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Bus Commuters' Jobs-housing balance in Beijing:

An exploration using large-scale synthesized smart card data

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1

3 **ABSTRACT**
4

5 Existing jobs-housing studies have rarely (a) used smart card data provided by the public transportation
6 agency and (b) focused on commuters of bus mode. In this study, massive smart card data were used to
7 estimate 216,844 bus commuters' workplace and residence locations in Beijing. This enables a jobs-
8 housing study of bus commuters in the metropolis with a much larger sample size than most existing
9 studies. This study indicates that Beijing's bus commuters (a) have a shorter actual required commuting
10 (ARC) and minimum required commuting (MRC) than commuters in four other auto-dependent western
11 cities with comparable population and/or land use sizes; (b) have a longer ARC and MRC than
12 commuters of all modes in Guangzhou, another metropolis in South China that is half of the size of
13 Beijing. Using local expert consultations, field surveys and information provided by on-line housing
14 search engines to supplement smart card data, this study has established five land-use prototypes of jobs-
15 housing imbalance and has proposed countermeasures to address the imbalance.

INTRODUCTION

Car dependence, traffic congestion, long commute and associated air pollution and Greenhouse Gas

(GHG) emissions have become notable phenomena that characterize many populous cities. Planners,

policy analysts and public agencies have advocated or even incentivized jobs-housing balance as a way to

reduce peak-period travel and optimize commutes, in particular, commutes by driving alone (1-6). Not

surprisingly, different factors contribute to jobs-housing balance or imbalance among different social

groups in different locales. In the United States (US), for instance, suburbanization of jobs, housing

segregation, inefficient public transportation services, race and "automobile mismatch" may all more or

less contribute to jobs-housing imbalance (or spatial mismatch) for the low-income minority or new

immigrants (7-10). In China, the disappearance of working unit ("Danwei") compounds and the

introduction of the commercial housing market led to increasing jobs-housing imbalance of workers in

large cities such as Beijing and Guangzhou (11-15).

There has been a large body of literature on jobs-housing balance and related topics such as excessive

commute and commute efficiency. Horner (16) and Ma and Banister (17), for instance, have provided a

good review of such literature in the western context, respectively. Many existing studies of jobs-housing

balance have dealt with total commuting flow and have treated workers and job/workplace as

homogeneous (18). This is especially true when we look at two seminal manuscripts (19, 20) and articles

that attempt to extend them in different contexts (4, 21-23). To increase policy relevance of their research,

an increased number of authors have paid attention to worker, workplace and/or employer heterogeneity.

Crane (24), Gordon et al. (25) and Kim (26), for instance, all show that employees can be owners or

renters and this status affects their commuting distance, that is, jobs-housing balance. Though not directly

dealing with jobs-housing, Kwan (27) indicate that individual and household activity schedules and time-

budgets are critically important too in terms of influencing one's activity sphere. Giuliano and Small (28)

1   study jobs-housing balance among workers of different occupations, finding that service workers have the

2   lowest average commutes.

3

4   However, few authors have looked at jobs-housing balance of commuters by mode, that is, mode choice

5   heterogeneity. This may be because of three reasons. **First,** conducting and processing surveys to get

6   reliable information about individual-level jobs-housing balance and mode choice has not been cheap and

7   has become increasingly expensive. In the US, for instance, the cost to get the information was

8    $195/household in 1995 and was $411 in 2001[1]. **Second,** driving is the dominant commute mode in most

9   developed countries and thus comparatively more attention has been given to jobs-housing balance of

10   driving commuters in these countries, where most relevant studies have been conducted. **Third,** despite

11   that we know commuters of different mode choices could face different degree of jobs-housing imbalance

12   (e.g., see (7)), little has been done on causes, implications and cures of the differences. In developing

13   countries such as China, nevertheless, the study of jobs-housing balance of bus commuters is still quite

14   relevant. There are a significant percentage of residents or commuters by bus and there are millions of

15   them, even in leading cities there. In Beijing, for instance, over five millions or 28% of the residents still

16   commuted by bus as of 2010[2].

17

18   Given the above, there is a need to separately study the jobs-housing balance of bus commuters in

19   developing countries. Using smart card data processed by Beijing Institute of City Planning, this

20   manuscript/study investigates the character of jobs-housing balance of bus commuters in Beijing.

21   Adopting the concepts of excessive commute, minimum/maximum required commutes and commute

22   efficiency, this study estimates the amount of excessive commute of these commuters and how efficient

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[1] Cost based on a letter from Committee to Review the Bureau of Transportation Statistics' Survey Programs to Ashisen Sen, US Bureau of Transportation Statistics on June 18, 2002, which is available at: http://onlinepubs.trb.org/onlinepubs/reports/nhts.pdf.

[2] Based on 2011 Annual Report of Beijing's Transportation Development (In Chinese, internally circulated report), Beijing Transportation Research Center.

their commute is. Also, this study compares its findings with those in existing studies whenever possible in order to expand our knowledge about jobs-housing balance and relevant topics. This study differs from existing ones and possibly contributes to the research on jobs-housing in these dimensions: (a) It specifically deals with bus commuters, a subgroup of the general commuter that has rarely been studied so far; (b) It uses commuter data that are of much greater sample size than those in most existing studies----there are 216,884 samples in this study; (c) It explores a new way to synthesize widely available smart card data in the public transportation sector and other supplementary data and information publicly available to establish land-use prototypes of jobs-housing imbalance so as to propose better countermeasures.

