Changes in physical activity and weight following car ownership in Beijing, China: a quasi-experimental cross-sectional study

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Changes in physical activity and weight following car ownership in Beijing, China: a quasi-experimental cross-sectional study

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Abstract

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

Design: Quasi-experimental cross-sectional study using a lottery drawing for vehicle ownership permits, stratified by winners and losers.

Setting: Beijing restricted the number of new vehicles allowed in January 2011 and established a lottery to distribute permits to purchase vehicles. The lottery was quickly oversubscribed, and the probability of winning fell below 2% per month.

Participants: By 2012, over 1 million individuals residing or paying taxes in Beijing and wishing to purchase a vehicle had entered the permit lottery. We surveyed individuals age 18 and older from a random sample of households that had entered the lottery between January 2011 and November 2015.

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

Main Outcome Measures: Transit usage (number of subway and bus rides per week), daily physical activity (minutes of walking or bicycling per day), and weight, measured once in early 2016. Prior to data collection we hypothesized that car ownership decreased transit usage and daily physical activity and increased weight.

Results: A total of 937 individuals were analyzed, including 180 permit winners. Winning the vehicle permit lottery resulted in an additional vehicle purchase 91% of the time

(95% CI, 89-94%; P<0.001). Approximately five years after winning, winners took significantly fewer weekly transit rides (2.9 rides [95% CI, 0.7-5.1 rides], P=0.01) and engaged in significantly less daily walking and bicycling (24.2 minutes [95% CI, 8.1-40.3 minutes], P=0.003) than those that did not win the lottery. Average weight was not significantly different for winners and losers, but among individuals 50 and older, winners' weight increased relative to losers (10.3 kg [95% CI, 0.5-20.2 kg], P=0.04) at 5.1 years after winning.

Conclusions: Vehicle ownership in a rapidly growing global city led to long-term reductions in physical activity and weight gain. Continuing surges in car usage and ownership in developing and middle-income countries may adversely affect physical health and obesity rates.

Summary Box

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
- To date no studies have exploited randomisation to estimate the relationships 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 amongst lottery participants
- Survey data from lottery participants revealed that lottery winners reduced their transit usage, decreased their physical activity, and, among older participants, gained weight, relative to those that did not win

Manuscript

Introduction: Obesity rates are rising worldwide, including in China, but the underlying causes are poorly understood.(1) One possible culprit is the long-term decline in active forms of transportation. Previous research has revealed significant cross-sectional or longitudinal associations between reported physical activity, body mass, and car use or automobile-centric environments,(2–13) and the question of how car ownership affects physical activity is important for both public health and environmental policy.(14) Nevertheless, the relationship between car ownership and physical activity remains unclear, given the confounding inherent in observational data. In this study we exploited random assignment of automobile purchase permits to households in Beijing, China to estimate the relationships between car ownership, physical activity, and weight.

Methods: To address congestion, in January 2011 Beijing capped the number of new vehicles allowed at 240,000 each year and introduced a vehicle permit (license plate) lottery. After that date, only residents who entered and won the lottery could purchase a new or used vehicle. Drawings occurred monthly, and winners had to purchase a car within six months of winning. By mid-2012 the probability of winning fell below 2 percent per month.

The sample was drawn from of a group of households collected by the Beijing Transportation Research Center (BTRC). The BTRC conducted a transportation survey of a random sample of 40,000 households from Beijing in Fall 2014, stratifying by district. The transportation survey included questions on whether a household entered the vehicle permit lottery. Among households with lottery entrants, a stratified random subsample was further surveyed with questions related to the permit lottery in early 2016. Since there were 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 approximately 22%. Nevertheless, response rates were similar between winning households and losing households — 21.8% and 22.2% respectively — suggesting that there was no response bias related to the exposure itself. The resulting sample contained 180 winners and 757 losers. The sample size was considered sufficient to detect an effect of approximately 0.2 standard deviations in the primary outcomes — transit rides, minutes spent walking and bicycling, and weight — with 80% power. The 2016 survey asked questions on car ownership, use of public transportation, daily minutes spent walking or bicycling, and weight, which constitute the key outcome variables for this analysis.

Using data from the 2014 BTRC transportation survey, we found that 2016 survey respondents were broadly similar to non-respondents on many characteristics:

household size, number of adults, number of working adults, number of children, household income, gender, age, and education (see Supplementary Appendix). In most cases the mean differences between respondents and non-respondents were small, and in all cases they were on the order of 0.1 standard deviations or less.

