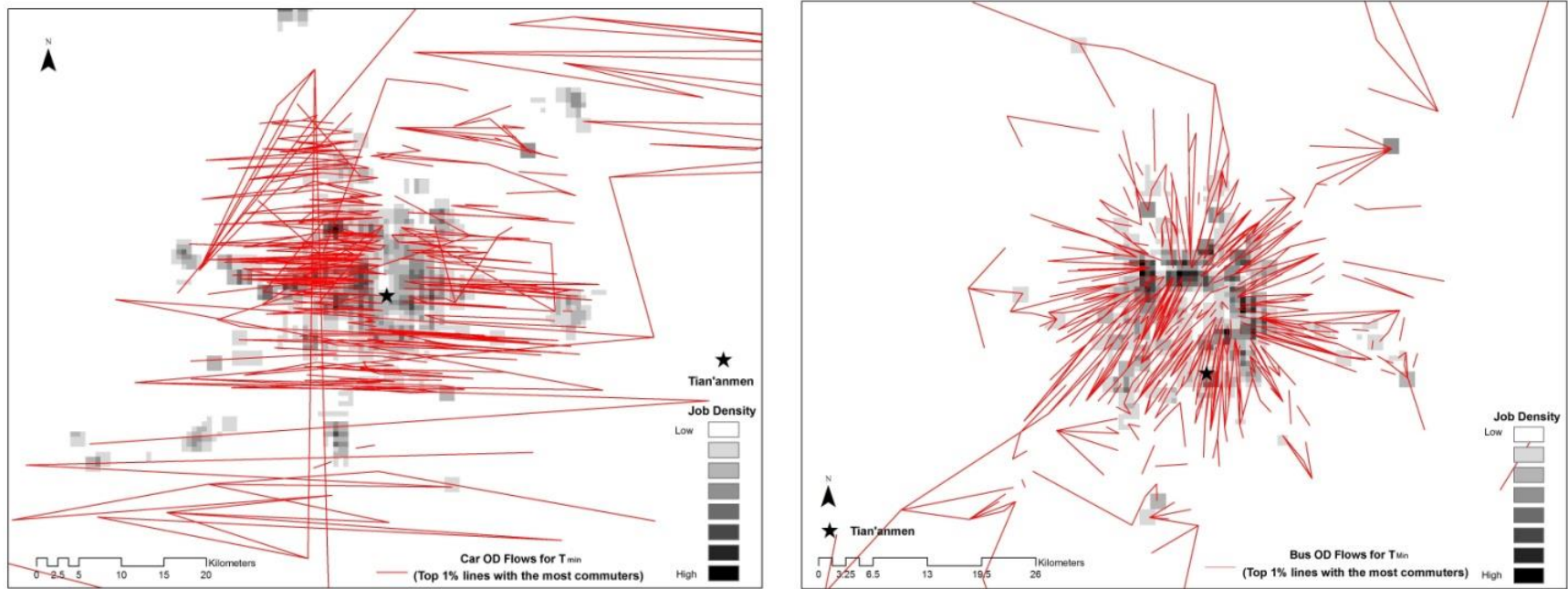


Figure 2. Top one per cent of origin-destination flows for the minimum solution (T_{\min}) by car and public transport

427

428 Figure 2 shows a graphical display of the top one per cent of OD flows associated with the
429 minimum solution (T_{\min}) for car and bus. In other words, it shows what the pattern of commutes
430 would look like in a perfect efficiency scenario where individuals were commuting, on average,
431 to the closest possible workplace. The results are interesting in that they demonstrate graphically
432 the difference in the complexity of origins and destinations associated with the two modes of
433 transport. For the car, origin and destination flows are much more dispersed and complex
434 whereas the bus flows are remarkably radial in nature and are oriented towards flows along
435 radial routes converging in the centre. For the car, they highlight that even under the perfect
436 efficiency assumptions of the minimum solution, origin and destination flows associated with the
437 existing distribution of car users are highly dispersed and more random in nature. This suggests
438 that in the specific case of Beijing, the primary role of the car is to accommodate more complex
439 trips that, in the main, involve more inter-suburban or cross-commuting trips not oriented
440 towards the centre.