This manuscript is organized as follows. Next section (Section 2) is a survey of relevant literature. Section 3 provides an overview of the case city and describes how the 216,884 samples were extracted from the smart card data. Section 4 empirically estimates excessive commute, minimum/maximum required commutes and commute efficiency of the samples. Section 5 discusses the findings based on the empirical evidence and proposes prototypes of areas suffering severe jobs-housing imbalance in Beijing. Section 6 concludes and discusses directions of further studies.

RELEVANT LITERATURE

Jobs-housing balance describes the relationship of the total numbers of jobs and housing units within a given geographical area or within a given travel distance or travel time (3, 4, 29, 30). Under the strong assumptions that all jobs, workers and housing units are homogeneous and workers can switch jobs or housing at little or no cost, authors show that there exists a Minimum Required Commute (MRC) for all

1   workers (19, 20). But the Actual Required Commute (ARC) for all workers is always bigger than MRC.

2   The differences between MRC and ARC are called wasteful commute (19) or excessive commute (17, 18,

3   23, 31-41).

4

5   Based on the concepts of ARC and MRC, Horner (23) proposes a way to evaluate the commute efficiency

6   of different cities. He points out that in addition to MRC, there exists the maximum required commute

7   (MaxRC). Employing the following two ratios, one can best compare commute efficiency or jobs/housing

8   balance across cities:

9

10 $E=\left(\frac{ARC-MRC}{ARC}\right)100$ (1)

11

12 $C_u=\left(\frac{ARC-MRC}{MaxRC-ARC}\right)100$ (2),

13

14 where E shows how much excess commute there is or how good jobs/housing balance is in a city, C_u

15 reflects how much "commute potential" of a city has been used. The smaller C_u is, the more efficient the

16 commute or the better jobs/housing balance is.

17

18 Using the 1990 US census data, Horner (23) compares the commute efficiency of 26 US cities. Like most

19 existing studies highlighted in (17). Horner's comparisons do not differentiate commuters by mode choice.

20 Thus, one cannot conclude from his studies that whether bus commuters' jobs/housing balance is better or

21 worse than other commuters. But when mode choice of commuters is considered, there tends to be more

22 relevant insights. Levinson (42), for instance, finds that accessibility to jobs and housing has a negative

23 relationship with distance, and that transit commuters appear to have higher accessibility than automobile

24 users. In another study, Cervero (43) finds that low density, single use and non-integrated features of

25 many US suburban employment centers (SECs) contribute to auto dependence. The emergence of SECs

with high densities, rich mixtures of land use and nearby affordable housing (that is, better jobs-housing balance) would increase public transit efficiency and usage as well as mitigate congestion over the long run. Cervero and Duncan (44) and Kockelman (45) use micro-data from travel diaries, regressing individual or household vehicle miles traveled (VMT) on land use measures (including jobs-housing balance metrics) plus variables that controlled for household income and survey respondent gender, age, and ethnicity among other demographic characteristics. Their studies are more sophisticated than studies that used data aggregated to census tracts or other geographic areas (e.g. 23, 30, 46). They show how jobs-housing imbalance could partially contribute to auto dependence and higher VMT. Largely built on the above work and many others, Horner and Mefford (7) develop a conceptual approach synthesizing research on spatial mismatch and jobs–housing balance, including disaggregation studies of the phenomena by mode of transportation, within the broader excess commute framework. Using residential and workplace location data from Atlanta, they show that (a) minority's home-work alternatives (after controlling mode of travel) are more spatially constrained; (b) race and mode choice should be simultaneously considered when studying jobs-housing balance. In a recent study, Murphy (38) specifically studies the extent of mode-based excess commuting in Dublin, Ireland. He finds that excess commute is considerably greater for drivers. In other words, there is greater commute inefficiency and worse jobs-housing balance associated with driving.

In addition to the above studies related to jobs-housing balance in the western context, there are also parallel studies in the Chinese context. Based on travel survey data of a small sample of workers (n≤ 750) in Beijing, Wang and Chai (11) and Zhao et al. (14) find that:

(a) The traditional employer-provided housing system in China contributed to a better jobs-housing balance and a shorter commute;

1   (b) The marketization of housing supply in China decreased jobs-housing balance and lengthened workers'

2   commute.

3

4   Largely due to urban expansion and suburbanization of affordable housing, all commuters and commuters

5   from affordable housing projects also see an increase in their commuting distance in selected cities such

6   as Beijing (15, 47-51). But again, few studies about jobs-housing balance in the Chinese context have

7   focused on bus commuters. One of the few such studies is (47), which focuses on jobs-housing balance in

8   two affordable housing projects in Beijing and found that bus commuters' commuting time was greater

9   than that of auto commuters.

10

11

12   **THE CASE CITY AND THE DATA**

13   As the capital of China, Beijing now has over 20 million residents and is becoming one of the most

14   populous cities in the world. The land size of Beijing metropolitan area is 16, 410 km^2, making it one of

15   the biggest in China. Beijing Public Transportation Company, a state-owned company provides public

16   bus services in the metropolitan area. As of 2011, the company has 28, 343 buses on 948 bus routes with

17   a total length of 187,500 km. In 2011 alone, these buses produced vehicle kilometers traveled of 1.7

18   billion and transported total passenger of 4.9 billion[3]. As of 2005, over 90% of bus riders in Beijing

19   swiped an anonymous smart card when boarding and alighting (for suburb routes) or when boarding (for

20   inner-city route) to pay for their fare. The swipes automatically generate the following information of

21   cardholders:

22   (a) Bus trip origin and/or destination information;

23   (b) Boarding and/or alighting time;

---

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

1   (c) Unique card number and card type (student card at a discount vs. regular card);

2

3   This information (a) to (c) is instantly sent to and is stored at a central server. For this study, we

4   requested a whole week's data from the server administrator. The data eventually provided to us contain

5   77,976,010 bus trips of 8,549,072 non-distinct cardholder records between April 7 and April 13, 2008.