All outcomes were based on survey responses. Previous work in the Chinese context has found self-reports of physical activity to have good reliability and moderate validity, and weight self-reports have been found to be reliable and valid.(15,16) Nevertheless, the accuracy of weight self-reports has been shown to be inversely related to changes in weight.(17) Our measures could thus underestimate the magnitude of activity or weight changes if individuals anchor on their previous activity levels or weights.

Stata (StataCorp), version 15.1, was used to estimate "intention-to-treat" (ITT) 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 winners were intended not to be treated. ITT analysis exploiting the lottery was important because the majority of license plates in Beijing were issued prior to the lottery and thus not randomised. Furthermore, trading or rental of license plates on the secondary market has occurred.(18) Thus winning the lottery is the only valid source of randomisation, and while trading in the secondary market was widely documented, there has never been any suggestion that the lottery itself was corrupted (the lottery's public nature ensured that buying or borrowing a license 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 faced better odds and experienced more chances to win. Thus all regressions controlled for a cubic 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).

Since the survey date was approximately constant across households, variation in the date on which winners won generated variation in the time elapsed between winning and outcome measurement. All regressions controlled for years since winning. Because the associations for some outcomes may evolve over time, we interacted winning with years since winning and report 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 elapsed times, respectively, between winning and being surveyed. Weight-gain has a strong age-related component,(19) so we estimated separate activity and weight regressions for individuals over 40 or 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 was different than zero. Two-sided hypothesis tests were conducted, with *p*-values under 0.05 considered significant.

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 broadly disseminate the results of the published study via traditional media and social media, but we have no way to directly contact the original survey respondents as we do not have their contact information.

Results: By the time of survey, individuals that won the permit lottery purchased an average of 0.91 more vehicles (95% CI, 0.89-0.94 vehicles; P<0.001) than those that did not. This 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.(20) Consistent with successful lottery randomisation, there were no statistically significant differences between lottery winners and losers in terms of household size, fulltime or part-time employment, gender, age, education level, marital status, or household income (Table 1). The largest difference between winners and losers was a statistically insignificant 0.14 standard deviation difference in household income; in supplementary analyses we verified that also controlling for household income did not change our conclusions (Supplementary Appendix). The average lottery loser took 6.2 transit rides per week, spent 57 minutes per day bicycling or walking, and weighed 70 kilograms (kg).

When controlling for lottery date of entry and years since winning, individuals that won the lottery took 2.8 fewer transit rides per week (95% CI, 1.9-3.8 rides; P<0.001) than those that did not win. Compared to those that did not win the lottery, the difference in daily minutes spent walking or biking was –3.8 minutes (95% CI, –11.6-4.1 minutes; P=0.350) for winning individuals, and average weight was 0.11 kg higher for winners than for losers (95% CI, –2.6-2.8 kg; P=0.935).

The coefficient on years since winning was –0.04 rides (P=0.917) in the weekly transit rides regression, –8.0 minutes (P=0.025) in the minutes spent walking or biking regression, and 0.8 kg (P=0.503) in the weight regression. The second result was statistically significant, implying that some associations may 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 that won the lottery took 2.7 fewer transit rides per week (95% CI, 0.9-4.5 rides; P=0.003) than those that did not win at 0.1 years after winning and 2.9 fewer transit rides per week (95% CI, 0.7-5.1 rides; P=0.01) at 5.1 years after winning. Compared to those that did not win the lottery, daily minutes spent walking or biking were 15.8 minutes higher (95% CI, –5.9-37.4 minutes; P=0.153) for winning individuals 0.1 years after winning, 4.2 minutes lower

(95% CI, –3.5-11.9 minutes; P=0.286) 2.6 years after winning, and 24.2 minutes lower (95% CI, 8.1-40.3 minutes; P=0.003) 5.1 years after winning. The results at 0.1 years and 2.6 years were statistically insignificant, while the association at 5.1 years achieved statistical significance. Average weight was not significantly different for winners and losers at any point.

For individuals age 40 and older, average weight was 3.3 kg higher (95% CI, –0.3-6.8 kg; P=0.074) 2.6 years after winning when compared to losers, and 5.2 kg higher (95% CI, –2.6-13.0 kg; P=0.190) 5.1 years after winning (Table 3). For individuals age 50 and older, average weight was 4.7 kg higher (95% CI, 0.0-9.3 kg; P=0.048) 2.6 years after winning, and 10.3 kg higher (95% CI, 0.5-20.2 kg; P=0.040) 5.1 years after winning. Decreases in minutes spent walking or bicycling were correspondingly larger for individuals age 50 and older than for individuals age 40 and older. For those 50 and older, average daily minutes spent walking or biking were 29.8 minutes lower (95% CI, 5.5-54.1 minutes; P=0.017) for winning individuals 5.1 years after winning, while for those 40 and older, average daily minutes spent walking or biking were 17.3 minutes lower (95% CI, –2.0-36.5 minutes; P=0.078) for winning individuals 5.1 years after winning.