441

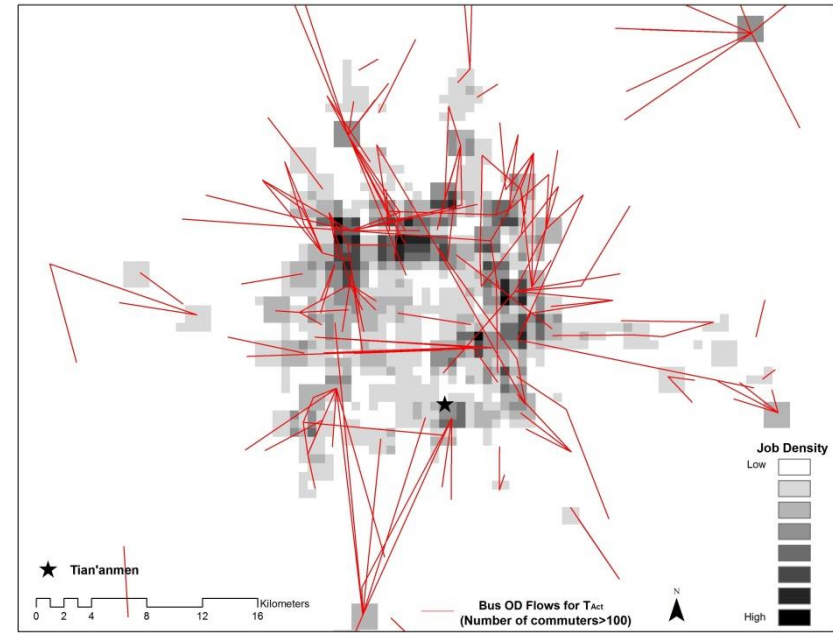
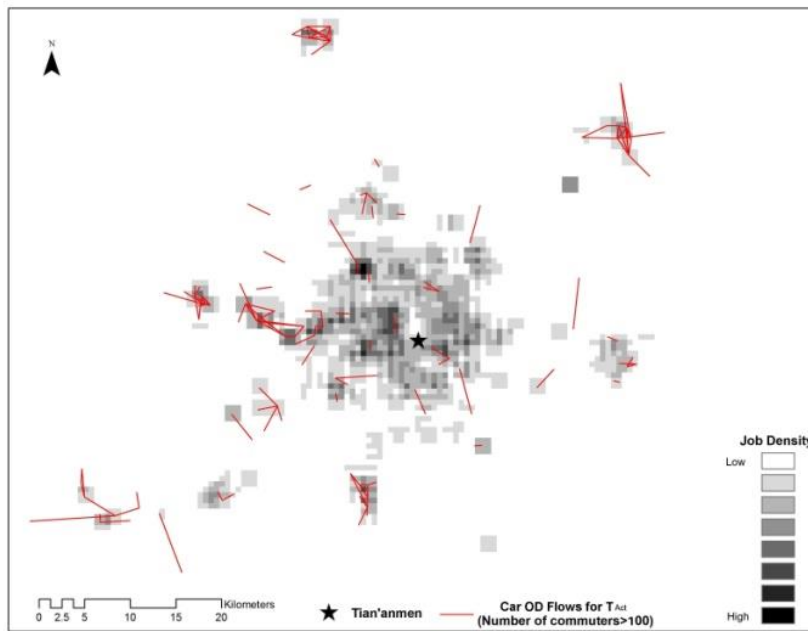
442 The results for T_{\max} are considerably higher for car users than for public transport users. This is
443 consistent with literature which has calculated these values by different mode (see Murphy,
444 2009). This demonstrates that, in the case of Beijing, the private transport network facilitates the
445 possibility of longer trips than those afforded by the bus network. Thus, individuals who have
446 longer commuting distances to their workplace are more likely to use the car over the bus than
447 for shorter journeys. In effect, the T_{\max} results for the bus (24.7 kms) show that individuals
448 commuting more than 24 kms to work simply cannot use the bus network and must transfer to
449 the car in order to reach their destination. This result has significant policy implications for
450 Beijing because it suggests that any moves towards decentralisation of employment would
451 undermine the role of the bus network in serving commuting trips and would likely lead to
452 considerable modal shift towards the car.