6   To identify a cardholder's workplace, we queried one-day data on a MS SQL Server and repeated the

7   work for seven days based on these rules:

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

9   (b) $D_j>=6$ hours, where D_k is the duration that a cardholder stays at place j, which is associated with all

10   bus stops within 500 meters of one another;

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

12   The most frequent identified workplace of a cardholder in seven days will be defined as the final

13   workplace of the cardholder in this study.

14

15   Similarly, we deduced from the data queries that a place would be a cardholder's home if the data meet

16   these conditions:

17   (a) The cardholder has an identified workplace;

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

19   (c) $D_h>=6$ hours, where D_k is the duration that a cardholder stays at place h, which is associated with all

20   bus stops within 500 meters of on another;

21   (d) $F_h >= F_j$, where F_h is the first most frequent place a cardholder starts a bus trip of a day within the

22   week, F_j is the trip frequency to or from j that the cardholder has.

23

1   Based on the above rules or conditions, we successfully found that there were 216,844 distinct

2   cardholders/workers commuting by bus in Beijing[4]. We then geocoded and aggregated cardholders' home

3   and workplace by traffic analysis zone (TAZ). In Beijing, following conventional rules about defining

4   TAZ boundaries, local planning agency divides the metropolitan area into 1,118 TAZs. Figure 1 is a map

5   of these TAZs and Tian'an Men Square, the agreed-upon center of Beijing.

6
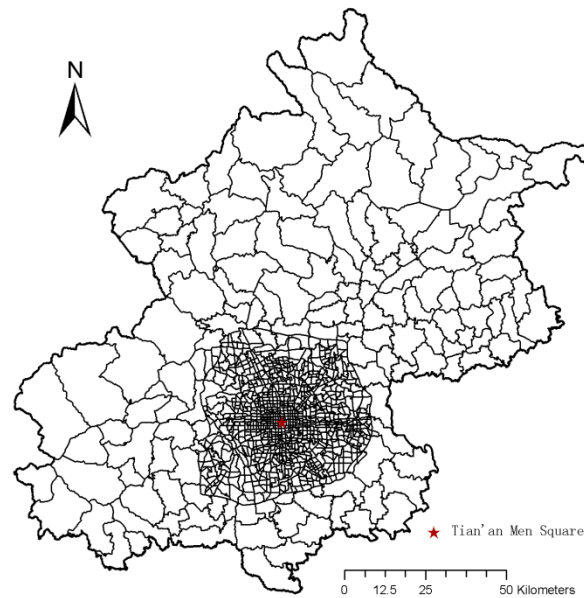
7

8   **FIGURE** 1: 1,118 TAZs in Beijing

9

10 In the end, for the 216,844 cardholders/workers, they reside in 729 distinct TAZs and work at 752 distinct

11 TAZs. Based on this information, we constructed the matrices of the commuting trips (M_t) as well as

12 journey-to-work distances (M_d) in support of this study. To be consistent with the distances used in

13 existing studies so that we can make apple-to-apple comparisons later on, the distances in M_d were linear

14 distances between centroids of TAZs for trips between two different TAZs. For trips within the same

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[4] Technical details about how we obtained the data can be found in Long Y, Thill J-C, 2012, "Combining smart card data, household travel survey and land use pattern for identifying housing-jobs relationships in Beijing" Working Paper, Beijing Institute of City Planning.

1   TAZ, the distance equals R_i, where $R_i = \sqrt{A_i/\pi}$, A_i is the area of TAZ_i. A portion of M_t and M_d is

2   visualized in Table 1.

3   **TABLE** 1: A Portion of M_t and M_d

4   (a) M_t

TAZ_h	TAZ_j						
	1	**2**	**3**	**4**	**5**		
1	120	0	0	0		changed to real values	
2	80	1	0	0	0	…	…
3	10	0	0	0	0	…	…
4	3	0	7	0	0	…	…
…	…	…	…	…	…	…	…
729	…	…	…	…	…	…	…

6   (b) M_d

TAZ_h	TAZ_j					changed to real values	
	1	**2**	**3**	**4**	**5**	…	
1	0.47	1.53	1.87	2.48	2.92	…	…
2	1.53	0.79	0.95	1.85	1.92	…	…
3	1.87	0.95	0.43	0.22	1.08	…	…
4	2.92	1.92	1.08	0.66	1.02	…	…
…	…	…	…	…	…	…	…
729	…	…	…	…	…	…	…

9   **EMPIRICAL ANALYSIS**

10   **ARC of the commuters**

11   We used the following formula to get the ARC of the 216,844 bus commuters in Beijing:

12   $ARC = \sum_h \sum_j \frac{t_{hj*}d_{hj}}{T}$,where

13   t_{hj} shows the number of commuters from TAZ_h (home) to TAZ_j (workplace);