Tests for whether age modified the associations between winning and the primary outcomes were statistically insignificant. When including an interaction between age and winning the lottery, the interaction term coefficient implied that an additional year of age increased the coefficient on winning by 0.05 weekly transit rides (95% CI, –0.03-0.13; P=0.225), 0.11 minutes spent walking or bicycling (95% CI, –0.58-0.79; P=0.767), and 0.21 kilograms (95% CI, –0.03-0.44; P=0.081).

Discussion: Those winning the permit lottery reported transit usage 45% lower than those that did not win, with a confidence interval ranging from 30% to 61%. Differences in physical activity materialized over time. Approximately 31 months after winning the permit lottery, winners spent 7% less time walking or bicycling than losers. At 61 months the reduction in walking or bicycling rose to 42%. These results — which exploit the randomisation of the permit lottery — represent associations with winning the permit lottery. Associations with purchasing an automobile would be approximately 10% larger in magnitude based on the fact that winning the lottery resulted in an additional vehicle purchase 91% of the time (1/0.91 = 1.1).(21)

Sensitivity analyses, detailed in the Supplementary Appendix, suggest that the results are robust to a variety of specification choices. 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, winners did not weigh significantly more than losers by 61 months. Among individuals aged 50 or older, however, winners weighed significantly more than losers by 31 and 61 months after winning. To interpret these results we note that the estimated 30 minute decline in daily physical activity for this subgroup translates to 140 kilocalories (kcal) of energy.(22) These magnitudes are relevant because changing energy balance by 100 kcal per day can prevent weight gain in many populations.(23) Indeed, applying basal metabolic rate equations from the literature suggests that a 140 kcal decrease in energy expenditure would induce a weight gain of 10.3 kg by 60 months (see Supplementary Appendix for details).(24) This matches the point estimate of a weight gain of 10.3 kg at 61 months that we found for individuals age 50 and older.

In a meta-analysis of 30 studies involving adults, 25 studies found an inverse association between active transport and body weight.(25,26) Previous studies have found associations between vehicle ownership or commuting by private vehicle and weight of between 1 kg and 10 kg.(2,5,6,8–12) The exposures in these studies did not perfectly match ours, but for the subgroup for which we found a statistically significant result, the estimated weight change was at the midpoint (at 31 months) to upper end (at 61 months) of this range. While our significant point estimates were at the upper range of associations from the existing literature, several considerations merit mention.

First, many studies focus on active commuting, but commuting only accounts for 15% of trips.(27) Studies that examined car ownership or active transport across all trips tend to find larger associations. For example, Bell et al. (2002) found that acquiring a motorized vehicle (motorcycle or car) was associated with a 1.8 kg weight gain in a Chinese sample; Parra et al (2009) found that males in households with motor vehicles weighed approximately 10 kg more in Colombia; Dons et al. (2018) found that Europeans that cycle daily weigh approximately 3.3 kg less than those that drive daily; Smart (2018) found that giving up one's car was associated with a 3 kg weight loss in the United States; and Turrell et al (2018) found that Australians that walked or cycled weighed approximately 8 kg less than those that drove.(2,5,11–13) The average association with various exposures across these studies was 5.2 kg.

Second, associations for younger age groups, while insignificant, were smaller in magnitude. For example, for individuals 40 and older, winning the lottery was associated with 3.3 kg higher weight on average than those that did not win. Finally, the confidence intervals for the significant weight associations were sufficiently wide to include most estimates from previous studies.

As in most randomised trials or natural experiments, the study sample was not randomly drawn from the population. In this case, only individuals with vehicle purchase interest applied for the lottery. Nevertheless, this population of over one million individuals in a major city with good public transportation alternatives is of policy interest since it consists of those likely to become car owners in the near future. Other limitations of the study include reliance on survey responses and limited geographic 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 impact on physical activity could be smaller than we estimated. Variation in the time elapsed between winning and the survey date arose from variation in when an entrant won. If earlier entrants — who tended to win earlier — differed from later entrants, the interaction between winning and years since winning could partially reflect this compositional change.

While few cities have automobile permit lotteries, many directly or indirectly restrict vehicle ownership or usage.(28) Our results suggest that these restrictions may confer significant public health benefits. More generally, when addressing rising obesity rates in middle-income countries, policymakers should consider the impacts of sharp upward trends in car usage and ownership.(29)

Dissemination plans: We plan to publicize the results from the published version via our respective universities' communications offices.

