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# Physical activity and weight following car ownership in Beijing, China: quasi-experimental cross sectional study

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## ABSTRACT

### OBJECTIVE

To determine the implications of car ownership for physical activity and weight in a global city.

### DESIGN

Quasi-experimental cross sectional study.

### SETTING

Beijing, China, 2011-15.

### PARTICIPANTS

People aged 18 and older from a random sample of households who had entered a permit lottery to purchase a vehicle between January 2011 and November 2015.

### INTERVENTIONS

Permit allowing purchase of a vehicle within six months of permit issuance.

### MAIN OUTCOME MEASURES

Transit use (number of subway and bus rides each week), physical activity (minutes of walking or bicycling each day), and weight, measured once in early 2016.

### RESULTS

Of 937 people analysed in total, 180 had won a permit to purchase a new vehicle. Winning the permit lottery resulted in the purchase of an additional vehicle 91% of the time (95% confidence interval 89% to 94%;  $P<0.001$ ). About five years after winning, winners took significantly fewer weekly transit rides ( $-2.9$  rides ( $-5.1$  to  $-0.7$ );  $P=0.01$ ) and walked and cycled significantly less ( $-24.2$  minutes ( $-40.3$  to  $-8.1$ );  $P=0.003$ ) than those who did not win the lottery. Average weight did not change significantly between lottery winners and losers. Among those aged 50 and older, however, winners' weight had increased relative to that of losers (10.3 kg (0.5 to 20.2);  $P=0.04$ ) 5.1 years after winning.

## CONCLUSIONS

These data indicate that vehicle ownership in a rapidly growing global city led to long term reductions in physical activity and increase in weight. Continuing increases in car use and ownership in developing and middle income countries could adversely affect physical health and obesity rates.

## Introduction

Obesity rates are rising worldwide, including in China, but the underlying causes are poorly understood.<sup>1</sup> One possible culprit is the long term decline in active forms of transportation. Previous research has disclosed substantial cross sectional or longitudinal associations between reported physical activity, body mass, and use of cars.<sup>2-13</sup> To understand how car ownership affects physical activity is important for both public health and environmental policy.<sup>14</sup> The relation between car ownership and physical activity remains unclear, given the confounding inherent in observational data. In this study we used the random assignment of permits for automobile purchase to households in Beijing, China, to estimate the relation between car ownership, physical activity, and weight.

## Methods

In January 2011, to deal with the problem of congestion, Beijing capped the number of new vehicles allowed at 240 000 each year and introduced a vehicle permit (licence plate) lottery. After that date, only residents who entered and won the lottery were entitled to a licence plate. The lottery was drawn monthly, and winners had to purchase a car within six months of winning. By mid-2012 the probability of winning fell below 2% a month.

The sample was drawn from a group of households collected by the Beijing Transportation Research Centre. The research centre conducted a transportation survey of a random sample of 40 000 households from Beijing in the autumn of 2014, stratifying by district. The survey included questions on whether a household had entered the vehicle permit lottery. Among households with lottery entrants, a stratified random subsample was further surveyed in early 2016 with questions about the permit lottery. Because the lottery had many more losers than winners, sampling was stratified by winning status, with only one third of losers sampled. All lottery entrants in a household were surveyed.

The average household response rate in the 2016 survey was about 22%. Response rates were similar for winning and losing households—21.8% and 22.2%, respectively—suggesting that there was no response bias related to the exposure itself. The resulting

## WHAT IS ALREADY KNOWN ON THIS TOPIC

Lifestyle trends, including declines in active transportation, are often cited as factors underlying rising obesity rates

Previous observational studies have documented cross sectional or longitudinal associations between car use and reduced physical activity or obesity

No studies have exploited randomisation to estimate the relations between car ownership, physical activity, and weight

## WHAT THIS STUDY ADDS

A vehicle permit lottery in Beijing effectively randomises the right to purchase a car among lottery participants

Survey data from lottery participants indicate that lottery winners reduce their transit use, decrease their physical activity, and, among older participants, gain weight, relative to those who did not win

sample comprised 180 winners and 757 losers. The sample size was considered sufficient to detect an effect of about 0.2 standard deviations in the primary outcomes—namely, transit rides, minutes spent walking and bicycling, and weight, with 80% power. The 2016 survey asked questions about car ownership, use of public transportation, minutes spent walking or bicycling daily, and weight, which are the key outcome variables for this analysis.