14   d_{hj} is the distance between TAZ_h and TAZ_j;

15   T is the total number of commuters.

1

MRC and MaxRC of the commuters

For the MRC and MaxRC calculations, we employed the standard linear programming method. The

calculations equal to solving the optimization problems as follows,

$$\min \frac{1}{T} * (\sum_h \sum_j t_{hj} * d_{hj}) \text{ or } \max \frac{1}{T} * (\sum_h \sum_j t_{hj} * d_{hj})$$

Subject to

$\sum_j t_{hj} = O_h,$

$\sum_h t_{hj} = D_j,$ and

$t_{hj} >= 0,$ where

O_h is the total number of commuters living in $TAZ_h,$

O_j is the total number of commuters working at $TAZ_j.$

E and C_u

After getting ARC, MRC and MaxRC, E and C_u were calculated using equations (1) and (2).

Results

Table 2 below presents the ARC, MRC and MaxRC, E and C_u of Beijing bus commuters as well as

relevant results we identified from selected existing studies.

TABLE 2: ARC, MRC and MaxRC, E and/or C_u of Beijing and Other Cities

Study/Survey	Mode, year	Sample size (City, if not Beijing)	ARC (km)	ARC (min)	MRC (km)	MaxRC (km)	E	C_u
This study	Bus, 2008	216,844	8.1	36.0****	3.0	37.3	64	17
The 2005 Survey*	Bus, 2005	6,651	8.4	40.5	-	-	-	-
The 2010 Survey*	Bus, 2010	9,778	-	60.3	-	-	-	-
Liu and Wang (52)	Bus, 2007	307	-	46.3	-	-	-	-
Wang and Chai (11)	Bus, 2001	227	-	55.1	-	-	-	-
Zhao et al. (14)	Bus and rail rapid system, 2001	220	-	52.4	-	-	-	-
Liu et al. (15)	All, 2001	1,500(Guangzhou)	4.5	-	1.9	-	58	-
	All, 2005	1,500(Guangzhou)	5.0	-	2.7	-	44	-
Horner (23)	All, 1990	n/a (26 US cities)	6.7~16.8	-	3.0~7.8	10.1~44.4	48~67	17~48
Horner (7)	Non-Hispanic white, 1990 - driving alone	n/a (Atlanta)	-	-	9.8	43.6	-	-
	Non-Hispanic white, 1990-bus		-		5.9	27.5	-	-
	Non-Hispanic black,1990-driving alone		-	-	7.7	30.2	-	-
	Non-Hispanic black, 1990-bus		-	-	6.0	18.8	-	-
	Non-Hispanic, other,1990-driving alone		-	-	6.2	35.1	-	-
	Non-Hispanic, other,1990 -bus		-	-	5.8	24.7	-	-
	Hispanic white, 1990-driving alone		-	-	7.2	35.3	-	-
	Hispanic white		-	-	6.2	21.7	-	-
Cropper et al. (53)	All, 1...	(Baltimore)	15.4	-	6.5	-	58	-
Kim (34)	All, 1991	782** (Los Angeles)	24.6	-	16.5	-	33	-
Frost et al. (22)	All, 1991	n/a (London)	13.3***	-	10.8***	-	19	-
Bulung et al. (31)	All, 1990	61,453***(Toronto)	11.4	-	4.0	-	65	-

[annotation: Misspelled — pointing to "Bulung et al. (31)"]

*Citywide travel survey conducted by Beijing Municipal Government.

**Households, not workers.

***Including inward commuters from outside the limits of the City of London.

****Based on the smart card data, in-bus time only.

It can be seen from Table 2 that:

First, thanks to the processed smart card data, this study was able to have the biggest sample size among all similar studies identified. Bus commuters in Beijing have a shorter ARC and/or MRC than commuters of all modes in four other cities (Los Angeles, Atlanta, London and Toronto) of comparable land size and/or population size. What's a little surprising is that, the ARC/MRC of bus commuters in Beijing is larger than those of all commuters in Guangzhou, another populous city in South China. But given that the land size of Guangzhou (about 7,400 km^2) is only about half of that of Beijing, this is probably understandable.

Second, if we disregard the time and sample selection issues, in-vehicle commuting time based on the processed smart card data is smaller than total commuting time from travel surveys of bus commuters in Beijing across the six studies/surveys highlighted in the table. This indicates that (a) smart card data do provide accurate estimates of in-vehicle commuting time, and (b) the in-vehicle commuting time could be used to cross-check the reliability of s   me given by travel surveys. For instance, the latter should at least be greater than the former since most would have to spend time finishing home-bus stop and bus stop-job trips.

Third, the percentage of excess/wasteful commute for bus commuters in Beijing (64%) is notably higher than most the other cities. The percentage of excess/wasteful commute for bus commuters in Beijing is comparable to that for all commuters in Philadelphia (67%, reported in (23)) and in Toronto (65%). Domestically, the percentage of excess/wasteful commute that   ng is larger than those of commuters of all modes in Guangzhou. All the above comparisons between Beijing and other cities, as a whole, indicate that bus commuters in Beijing have rather noticeable jobs-housing imbalance.

1 Fourth, the C_u value of Beijing bus commuters is the lowest among all values presented in the table. This

2 indicates that the jobs-housing imbalance of bus commuters in Beijing could potentially get worse. The

3 commuting time differences between two local surveys in 2005 and in 2010 have notably "encroached"

4 this potential.