References

1. Wu Y. Overweight and obesity in China. BMJ. 2006 Aug 19;333(7564):362–3.

2. Bell AC, Ge K, Popkin BM. The Road to Obesity or the Path to Prevention: Motorized Transportation and Obesity in China. Obes Res. 2002;10(4):277–83.

3. Frank LD, Andresen MA, Schmid TL. Obesity relationships with community design, physical activity, and time spent in cars. Am J Prev Med. 2004 Aug 1;27(2):87–96.

4. Ewing R, Schmid T, Killingsworth R, Zlot A, Raudenbush S. Relationship Between Urban Sprawl and Physical Activity, Obesity, and Morbidity. In: Urban Ecology [Internet]. Springer, Boston, MA; 2008 [cited 2018 Jul 18]. p. 567–82. Available from: https://link.springer.com/chapter/10.1007/978-0-387-73412-5_37

5. Parra DC, Lobelo F, Gómez LF, Rutt C, Schmid T, Brownson RC, et al. Household motor vehicle use and weight status among Colombian adults: Are we driving our way towards obesity? Prev Med. 2009 Aug 1;49(2):179–83.

6. Qin L, Stolk RP, Corpeleijn E. Motorized Transportation, Social Status, and Adiposity: The China Health and Nutrition Survey. Am J Prev Med. 2012 Jul 1;43(1):1–10.

7. Sugiyama T, Ding D, Owen N. Commuting by Car: Weight Gain Among Physically Active Adults. Am J Prev Med. 2013 Feb 1;44(2):169–73.

8. Flint E, Cummins S, Sacker A. Associations between active commuting, body fat, and body mass index: population based, cross sectional study in the United Kingdom. BMJ. 2014 Aug 19;349:g4887.

9. Flint E, Webb E, Cummins S. Change in commute mode and body-mass index: prospective, longitudinal evidence from UK Biobank. Lancet Public Health. 2016 Dec 1;1(2):e46–55.

10. Flint E, Cummins S. Active commuting and obesity in mid-life: cross-sectional, observational evidence from UK Biobank. Lancet Diabetes Endocrinol. 2016 May 1;4(5):420–35.

11. Dons E, Rojas-Rueda D, Anaya-Boig E, Avila-Palencia I, Brand C, Cole-Hunter T, et al. Transport mode choice and body mass index: Cross-sectional and longitudinal evidence from a European-wide study. Environ Int. 2018 Oct 1;119:109–16.

12. Smart MJ. Walkability, transit, and body mass index: A panel approach. J Transp Health. 2018 Mar 1;8:193–201.

13. Turrell G, Hewitt BA, Rachele JN, Giles-Corti B, Brown WJ. Prospective trends in body mass index by main transport mode, 2007–2013. J Transp Health. 2018 Mar 1;8:183–92.

14. Woodcock J, Edwards P, Tonne C, Armstrong BG, Ashiru O, Banister D, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. The Lancet. 2009 Dec 5;374(9705):1930–43.

15. Deng HB, Macfarlane DJ, Thomas GN, Lao XQ, Jiang CQ, Cheng KK, et al. Reliability and validity of the IPAQ-Chinese: the Guangzhou Biobank Cohort study. Med Sci Sports Exerc. 2008 Feb;40(2):303–7.

16. Stewart AL. The reliability and validity of self-reported weight and height. J Chronic Dis. 1982 Jan 1;35(4):295–309.

17. Perry GS, Byers TE, Mokdad AH, Serdula MK, Williamson DF. The Validity of Self-Reports of Past Body Weights by U.S. Adults. Epidemiology. 1995;6(1):61–6.

18. Guo O. Want to Drive in Beijing? Good Luck in the License Plate Lottery. The New York Times [Internet]. 2016 Jul 28 [cited 2019 Jul 17]; Available from: https://www.nytimes.com/2016/07/29/world/asia/china-beijing-traffic-pollution.html

19. Cornoni-Huntley JC, Harris TB, Everett DF, Albanes D, Micozzi MS, Miles TP, et al. An overview of body weight of older persons, including the impact on mortality The national health and nutrition examination survey i-epidemiologic follow-up study. J Clin Epidemiol. 1991 Jan 1;44(8):743–53.

20. Melnikow J, Kiefe C. Patient compliance and medical research. J Gen Intern Med. 1994 Feb 1;9(2):96–105.

21. Angrist JD, Imbens GW. Two-Stage Least Squares Estimation of Average Causal Effects in Models with Variable Treatment Intensity. J Am Stat Assoc. 1995;90(430):431–42.

22. Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ, et al. Compendium of physical activities: an update of activity codes and MET intensities. Med Sci Sports Exerc. 2000;32(9; SUPP/1):S498–S504.