We used data from the 2014 Beijing Transportation Research Centre transportation survey, and found that 2016 survey respondents were broadly similar to 2016 survey non-respondents for many characteristics: household size, number of adults, number of working adults, number of children, household income, sex, age, and education (supplementary appendix). Usually, the mean differences between respondents and non-respondents were small, and in all cases were of the order of 0.1 standard deviations or less.

All outcomes were based on survey responses. Previous work in the Chinese population has found that self reports of physical activity have good reliability and moderate validity, and self reports of weight are generally reliable.<sup>15 16</sup> Nevertheless, the accuracy of self reported weight has been shown to be inversely related to changes in weight and when weight is changing quickly it may not be reliable.<sup>17</sup> In that case the bias would attenuate our estimates, which could thus underestimate the magnitude of activity or weight changes if individuals do not quickly update their weights or activity levels.

Data were complete for most outcomes and key predictors. In general, we omitted missing data, rather than attempting to impute a value. We made exceptions, however, for two variables: the month of initial participation in the lottery and the month of winning the lottery. Although data on the year of lottery entry and year of winning were complete, the exact month of entry (or month of winning) was missing for 251 (26.8%) of 937 individuals. In these instances we replaced the missing month with 6.5 (that is, the midpoint between 1 and 12).

Stata (StataCorp, College Station, TX), version 15.1, was used to estimate intention to treat linear regressions of different outcomes on an indicator for winning the lottery, with standard errors clustered at the household level. Lottery winners were intended by the policy to be treated (with car ownership), while lottery losers were intended not to be treated. Intention to treat analysis exploiting the lottery was important because most licence plates in Beijing were issued before the lottery and thus not randomised. Furthermore, trading or rental of licence plates on the secondary market has occurred.<sup>18</sup> Thus winning the lottery is the only valid source of randomisation. Although trading in the secondary market is widely recorded, there has never been any suggestion that the lottery itself was corrupted. Owing to the public nature of the lottery, buying or borrowing a licence plate from an existing vehicle owner was a much safer strategy than attempting to corrupt the lottery administrators.

Winning the lottery was random, conditional on date of entry—participants who entered earlier had better odds and greater chances of winning. Thus all regressions controlled for a cubic function in date of entry. We checked lower and higher order polynomials in date of entry to ensure that results were not sensitive to polynomial order (supplementary appendix).

Because the survey date was approximately constant across households, variation in the date on which winning occurred generated variation in the time between winning and outcome measurement. Because the associations for some outcomes could evolve over time, we allowed interaction between winning and years since winning and reported predicted changes for an individual surveyed 0.1 years, 2.6 years, and 5.1 years after winning (see supplementary appendix for details). These values represented the minimum, average, and maximum times that had elapsed, respectively, between winning and being surveyed. Weight gain is strongly related to age.<sup>19</sup> Thus we estimated separately activity and weight regressions for individuals over 40 or over 50 years of age (corresponding to the top half or quarter of our sample's age distribution) and tested whether an interaction between age and winning the lottery differed from zero. We also tested whether an interaction between male sex and winning the lottery differed from zero. Two sided hypothesis tests were conducted, with Pvalues under 0.05 considered significant.

#### Patient and public involvement

The researchers did not control the intervention, so we did not involve lottery participants or the general public in the study design. We plan to disseminate the results of the published study widely through traditional media and social media, but we have no way of directly contacting the original survey respondents as we do not have their contact information. We plan to publicise the results from the published version through the communications offices of our respective universities.