5

6

7 **DISCUSSIONS**

8 **Commute Efficiency for Bus Commuters**

9 The above analyses have showed that bus commuters in Beijing face quite significant amount of

10 excess/wasteful commute. Two natural questions one could have after getting this finding are:

11 (a) What caused it?

12 (b) What we can do about it?

13 With only the smart card data, it is impossible for us to provide convincing answers to these questions.

14 But extra processing of the smart card data could still offer some clues. Based on M_d and M_t, two

15 matrices about trips and commuting distances between TAZs, specifically, we mapped out mean

16 commuting distances(MCDs) by TAZs within about 30 kilometers from Tian'an Men Square (Figure 2).
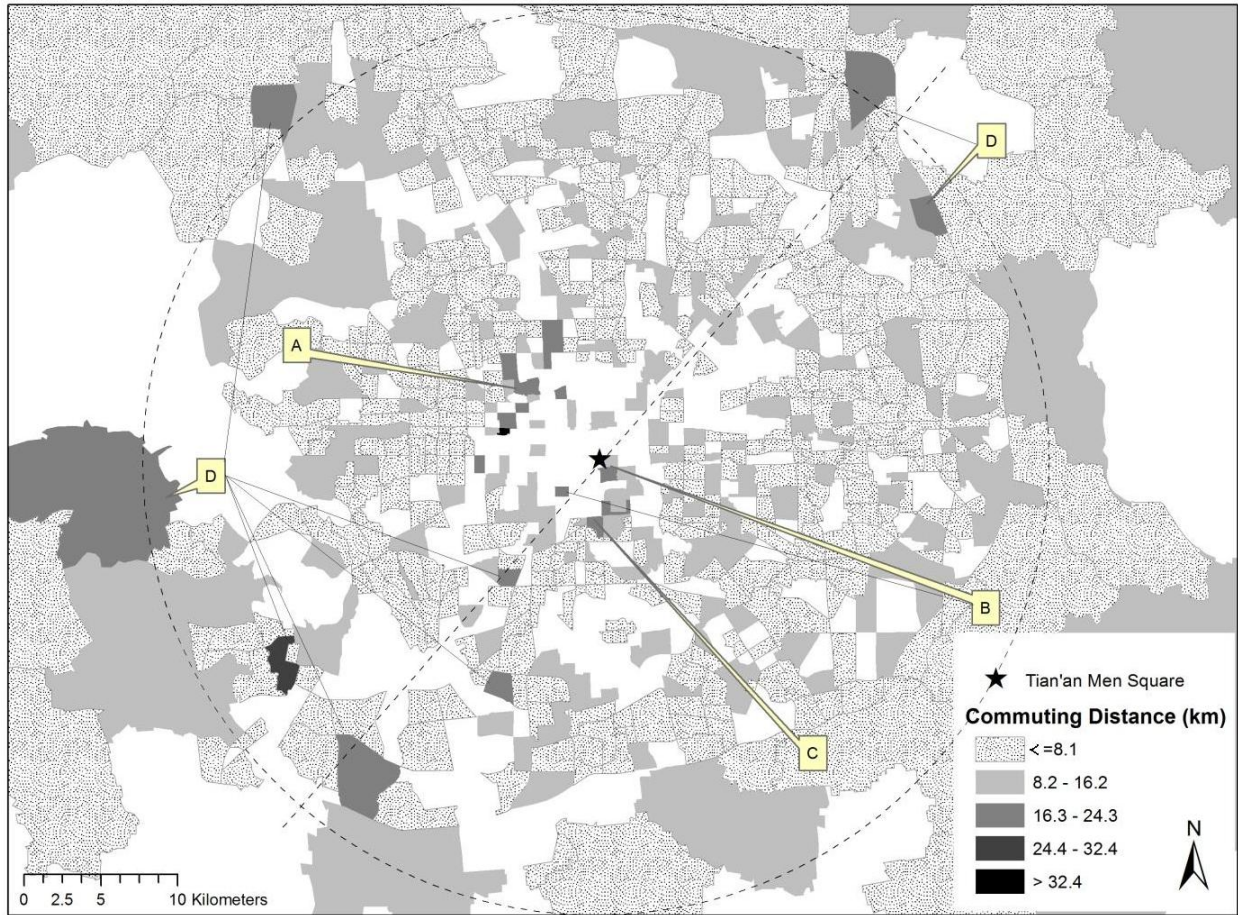
17
18
19
20
21
22
23

1   **FIGURE** 2: Mean Commuting Distances by TAZ in Beijing*

2

3   * TAZs with no-data are not mapped.

4

5   In the figure, TAZs where MCD is smaller or equals to the metropolis' ARC distance (8.1 km) is shown

6   in snowfield-ice polygons. Origin TAZs where MCD is bigger than 8.1 km are shown in graduated black

7   colors, the darker the colors, the longer distances are. If we assume that TAZs where the distance is

8   smaller or equals to 8.1 km have achieved jobs-housing balance then these balanced TAZs are quite

9   evenly distributed across the space and so as the imbalanced TAZs. This indicates that unlike the

10   conventional perception among local residents, one's residential location's distance to the center (DtC)

11   (Tian'an Men Square) has little to do [misspelled, explained more] ing distance/time. To validate, we

12   investigated the relationship between MCDs by TAZ (M=8.1, SD=3.8) and DtC by TAZ (M=20.4,

13   SD=15.8) using Person correlation coefficient. Analyses were performed to ensure no violation of

1   assumptions of normality and linearity. The results indicate that there was an only weak positive

2   correlation between MCD and DtC (r=0.04, *p*=0.25, *n*=729). Based on the above analysis, we concluded

3   that space (or more specifically DtC) does not play a significant role in determining bus commuters' jobs-

4   housing balance or imbalance.