23. Hill JO, Wyatt HR, Reed GW, Peters JC. Obesity and the Environment: Where Do We Go from Here? Science. 2003 Feb 7;299(5608):853–5.

24. Henry CJK. Basal metabolic rate studies in humans: measurement and development of new equations. Public Health Nutr. 2005 Oct;8(7a):1133–52.

25. Wanner M, Götschi T, Martin-Diener E, Kahlmeier S, Martin BW. Active Transport, Physical Activity, and Body Weight in Adults: A Systematic Review. Am J Prev Med. 2012 May 1;42(5):493–502.

26. Xu H, Wen LM, Rissel C. The Relationships Between Active Transport to Work or School and Cardiovascular Health or Body Weight: A Systematic Review. Asia Pac J Public Health. 2013 Jul 1;25(4):298–315.

27. United States Department of Transportation. National Household Travel Survey Daily Travel Quick Facts | Bureau of Transportation Statistics [Internet]. 2019 [cited 2019 Sep 30]. Available from: https://www.bts.gov/statistical-products/surveys/national-household-travel-survey-daily-travel-quick-facts

28. Nieuwenhuijsen M, Bastiaanssen J, Sersli S, Waygood EOD, Khreis H. Implementing Car-Free Cities: Rationale, Requirements, Barriers and Facilitators. In: Nieuwenhuijsen M, Khreis H, editors. Integrating Human Health into Urban and Transport Planning: A Framework [Internet]. Cham: Springer International Publishing; 2019 [cited 2019 May 24]. p. 199–219. Available from: https://doi.org/10.1007/978-3-319-74983-9_11

29. Chamon M, Mauro P, Okawa Y. Mass car ownership in the emerging market giants. Econ Policy. 2008 Apr 1;23(54):244–96.

Table 1: Descriptive Statistics of Sampled Lottery Participants

Characteristics	Lottery Winners (N = 180)		Lottery Losers (N = 757)	
Household (HH) size	3.01	(0.97)	2.94	(0.83)
Full-time employed HH members	1.73	(0.91)	1.75	(0.83)
Part-time employed HH members	1.18	(0.83)	1.11	(0.78)
Total HH lottery participants	1.58	(0.68)	1.62	(0.64)
Individual present for survey	0.81	(0.39)	0.76	(0.43)
Male	0.60	(0.49)	0.57	(0.50)
Age	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 HH income (10,000 RMB)	6.76	(6.81)	7.74	(6.79)

Notes: Each cell reports the subgroup mean (standard deviation) of the relevant characteristic. The level of observation is the individual.

Table 2: Relationships Between Winning Lottery and Transit Usage, Activity, and Weight

Time since winning:	0.1 years (min)	2.6 years (average)	5.1 years (max)
Dependent variable:			
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/biking	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)

Notes: Each row reports coefficients from a regression of the specified dependent variable on winning the car lottery, controlling for a cubic in lottery entry date. Negative values imply fewer transit rides and minutes daily walking/biking and lower weight in winners, compared to losers. Parentheses contain 95% CIs. N = 937 individuals.

Table 3: Age-stratified Relationships Between Winning Lottery and Transit Usage, Activity, and Weight

Time since winning:	0.1 years (min)	2.6 years (average)	5.1 years (max)
Dependent variable:			
		Individuals age 40 or older	
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/biking	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)
		Individuals age 50 or older	
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/biking	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)

Notes: Each row reports coefficients from a regression of the specified dependent variable on winning the car lottery, controlling for a cubic in lottery entry date, and limiting the estimation sample to individuals with age ≥ 40 or age ≥ 50. Negative values imply fewer transit rides and minutes daily walking/biking and lower weight in winners, compared to losers. Parentheses contain 95% CIs. N = 462 individuals (40 or older) or N = 245 individuals (50 or older).

Supplementary Appendix for "Changes in physical activity and weight following car ownership in Beijing, China: a quasi-experimental cross-sectional study"

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October 2019

1 Analytic Methods

We estimated "intention-to-treat" (ITT) linear regressions of different outcomes on an indicator for winning the lottery, with standard errors clustered at the household level. The regression took the form:

$$y_i = \beta_0 + \beta_1 win_i + \beta_2 win_i \cdot time\ win_i + \sum_{p=1}^{3} \gamma_p entry\ date_i^p + \varepsilon_i \quad (1)$$

Winning the lottery (win_i) was random conditional on date of entry ($entry\ date_i$), so all regressions controlled for a cubic in date of entry. The results were qualitatively robust to controlling for any order polynomial in date of entry (see Section 3). Survey responses were collected in early 2016, but different individuals won on different dates, generating variation in the time elapsed between winning and the time of survey. We interacted winning with years since win ($time\ win_i$) and report implied effects for an individual surveyed 0.1 years ($\hat{\beta}_1+0.1\cdot\hat{\beta}_2$), 2.6 years ($\hat{\beta}_1+2.6\cdot\hat{\beta}_2$), and 5.1 years ($\hat{\beta}_1 + 5.1 \cdot \hat{\beta}_2$) after winning. These values represented the minimum, average, and maximum elapsed times, respectively, between winning and being surveyed. Two-sided hypothesis tests were conducted, with p-values under 0.05 considered statistically significant.