#### Results

By the time of survey, individuals winning the permit lottery had purchased an average of 0.91 more vehicles (95% confidence interval 0.89 to 0.94;  $P < 0.001$ ) than those who had not won. This number of vehicles was close to the theoretical maximum of an additional 1.0 vehicles that winning the permit lottery allowed an individual to purchase and was higher than compliance rates in most clinical trials.<sup>20</sup> Consistent with successful lottery randomisation, no statistically significant differences were seen between lottery winners and losers in household size, full time or part time employment, sex, age, education level, marital status, or household income (table 1). The largest difference between lottery winners and losers was a non-significant difference of 0.14 standard deviations in household income. In supplementary analyses we verified that also controlling for household income did not change our conclusions (supplementary appendix).

**Table 1 | Descriptive statistics of sampled lottery participants**

Characteristics	Lottery winners (n=180)	Lottery losers (n=757)
Household size	3.01 (0.97)	2.94 (0.83)
Household members employed full time	1.73 (0.91)	1.75 (0.83)
Household members employed part time	1.18 (0.83)	1.11 (0.78)
Total household lottery participants	1.58 (0.68)	1.62 (0.64)
Individual present for survey	0.81 (0.39)	0.76 (0.43)
Male sex	0.60 (0.49)	0.57 (0.50)
Age (years)	41.60 (11.62)	40.34 (11.55)
Years of education	13.56 (2.90)	13.76 (2.83)
Married	0.87 (0.34)	0.83 (0.37)
Annual household income (¥10 000)	6.76 (6.81)	7.74 (6.79)

Data are number unless stated otherwise, as mean (standard deviation) values.

The average lottery loser took 6.2 transit rides a week, spent 57 minutes a day walking or bicycling, and weighed 70 kg. The number of people reporting their weight was less than for other outcomes (760 v 937), but the percentage of those with missing weight data was not statistically significant between winners and losers (77.2% v 82.0%).

We controlled for lottery date of entry and years since winning and found that by the time of the survey, individuals who won the lottery took 2.8 fewer transit rides a week (95% confidence interval 1.9 to 3.8;  $P<0.001$ ) than those who did not win. Compared with those who did not win the lottery, the difference in daily minutes spent walking or bicycling was  $-3.8$  minutes ( $-11.6$  to  $4.1$ ;  $P=0.35$ ) for winning individuals, and average weight was  $0.11$  kg higher for winners than for losers ( $-2.6$  to  $2.8$ ;  $P=0.94$ ).

The coefficient of regression of years since winning was  $-0.04$  weekly transit rides ( $P=0.92$ ),  $-8.0$  minutes ( $P=0.03$ ) in the time spent walking or bicycling, and  $0.8$  kg ( $P=0.50$ ) in weight regression. The second result was statistically significant, implying that some associations could build over time.

Table 2 reports coefficients corresponding to associations measured immediately after winning (0.1 years), the average observed number of years after winning (2.6 years), and the maximum observed number of years after winning (5.1 years). Individuals who won the lottery took fewer transit rides each week than those who did not win at 0.1 years after winning ( $-2.7$  (95% confidence interval  $-4.5$  to  $-0.9$ );  $P=0.003$ ) and at 5.1 years after winning ( $-2.9$  ( $-5.1$  to  $-0.7$ );  $P=0.01$ ). Compared with those who did not win the lottery, daily time spent walking or bicycling was higher (15.8 minutes ( $-5.9$  to  $37.4$ );  $P=0.15$ ) for winning individuals at 0.1 years, but lower for individuals at 2.6 and 5.1 years after winning ( $-4.2$  minutes ( $-11.9$  to  $3.5$ ),  $P=0.29$ ; and  $-24.2$  ( $-40.3$  to  $-8.1$ ),  $P=0.003$ ;

respectively). For these results, the association at 5.1 years achieved statistical significance. Average weight was not significantly different for winners and losers at any point.