5

6   The areas (TAZs) with the most severe jobs-housing imbalance, however, tend to follow these spatial

7   patterns:

8   (a) Clustering around in areas where is about 7 km northwest to Tian'an Men Square;

9   (b) Scattering near to each other in the west, southwest or southwest to Tian'an Men Square;

10   (c) Scattering around a half-circle with its center as the Tian'an Men Square and with a radius of 30

11   km (See Figure 2, the dash lines show the half-circle).

12 To better investigate the physical environment and community characteristics of the above areas, experts

13 (n=10) with profound local knowledge were consulted and field surveys were made after Figure 2 was

14 obtained. Based on the consultation and field surveys, we identified five land-use prototypes that could

15 have severe jobs-housing imbalance of bus commuters in Beijing. Table 3 summarizes the characteristics

16 of these prototypes and provides spatial index regarding how to find real-world examples in Figure 2. To

17 help one to locate concrete examples of these prototypes in Beijing, landmarks and directions are also

18 offered in Table 3.

19

20

21

22

1   **TABLE** 3: Land-use Prototypes of Extreme Jobs-housing Imbalance of Bus Commuters

Prototype	Characteristics	Landmarks and Directions	Spatial Index in Figure 2
1	University campuses, hotels and old Danwei compounds left with mostly apartment buildings	Minzu and Jiaotong Universities and areas in between; Beijing Technology and Business University and Capital Normal University (east campus) and areas adjacent to them; Beijing University of Aeronautics and Astronautics and Beijing University of Science and Technology and adjacent areas	A (Areas around and areas to its northeast)
2	Parks with luxury hotels, high-end apartments, specialized research institutes, hospitals and some mixed-use residential areas	Areas north to Yu Yuan Tan Park; Area adjacent to Tian Tan Park in the east	A (South to A, the darkest area); The U-shaped area south to the star
3	Traditional Hu'tong with old, cheap, small, shared and underserviced rental housing units	Areas in between Qian Men Da Jie and Zhu Shi Kou Da Jie	B
4	Residential areas with mixed-age housing units adjacent to freeway interchanges or arterials, railways within the fifth ring road	Areas near Yong Ding Men and Nan Sha Wo Bridges	C
5	Low density, developing areas with relatively cheap housing units in the suburb	Areas adjacent to the sixth ring road and Jingshi Freeway interchange; Areas adjacent to Yan Chun Railway Station	D

2

3   To visualize the areas highlighted in Table 3, we used www.baidu.com, a leading search engine providing

4   map services in China, to generate bird's eye photos and detailed maps (see Figure 3).

5

6

7

8

(a) Prototype 1&2*

Hang

*Within the circle are the areas north to Yu Yuan Tan Park, the blue lake in the lower left. Here, there is the General Hospital of Navy and Danwei Compounds of the Hospital and "Han Tian", Astronautics Science and Technological Research Institute of China. To its north are Beijing Technology and Business University and Capital Normal University (east campus) and areas adjacent to them.
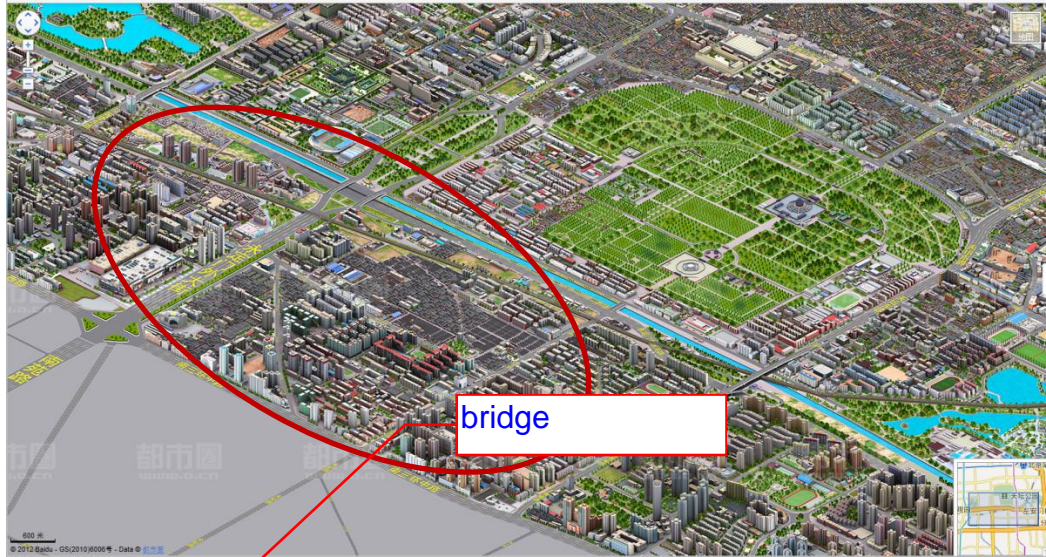
(b) Prototype 3*

*Within the circle are traditional Hu'tong in between Qian Men Da Jie and Zhu Shi Kou Da Jie.