Weight-gain has a strong age-related component, so we estimated separate activity and weight regressions for individuals over 40 or 50 years of age, which corresponded to the top half or quarter of our sample's age distribution. In addition, we tested whether an interaction between age and winning the lottery was different than zero.

This regression took the form:

$$y_i = \alpha_0 + \alpha_1 win_i + \alpha_2 win_i \cdot age_i + \alpha_3 age_i + \alpha_4 win_i \cdot time\ win_i + \sum_{p=1}^{3} \pi_p entry\ date_i^p + u_i \quad (2)$$

To test whether age modified the association between winning (win_i) and the outcome (y_i), we tested the hypothesis $\alpha_2 = 0$.

2 Analysis of Survey Respondents and Non-respondents

As described in the manuscript, the analytic sample was drawn from a stratified random sample of households collected by the Beijing Transportation Research Center (BTRC). The BTRC conducted a transportation survey of a random sample of 40,000 households from Beijing in Fall 2014, stratifying by district. The transportation survey included questions on whether a household entered the vehicle permit lottery. Among households with lottery entrants, a stratified random subsample was further surveyed with questions related to the permit lottery in early 2016. Since there were many more losers than winners, sampling was stratified by winning status, with only one-third of losers sampled.

The average household response rate in the 2016 survey was approximately 22%, and response rates were similar between winners and losers. Using data from the 2014 BTRC transportation survey, we compared characteristics for 2016 survey respon-

Table S1: Average characteristics of 2016 survey respondents and non-respondents

Characteristics	Respondent (N = 773)		Non-respondent (N = 2733)	
Household (HH) size	3.06	(0.89)	3.08	(0.99)
Adult HH members	2.69	(0.80)	2.72	(0.88)
Working HH members	1.77	(0.78)	1.76	(0.80)
Child HH members	0.40	(0.51)	0.38	(0.52)
Male	0.59	(0.49)	0.59	(0.49)
Age	38.5	(11.1)	38.1	(11.2)
Years of education	13.6	(2.8)	13.9	(2.8)
Annual HH income	8.84	(6.11)	9.12	(6.70)

Notes: Each cell reports the subgroup mean (standard deviation) of the relevant characteristic. HH income measured in 10,000 RMB. The level of observation is the individual. Data are from 2014 BTRC survey.

dents and non-respondents. We found that they were broadly similar on a variety of characteristics: household size, number of adults, number of working adults, number of children, household income, gender, age, and education (Table S1). In most cases the mean differences between respondents and non-respondents were small, and in all cases they were on the order of 0.1 standard deviations or less. Since these data come from the 2014 BTRC survey, the values and variable codings do not exactly match the 2016 survey summary statistics in the manuscript. Furthermore, the observation counts differ from our analytic sample because, while the number of households remains constant between the two samples, the number of individuals within each household can change.

3 Robustness to Regression Specification

Since winning the lottery was random conditional on date of entry, it was important to flexibly control for date of entry. In our main regression estimates we controlled for a cubic polynomial in date of entry, but there was no specific reason to prefer this over a polynomial of a different order, beyond the cubic being sufficiently flexible to incorporate an inflection point. Thus it was important to check that our results were robust to any reasonable choice of polynomial. Table S2 reports the range of estimates for each result from the manuscript's Table 2 when controlling for polynomials of order p, with p ranging from 1 to 5. The upper-left cell in Table S2, for example, reads "–2.78 to –2.65", indicating that the minimum estimate of the effect on transit rides at 0.1 years after winning the lottery is –2.78, which occurs when controlling for a linear function of date of entry, while the maximum estimate of the effect on transit rides at 0.1 years is –2.65, which occurs when controlling for a quintic function of date of entry. Table S3 reports the equivalent exercise for the manuscript's Table 3. In all cases the range of estimates within each cell is tightly centered around the original (cubic polynomial order) estimate. Thus all of our results were qualitatively robust to choice of polynomial order.