For individuals aged 40 and older, average weight was  $3.2$  kg higher (95% confidence interval  $-0.3$  to  $6.8$ ;  $P=0.07$ ) at 2.6 years after winning in comparison with losers, and  $5.2$  kg higher ( $-2.6$  to  $13.0$ ;  $P=0.19$ ) at 5.1 years after winning (table 3). For individuals aged 50 and older, average weight was  $4.7$  kg higher ( $0.0$  to  $9.3$ ;  $P=0.05$ ) at 2.6 years after winning, and  $10.3$  kg higher ( $0.5$  to  $20.2$ ;  $P=0.04$ ) at 5.1 years after winning. Decreases in minutes spent walking or bicycling were correspondingly larger for individuals aged 50 and older than for those aged 40 and older. Average daily minutes spent walking or bicycling 5.1 years after winning were lower for those aged 50 and older ( $-29.8$  minutes ( $-54.1$  to  $-5.5$ );  $P=0.02$ ), and for those aged 40 and older ( $-17.3$  minutes ( $-36.5$  to  $2.0$ );  $P=0.08$ ).

Results of tests examining whether age modified the associations between winning and the primary outcomes were not significant. When a linear interaction was included between age and winning the lottery, the interaction term coefficient suggested that an additional year of age increased the coefficient on winning by  $0.05$  weekly transit rides (95% confidence interval  $-0.03$  to  $0.13$ ;  $P=0.23$ ),  $0.11$  minutes spent walking or bicycling ( $-0.58$  to  $0.79$ ;  $P=0.77$ ), and  $0.21$  kg ( $-0.03$  to  $0.44$ ;  $P=0.08$ ). When the sample was limited to individuals who were surveyed at least 0.9 years after winning, the age interaction became statistically significant, with significance peaking for individuals surveyed over one year after winning ( $P=0.007$ ). This significance faded when the sample was limited to individuals surveyed at least two years after winning (supplementary appendix).

Results of tests examining whether sex modified the associations between winning and the primary outcomes were not statistically significant (table 4). When including an interaction between male sex and winning the lottery, the interaction term coefficient suggested that, compared with female winners, male winners had a reduced change in weekly transit rides ( $-0.91$  rides ( $-2.72$  to  $0.90$ );  $P=0.32$ ), time spent walking or bicycling ( $-4.37$  minutes ( $-21.65$  to  $12.90$ );  $P=0.62$ ), and weight ( $-1.84$  kg ( $-7.68$  to  $3.99$ );  $P=0.54$ ).

## Discussion

### Principal findings

Our results indicate that those individuals winning a lottery permit to purchase a car reported transit use

**Table 2 | Associations between winning the lottery and transit use, activity, and weight**

Dependent variables	Time since winning (95% CI)		
	0.1 years (minimum)	2.6 years (average)	5.1 years (maximum)
Weekly transit rides	$-2.73$ ( $-4.53$ to $-0.92$ )	$-2.82$ ( $-3.79$ to $-1.85$ )	$-2.91$ ( $-5.13$ to $-0.7$ )
Minutes daily walking/bicycling	$15.77$ ( $-5.85$ to $37.39$ )	$-4.2$ ( $-11.94$ to $3.53$ )	$-24.18$ ( $-40.28$ to $-8.08$ )
Weight (kg)	$-1.74$ ( $-8.04$ to $4.57$ )	$0.14$ ( $-2.54$ to $2.83$ )	$2.03$ ( $-3.93$ to $7.98$ )

Each row reports coefficients from a regression of the specified dependent variable on winning the car lottery, controlling for a cubic function in lottery entry date. Negative values imply fewer transit rides, fewer minutes daily walking/bicycling, and lower weight in winners than in losers. Number of individuals=937 (760 for weight regressions).