(c) Prototype 4*

bridge

*Within the circle the brike crossing the river is Yong Ding Men Bridge. To the bridge's southeast and southwest there co-exist new real estate development (the high-rise buildings) emerged in the past two decades or so and low-rise old apartments built prior to the former.

(d) Prototype 5*

*Within the circle the bigger interchange is the sixth ring road and Jingshi Freeway interchange. Around the interchange, there are low-density developing areas with cheap housing units.

FIGURE 3: Visualization of the Prototypes

At this point, due to the fact that we could not identify any specific bus commuters directly from the smart card data and conduct surveys of, or interviews with them, we still do not know what exactly caused severe jobs-housing imbalance in Beijing. Publicly available disaggregate housing, travel and

1   employment data about Beijing are very limited. The ones we could find offer no clues. Thus we turned

2   to other ways. We conducted internal discussions among a small group of experienced local urban

3   planners and analysts (n=10) and referred to (11,12, 47, 49-50), which generated speculated reasons and

4   empirical evidences summarized in Table 4.

5   **TABLE** 4: Speculated Reasons Causing Severe Jobs-housing Imbalance

Prototype	Speculations	Empirical evidences*
1	Housing side: Some fresh university graduates still live in a cheap, shared apartment near their respective alma mater but work in another locale; other fresh graduates also prefer to live in or around a university campus, where they could efficiently find a roommate to reduce rent, cheap food and services Job side: universities often do not offer a variety of jobs like CBDs and thus residents living in or around have to find a job in another locale	Many local housing on-line search engines offer tailored functions for users to efficiently locate housing near university campuses; A room's rent in a shared apartment near a university can be as cheap as a couple hundred RMB per month (see: http://bj.ganji.com/fang1/daxue/bjgsdx/)
2	Housing side: Some renters managed to live an affordable apartment or room in such a premium area Job side: Specialized research institutes, luxury hotels and hospitals offer only limited types of job opportunities such as researcher, nurse, doctor and front desk clerk and thus local residents want other opportunities have to work elsewhere; some workers simply made trade-offs between residential amenities and commuting distance	Funan Residential Area, an old community which is adjacent to Yu Yuan Tan Park, for instance, offers housing prices that are comparable to areas nearby despite its premium location, based on www.anjuke.com.
3	Housing side: Cheap rental housing units relatively ample in Hu'tong Job side: Few non-service-sector and well-paid job opportunities available in Hu' tong	Except hotels and restaurants, very few employers are located in Hu'tong, based on www.baidu.com.
4	Housing side: Housing units adjacent to freeway interchanges or arterials, railways are often relatively cheaper due to noise and pollution from through traffic but this means affordability to some workers Job side: Residential areas predominantly built for housing provide few job opportunities for local residents	Average second-hand apartment price to the southeast of Yong Dong Men Bridge, for instance, is around RMB 26,000/square meter according to www. http://beijing.anjuke.com as of July 2012, which is cheaper than the average elsewhere around the inner city
5	Housing side: Much cheaper housing prices than in the inner city Job side: low-density developing areas in suburb offer few job opportunities of any kind	New housing pricing near the sixth ring road and Jingshi Freeway, for instance, is around RMB 8,000-13,000/square meter, which is much cheaper than anywhere in the inner city

6   *Few public data were available and so we turned to leading private on-line housing or generic searching engines to get
7   evidences.

8

1 Based on reasons listed in Table 4, we now could better answer Question (b) posed above: "What we can

2 do about bus commuters' excess commute or jobs/housing imbalance in Beijing?".

3 **First,** we have to understand better first why commuters chose to live in the prototype areas. In prototype

4 area I, for instance, we speculated that fresh graduates prefer to live in or around university campuses. But

5 we do not know exactly why they do so despite that we guessed that the primary reason is efficiency in

6 finding a roommate, housing/services affordability and/or familiarity with local communities (for those

7 living in or around their alma mater).

8

9 **Second,** we probably need to provide access to pleasant parks and other public infrastructure such as

10 quality schools and hospitals across the space so that commuters do not need to sacrifice commuting

11 distance for such access. In prototype II, we speculate that some commuters have done that. There are

12 also empirical evidences that support our speculation in (54).

13

14 **Third,** we should consider affordable housing options near employment centers so that employees do not

15 have to live in areas that are cheap but far away from their workplace. We know this is not easy and most

16 large-scale affordable housing projects (such as Hui Long Guan and Tian Tong Yuan with decades of

17 history) completed in Beijing are located in the suburb, where few established employment centers were

18 located. Even today, according to (54), except Wang Jing and its hosting district[5] provide employment

19 opportunities for 75 percent of local residents, all other large-scale affordable housing projects or new

20 housing projects in Beijing's suburb and their respective hosting districts could only do so for 30 percent

21 of local residents. But we could think about hundreds and even thousands of small-scale affordable

---

[5] District is an important administrative unit in China. In Beijing's inner city, for instance, there are eight districts. Each district has its own government and is responsible for providing a wide range of services like a large city in the US.

1   housing projects by private parties. We could incentivize them to build, own and/or operate affordable

2   apartments or units in job-rich and housing-deficient districts or areas.