Comparisons of characteristics (manuscript Table 1) revealed no statistically significant differences between lottery winners and losers. Nevertheless, there was a 980 RMB (0.14 standard deviation) difference in average household income between winners and losers. To ensure that this difference did not affect our results, we estimated supplementary specifications in which we controlled for household income in

Table S2: Estimate robustness of main results to polynomial order in lottery entry date control

Time since winning:	0.1 years (min)	2.6 years (average)	5.1 years (max)
Dependent variable:			
Weekly transit rides	-2.78 to -2.65	-2.82 to -2.79	-2.94 to -2.86
Minutes daily walking/biking	15.77 to 16.24	-4.2 to -3.94	-24.36 to -24.08
Weight (kg)	-1.74 to -1.25	0.14 to 0.16	1.57 to 2.07

Notes: Each row reports the range of coefficients from regressions of the specified dependent variable on winning the car lottery, controlling for a polynomial of order p in lottery entry date. The polynomial order k is allowed to vary from $p = 1$ to $p = 5$. Negative values imply fewer transit rides and minutes daily walking/biking and lower weight in winners, compared to losers. $N = 937$ individuals.

Table S3: Estimate robustness of age stratified results to polynomial order in lottery entry date control

Time since winning:	0.1 years (min)	2.6 years (average)	5.1 years (max)
Dependent variable:			
	Individuals age 40 or older		
Weekly transit rides	-2.25 to -2.01	-2.11 to -2.08	-2.19 to -1.96
Minutes daily walking/biking	11.95 to 12.63	-2.59 to -2.47	-17.62 to -17.04
Weight (kg)	1.29 to 1.78	3.24 to 3.33	4.81 to 5.34
	Individuals age 50 or older		
Weekly transit rides	-2.94 to -2.69	-1.98 to -1.9	-1.25 to -0.91
Minutes daily walking/biking	26.35 to 28.06	-2.25 to -0.66	-30.84 to -28.86
Weight (kg)	-1 to -0.16	4.44 to 4.76	9.69 to 10.35

Notes: Each row reports the range of coefficients from regressions of the specified dependent variable on winning the car lottery, controlling for a polynomial of order p in lottery entry date, and limiting the estimation sample to individuals with age $\geq$ 40 or age $\geq$ 50. The polynomial order k is allowed to vary from $p = 1$ to $p = 5$. Negative values imply fewer transit rides and minutes daily walking/biking and lower weight in winners, compared to losers. $N = 462$ individuals (40 or older) or $N = 245$ individuals (50 or older) all regression specifications. Tables S4 and S5 present our results if we control for household income. The results are very close to the results in our manuscript tables, demonstrating that our findings are robust to the choice of whether to control for household income.

To further test the robustness of our results, we estimated specifications in which we controlled for household income and district fixed effects. Tables S6 and S7 present our results if we control for district fixed effects as well as household income. Relative to specifications with no controls, the associations with weekly transit rides are somewhat smaller, but in general they remain statistically significant. Finally, we estimated specifications in which we controlled for household size, full-time and part-time employment, and age, as well as household income and district fixed effects. Tables S8 and S9 present our results if we control for these additional covariates on top of district fixed effects and household income. The results are qualitatively similar to the specifications with no controls and those in Tables S4–S7. Overall our results are not very sensitive to the inclusion or exclusion of controls, as we would expect given the lottery randomisation.

Weekly transit rides were approximately a count variable. Because the survey allowed respondents to freely enter the number of transit rides per week, in a small number of cases (less than 1%) respondents entered fractional values. To confirm that our results were not sensitive to the (approximate) count nature of the variable, we conducted a sensitivity analysis rounding the fractional responses to the nearest integer and estimating a Poisson model. The regressors in this model were identical to our baseline regression model, Equation (1), but we estimated the model using

Table S4: Relationships Between Winning Lottery and Transit Usage, Activity, and Weight, Controlling for Income

Time since winning:	0.1 years (min)	2.6 years (average)	5.1 years (max)
Dependent variable:			
Weekly transit rides	-2.74 (-4.49 to -0.99)	-2.61 (-3.57 to -1.66)	-2.49 (-4.65 to -0.32)
Minutes daily walking/biking	15.74 (-5.75 to 37.22)	-3.71 (-11.53 to 4.11)	-23.16 (-38.95 to -7.37)
Weight (kg)	-1.74 (-8.06 to 4.58)	0.18 (-2.5 to 2.86)	2.1 (-3.82 to 8.01)

Each row reports coefficients from a regression of the specified dependent variable on winning the car lottery, controlling for a cubic in lottery entry date and household income. Negative values imply fewer transit rides and minutes daily walking/biking and lower weight in winners, compared to losers. Parentheses contain 95% CIs. N = 937 individuals.