**Table 3 | Age stratified associations between winning the lottery and transit use, activity, and weight**

Dependent variables	Time since winning (95% CI)		
	0.1 years (minimum)	2.6 years (average)	5.1 years (maximum)
<b>Individuals aged ≥40</b>			
Weekly transit rides	-2.18 (-4.13 to -0.24)	-2.1 (-3.35 to -0.85)	-2.02 (-5.16 to 1.12)
Minutes daily walking/bicycling	12.1 (-4.66 to 28.86)	-2.59 (-12.12 to 6.94)	-17.29 (-36.52 to 1.95)
Weight (kg)	1.29 (-5.07 to 7.65)	3.24 (-0.31 to 6.8)	5.2 (-2.59 to 12.99)
<b>Individuals aged ≥50</b>			
Weekly transit rides	-2.88 (-5.57 to -0.19)	-1.9 (-3.61 to -0.18)	-0.91 (-5.45 to 3.63)
Minutes daily walking/bicycling	27.4 (-0.28 to 55.08)	-1.19 (-13.76 to 11.38)	-29.78 (-54.08 to -5.49)
Weight (kg)	-1 (-8.4 to 6.4)	4.67 (0.04 to 9.31)	10.34 (0.49 to 20.19)

Each row reports coefficients from a regression of the specified dependent variable on winning the car lottery, controlling for a cubic function in lottery entry date, and limiting the estimation sample to individuals aged 40 or more or 50 or more. Negative values imply fewer transit rides, fewer minutes daily walking/bicycling, and lower weight in winners than in losers. Number of individuals aged 40 or more=462 (378 for weight regressions); number of individuals aged 50 or more=245 (193 for weight regressions).

45% lower than those who did not win (95% confidence interval 30% to 61%). Differences in physical activity became apparent over time. About 2.6 years after winning, winners spent 7% less time walking or bicycling than losers. At 5.1 years the reduction in walking or bicycling rose to 42%. These results, which use randomisation of the permit lottery, show associations with winning the lottery. Associations with purchasing an automobile were about 10% larger because winning the lottery resulted in an additional vehicle purchase 91% of the time ( $1/0.91=1.1$ ).<sup>21</sup>

Sensitivity analyses (details shown in the supplementary appendix) suggest that the results are robust for a variety of specifications. Briefly, the overall conclusions did not depend on the order of polynomial used to control for lottery date of entry, the inclusion of controls for household income, district fixed effects, household employment, or age in our regression specifications, or the use of a Poisson regression for count data (weekly transit rides).

In the overall sample, the increase in weight of lottery winners was not significantly greater than that of losers by 5.1 years. Among individuals aged 50 or older, however, the increase in weight of winners was significantly greater than that of losers by 2.6 and 5.1 years after winning. To interpret these results, we note that the estimated 30 minute decline in daily physical activity for this subgroup translates to 140 kcal less energy used (1 kcal=4.18 kJ=0.00418 MJ).<sup>22</sup> These magnitudes are relevant because changing the energy balance by 100 kcal/day can prevent weight gain in many populations.<sup>23</sup> Indeed, applying reported basal metabolic rate equations suggests that a 140 kcal decrease in energy expenditure a day would induce a weight gain of 10.3 kg by 5 years (see supplementary appendix for details).<sup>24</sup> This significant weight gain

matches the point estimate of a weight gain of 10.3 kg at 5.1 years that we found for individuals aged 50 and older.

### Comparison with other studies

In a meta-analysis of 30 studies involving adults, 25 studies found an inverse association between active transport and body weight.<sup>25 26</sup> Previous studies have found associations between vehicle ownership or commuting by private vehicle and increased weight of between 1 kg and 10 kg.<sup>2 5 6 8-12</sup> The exposures in these studies did not match ours perfectly, but for the subgroup for which we found a statistically significant result, the estimated weight difference was at the midpoint (at 2.6 years) to upper end (at 5.1 years) of this range. Although our significant point estimates were at the upper range of associations found in existing reports, several considerations deserve mentioning.