3

4   **Fourth,** we could move jobs closer to employees. There are now lots of "affordable" housing projects in

5   the suburbs of Beijing. We could selectively encourage small employers to establish their business in the

6   project areas by offering tax deduction and low-interest business loans. Similarly, we could provide

7   residents in the suburb who self-employ the same treatment and on-the-job trainings. Another option is to

8   encourage telecommuting, which makes commuting and jobs-housing balance much less relevant than

9   ever. Given the relatively low set-up costs, this may work best for Prototype V areas in Beijing. To make

10 this happen, however, we need to work on both ends: the employee end and the employer end.

11

12 **Potentials of Smart Card Data**

13 Most existing studies of jobs-housing balance and related topics have relied on self-reported travel survey

14 data. Due to the cost to administrate a large-scale travel survey and to process relevant responses, the

15 sample size of the survey is often quite small. In Table 1, for instance, most of the other studies about

16 Beijing have only a couple hundred of samples. Despite that these many samples could reasonably

17 represent the commuter population in terms of their travel behaviors and socio-demographic

18 characteristics they often cannot well represent global phenomena such as jobs-housing balance. In the

19 case of Beijing, assuming that we got workplace and housing information 6,000 samples from travel

20 surveys and these samples are evenly distributed across all TAZs, there would be only four or five

21 samples for each TAZ as there are 1,118 TAZs. No matter how hard we try, deducing any useful insights

22 into metropolitan-scale jobs-housing balance based on four or five samples at each TAZ is still

23 technically challenging. In comparison, smart card data can efficiently and economically provide

1   workplace and housing information of samples that are forty or even fifty times bigger. This facilitates

2   studies of metropolitan-scale jobs-housing balance and significantly increases the representation and

3   reliability of related analyses. Therefore, smart card data have provided an alternative way for analysts to

4   study jobs-housing balance and related topics at the metropolitan scale.

5

6   But there are still enhancements that can be made to increase the value of smart card data, which contain

7   no socio-economic information about cardholders/commuters. One proposed enhancement is to link smart

8   card data to resident card data for all cardholders who authorize the data administrator to do so. In China

9   and many other countries, resident card data are universally available and they at least provide

10   information such as age, gender, marriage status and current home address of a resident. The other

11   proposed enhancement is to ask anyone who purchases a smart card to voluntarily fill in an anonymous

12   form that collects minimum amount of socio-economic information about him or her of interest to policy

13   analysts. In return, she or he can get some bonus monetary value on the smart card or can reclaim a new

14   smart card for free if she or he loses the original card, which is not offered currently.

15

16

17   **CONCLUSIONS**

18   In this study, massive smart card data were used to get 216,844 bus commuters' workplace and residential

19   locations. This enables a jobs-housing study of bus commuters in a metropolis with a much larger sample

20   size than most existing studies. This study indicates that bus commuters in Beijing (a) have a shorter ARC

21   and MRC than commuters in four other auto-dependent western cities with comparable population and/or

22   land use sizes; (b) have a longer ARC and MRC than commuters of all modes in Guangzhou, another

23   metropolis which is half of the size of Beijing. Overall, Beijing's bus commuters face severe excess

24   commute ($E=64\%$) but still only use a relatively small portion of the commute potential ($C_u=17\%$). As the

1 city expands and if nothing is done about correcting their jobs-housing imbalance, Beijing's bus

2 commuters could encounter even more severe excess commute. Bus commuting time differences between

3 two local travel surveys in 2005 and in 2010 have partially reflected this trend.

4

5 To help reverse the trend, this study has supplemented the smart card data with local expert knowledge,

6 field surveys and with information provided by on-line housing searching engines so as to better

7 investigate bus co[mmuting] imbalance in Beijing and ways to correct it. This study has

8 established five la[rge] [jo]bs-housing imbalance. It has used local experts to speculate

9 reasons for the imbalance of each prototype. It also proposed solutions to the imbalance based on the

10 prototypes and speculated reasons. By doing [so, this stud]ly has expanded the relatively 'static'

11 analysis of the status quo (i.e., one-time quantification of a city's jobs-housing balance, commuting

12 efficiency, excess commute, etc.) of a city into one of relevant dynamics. Understanding the dynamics

13 enables us to propose more relevant solutions to the problems identified. To other researchers who want

14 to use smart card data to conduct more studies, this study may have provided a good example and a

15 generic roadmap regarding how to enhance the value of smart card data with complementary data or

16 knowledge.

17

18 Lastly, despite that the above merits of this study, it can still be improved in at least three aspects in the

19 future. **First,** it needs to be linked to local household travel surveys, particularly the responses given by

20 bus commuters. This would allow one to know better these commuters' job-, housing- and transportation-

21 related decisions and concerns. This would also enable one to better validate or invalidate existing expert

22 speculations about them. Of course, there are barriers to be overcome as there has been a tradition among

23 local agencies to hoarding survey responses and share them within the agencies. **Second,** it can collect

24 data to study jobs-housing balance and related issues among auto and bicycling commuters too. Now, the

study does not make any comparisons between them and bus commuters. Thus one does not know

whether problems identified in this study are unique to bus commuters. **Third,** this study would be

greatly enhanced if smart card data that include rail rapid system swipe information would be used. The

smart card data administrator has such information but for some reasons they were unwilling to provide it

for this study. Of course, adding this extra information would make smart card data processing and

validation more complicated and challenging. However, with this extra information would enable one to

better understand jobs-housing balance of more commuters, in particular, those commuters who primarily

or solely use rail rapid system or those who use both bus and rail rapid system. This could be extremely

important for a metropolis like Beijing that sees a growing rail rapid system and an increased share of rail

rapid system commuters.

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