453

454 The foregoing result is also highlighted by the respective travel ranges for the two modes (Table
455 3). They show that the commuting range for car users is 9.4 kms greater than that for bus users.
456 This reinforces the previous point emerging from the T_{\max} results and ultimately highlights the
457 possibility for car users to live further from employment destinations than bus users. Thus, the
458 results suggest, quite concretely, that the car facilitates a greater separation between home and
459 work land uses than the bus. Moreover, it suggests that the greater intermixing of jobs-housing
460 associated with the bus (i.e. T_{\min}) has not facilitated an improvement in the range of commuting
461 possibilities for bus users².

² In similar studies, a lower T_{\min} normally translates into a higher T_{\max} but this is not the case for our results.

462



463 **Figure 3: Origin-destination flows for the actual pattern of trip making (T_{Act}) by car and public transport**

464

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

474
475 All of these assertions are consistent with the observed values of T_{act} . Given the lower values of
476 T_{min} for bus users over car users, one would expect T_{act} to be lower for that mode. The results
477 show that this is indeed the case (Table 3). T_{act} for bus users (8.2 kms) is 3 kms lower on average
478 than for car users. Indeed, T_{min} is 40.0% larger for car users than for bus users and similarly T_{act}
479 is 36.6% larger for car users than for bus users. This implies a close correlation between T_{min} and
480 T_{act} indicating that the greater intermixing of jobs-housing functions associated with bus users
481 allows individuals who use that mode to reduce their observed commuting costs to a greater
482 extent than car users.

483
484 The results for the commuting efficiency indicator excess commuting (EC) also reinforce this
485 relationship between T_{min} and T_{act} for bus and car users in that they show that excess commuting
486 is similar for both modes. However, despite bus users having a lower T_{min} and T_{act} , they show
487 that excess commuting is slightly higher for bus users (69.5%) than for car users (68.8%). This
488 implies that relative to the existing distribution of home-work land use arrangements for each
489 mode (i.e. T_{min}), there is little difference in the commuting efficiency between modes as
490 evidenced by the EC statistic. For the case of Dublin, EC for public and private transport was
491 59.8% and 78.4% respectively. It is clear then that excess commuting for bus in Beijing is
492 considerably higher than the corresponding results for public transport in Dublin; for car they are
493 considerable lower. However, when compared with other Chinese cities, Beijing exhibits
494 relatively high levels of excess commuting. Liu et al's (2008) 2005 analysis of excess
495 commuting in Guangzhou found (for all trips) only 44.7% of commuting to be excessive. While
496 they used simulated data and relatively small samples which might undermine the strength of the
497 results, the difference, nevertheless, is remarkably large and implies that commuting patterns in
498 Beijing are more inefficient than those in Guangzhou.

499
500 Turning to the C_u statistic which highlights the extent to which a city's existing commuting
501 capacity is being utilised, it is clear that the differences are also only marginal between car and
502 bus modes (Table 3). However, the results show that the C_u values are slightly lower for car

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

503 users than for bus users implying that car users consume less overall of their available
 504 commuting resources than bus users, albeit only marginally. This general trend is similar to the
 505 results emerging from Murphy's (2009) research on Dublin. However, the magnitude of the
 506 difference in the modal results is quite different between Dublin and Beijing. In Dublin the
 507 difference in car and public transport C_u values was almost 7.0% whereas in Beijing the
 508 difference is only 1.4%. Taken together, the results for EC and C_u for Beijing highlight that
 509 within the context of the existing distribution of jobs and housing functions, bus use is associated
 510 with slightly more inefficient commuting patterns than car use. However, this must be viewed
 511 within the context of the T_{min} and T_{act} values which demonstrate a better jobs-housing balance for
 512 bus users and also that bus users commute, on average, 3 kms less per trip than car users in
 513 Beijing. Thus, while actual commuting is more inefficient for bus users relative to the
 514 arrangement of land uses compared to car users, bus users do still take, on average, shorter trips
 515 in absolute terms than car users. Of course, the implication here is not that we should encourage
 516 more car travel which has a whole range of additional negative sustainability implications
 517 beyond EC an C_u measures alone but that policymakers should attempt to put in place
 518 arrangements to ensure that travelling along the bus network is more efficient than on the car
 519 network so that commuting via public transport will be encouraged over the car.