Firstly, many studies have focused on active commuting, but commuting accounts for only 15% of trips.<sup>27</sup> Studies that examined car ownership or active transport for all trips tended to find larger associations. For example, Bell et al found that acquiring a motorised vehicle (motorcycle or car) was associated with a 1.8 kg weight gain in a Chinese sample<sup>2</sup>; Parra et al found that men in households with motor vehicles weighed about 10 kg more in Colombia than men without motor vehicles<sup>5</sup>; Dons et al found that Europeans who cycle daily weigh about 3.3 kg less than those who drive daily<sup>11</sup>; Smart found that giving up one's car was associated with a 3 kg weight loss in the United States<sup>12</sup>; and Turrell et al found that Australians who walked or cycled weighed about 8 kg less than those who drove.<sup>13</sup> The average association with various exposures across these studies was 5.2 kg.

Secondly, associations for younger age groups, although not significant, were smaller in magnitude. For example, for individuals aged 40 and older, winning the lottery was associated with a 3.2 kg increase in weight at 2.6 years, on average, compared with those who did not win. Finally, the confidence intervals for the significant weight associations were sufficiently wide to include most estimates from previous studies.

**Table 4 | Sex modification of associations between winning the lottery and transit use, activity, and weight**

Dependent variables	Sex interaction coefficient (95% CI)	P value
Weekly transit rides	-0.911 (-2.721 to 0.899)	0.324
Minutes daily walking/bicycling	-4.374 (-21.647 to 12.899)	0.620
Weight (kg)	-1.841 (-7.675 to 3.993)	0.537

Each row reports the coefficient on an interaction between male sex and winning the car lottery from a regression of the specified dependent variable on winning the car lottery, controlled for years since winning, and a cubic function in lottery entry date. Negative values imply fewer transit rides, fewer minutes daily walking/bicycling, and lower weight in winners than in losers. Number of individuals=937 (760 for weight regressions).

## Strengths and limitations

Our study used quasi-randomisation of car ownership from a lottery to estimate associations with physical activity and weight, but it had several limitations. As in most randomised trials, the study sample was not randomly drawn from the population. In this case, only individuals who were interested in buying a vehicle applied for the lottery. This population of over one million individuals in a major city with good alternative public transportation is nevertheless of interest because it comprises those likely to become car owners in the near future. Other limitations of the study included reliance on survey responses and limited geographical coverage.

We lacked information on other leisure time activity (beyond walking and bicycling), so we could not explore substitution effects. If some individuals responded to a reduction in active transport by exercising at the gym, for example, the total effect of physical activity on weight could be smaller than we estimated. Finally, variation in the time elapsed between winning and the survey date arose from variation in time at which an entrant won. If earlier entrants differed from later entrants, the interaction between winning and years since winning could partially reflect this compositional change.

## Conclusions and policy implications

Few cities have automobile permit lotteries, but many directly or indirectly restrict vehicle ownership or use.<sup>28</sup> Our results suggest that these restrictions could confer considerable public health benefits. More generally, when dealing with rising obesity rates in middle income countries, policymakers should consider the effect of sharp upward trends in car use and ownership.<sup>29</sup>

**Contributors:** MLA and FL co-led the study design and data analysis. JY led data collection. MLA led preparation of the manuscript. FL attests that that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted. MLA is guarantor.

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**Ethical approval:** Ethics committee review and approval was received from the UC Berkeley Committee for the Protection of Human Subjects.

**Data sharing:** Statistical code is available from the corresponding author at [lufangwen@ruc.edu.cn](mailto:lufangwen@ruc.edu.cn). Underlying data are confidential.

The lead author (MLA) affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned have been explained.

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**Web appendix: Supplementary appendix**