520 **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%

521

522 **Conclusions**

523 Contemporary Chinese cities are highly dynamic. The rapidity of urban transformation right
 524 across the country is quite remarkable with transport infrastructure and land use functions
 525 witnessing rapid change over the last two decades in particular. In Beijing for instance, the
 526 subway network length has more than doubled from 184 kms to 465 kms between 2008 and 2013
 527 alone. Thus, the geography of transport patterns is changing rapidly over much shorter periods of
 528 time than we have traditionally become accustomed to. This means that for excess commuting
 529 and related transport studies dynamic input data is needed to more quickly assess the nature of
 530 change. Indeed, Shen et al. (2013) have demonstrated that commuting in Beijing is highly
 531 complex with many people using both the bus and car on various weekdays because of the
 532 existing car-use restriction law. In this sense then, the commute mode being utilised by urban
 533 residents is not as fixed as might be the case in other jurisdictions. While our study only provides
 534 a snapshot of transport patterns in a Chinese city, our approach which uses smartcard data as
 535 input for analysing the efficiency of trip patterns along the bus network has the potential to be a
 536 much more dynamic source of data for input into transport studies than traditional survey data.
 537 This study has demonstrated how this data can be manipulated and utilised for assessing very
 538 recent public transport patterns and therefore has the potential to incorporate more dynamic
 539 analysis of a city's transport patterns as technology moves increasingly towards the use of 'big
 540 data' for aiding urban planning (see Kitchin, 2014). However, it is important to note that our

541 analysis only incorporates bus data for public transport and because of this a significant
542 proportion of commuting is missed within our analysis. Thus, our results and associated
543 conclusions are limited in this regard and while the absolute values are likely to change if other
544 public transport trips were included it is unlikely that the overall trend would change
545 significantly given that subway use accounts for only ten per cent of overall commuting in
546 Beijing. Nevertheless, it would be useful for future research to incorporate all public transport
547 trips in a similar analysis with a view to determining how the current results might change.

548

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

560

561 The results also highlight that Beijing is a considerably more monocentric city than many
562 western cities. The upshot of this is that modal shifts from bus to car does not confer huge
563 efficiency benefits upon car users relative to bus users due to the fact that employment has not
564 been decentralised to anywhere near the same extent as in many western cities and this is
565 evidenced by the relative T_{\min} values for both modes. Where employment is decentralised, it
566 clearly confers significant additional benefits on car users relative to public transport users (see
567 Murphy, 2012). The fact that Beijing has not gone down this route and has maintained a more
568 monocentric-like urban structure has actually allowed the bus to increase its modal share in
569 recent years and this is contrary to what has happened in most western cities that have pursued
570 decentralisation strategies via polycentric urban models. In terms of efficiency indicators such as
571 excess commuting and capacity utilisation, our study shows that Beijing's excess commuting is
572 high for bus and low for car relative to other cities that have assessed these indicators by mode.
573 Quite why this is the case would require more detailed research with a temporal component to
574 map changes in commuting efficiency onto changes in land use arrangements.

575

576 More broadly, the generally lower values of T_{\min} for Beijing relative to other cities of a similar
577 size, suggests that the legacy/impacts of the Danwei phenomenon persists in Chinese cities.
578 However, as shown in other studies, the dismantlement of Danwei, rapidly changing residential
579 preferences, broader motorisation and suburbanisation can undermine the positive efficiency
580 impacts of Danwei. In our view, there are lots of uncertainties in terms of the phenomena's
581 impacts on jobs-housing balance and commuting patterns. However, this also means that rich

582 opportunities exist for further research on the issue which, to some extent at least, our study
583 provides insights into even if they are somewhat indirect.

584

585 Our graphical maps of key origin-destination flows are an innovative approach to demonstrating
586 flows of actual travel patterns as well as those associated with the minimum solution of the TPLP.
587 In this sense they are a useful addition to aid with the interpretation of results emerging via the
588 excess commuting framework. They demonstrate spatial variations in flow patterns associated
589 with T_{\min} and T_{act} and provide useful insights into the geography of transport flows associated
590 with these solutions which are otherwise lost in previous studies of the same nature.

591

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

603

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