Table S5: Age-stratified Relationships Between Winning Lottery and Transit Usage, Activity, and Weight, Controlling for Income

Time since winning:	0.1 years (min)	2.6 years (average)	5.1 years (max)
Dependent variable:			
	Individuals age 40 or older		
Weekly transit rides	-2.12 (-4.04 to -0.2)	-1.95 (-3.2 to -0.71)	-1.79 (-4.93 to 1.35)
Minutes daily walking/biking	12.22 (-4.65 to 29.1)	-2.32 (-11.89 to 7.25)	-16.86 (-36 to 2.28)
Weight (kg)	1.31 (-5.04 to 7.65)	3.26 (-0.25 to 6.78)	5.22 (-2.58 to 13.03)
	Individuals age 50 or older		
Weekly transit rides	-3.01 (-5.7 to -0.32)	-1.78 (-3.53 to -0.03)	-0.55 (-5.14 to 4.04)
Minutes daily walking/biking	26.37 (-1.97 to 54.7)	-0.23 (-13.01 to 12.54)	-26.83 (-51.17 to -2.5)
Weight (kg)	-1 (-8.44 to 6.45)	4.67 (0.05 to 9.29)	10.33 (0.46 to 20.21)

Notes: Each row reports coefficients from a regression of the specified dependent variable on winning the car lottery, controlling for a cubic in lottery entry date and household income, and limiting the estimation sample to individuals with age ≥ 40 or age ≥ 50. Negative values imply fewer transit rides and minutes daily walking/biking and lower weight in winners, compared to losers. Parentheses contain 95% CIs. N = 462 individuals (40 or older) or N = 245 individuals (50 or older).

Table S6: Relationships Between Winning Lottery and Transit Usage, Activity, and Weight, Controlling for Income and District FEs

Time since winning:	0.1 years (min)	2.6 years (average)	5.1 years (max)
Dependent variable:			
Weekly transit rides	-2.25 (-3.99 to -0.52)	-2.12 (-3.08 to -1.16)	-1.99 (-4.26 to 0.29)
Minutes daily walking/biking	14.95 (-7.36 to 37.26)	-3.41 (-11.13 to 4.31)	-21.77 (-37.94 to -5.59)
Weight (kg)	-1.21 (-7.73 to 5.31)	-0.15 (-2.91 to 2.61)	0.91 (-5.26 to 7.07)

Each row reports coefficients from a regression of the specified dependent variable on winning the car lottery, controlling for a cubic in lottery entry date, household income, and district fixed effects (FEs). Negative values imply fewer transit rides and minutes daily walking/biking and lower weight in winners, compared to losers. Parentheses contain 95% CIs. N = 937 individuals.

Table S7: Age-stratified Relationships Between Winning Lottery and Transit Usage, Activity, and Weight, Controlling for Income and District FEs

Time since winning:	0.1 years (min)	2.6 years (average)	5.1 years (max)
Dependent variable:			
	Individuals age 40 or older		
Weekly transit rides	-1.67 (-3.6 to 0.27)	-1.39 (-2.73 to -0.05)	-1.11 (-4.51 to 2.29)
Minutes daily walking/biking	9.84 (-6.44 to 26.12)	-1.15 (-10.98 to 8.68)	-12.15 (-32.19 to 7.9)
Weight (kg)	1.49 (-4.79 to 7.76)	3.74 (0.02 to 7.46)	5.99 (-2.24 to 14.22)
	Individuals age 50 or older		
Weekly transit rides	-1.91 (-4.75 to 0.93)	-0.58 (-2.5 to 1.34)	0.75 (-4.45 to 5.95)
Minutes daily walking/biking	20.76 (-5.71 to 47.22)	5.88 (-7.53 to 19.29)	-9 (-33.12 to 15.12)
Weight (kg)	-1.91 (-9.11 to 5.3)	5.5 (0.31 to 10.69)	12.91 (0.9 to 24.92)

Notes: Each row reports coefficients from a regression of the specified dependent variable on winning the car lottery, controlling for a cubic in lottery entry date, household income, and district fixed effects (FEs), and limiting the estimation sample to individuals with age ≥ 40 or age ≥ 50. Negative values imply fewer transit rides and minutes daily walking/biking and lower weight in winners, compared to losers. Parentheses contain 95% CIs. N = 462 individuals (40 or older) or N = 245 individuals (50 or older).

Table S8: Relationships Between Winning Lottery and Transit Usage, Activity, and Weight, Controlling for Income, District FEs, Employment, and Age

Time since winning:	0.1 years (min)	2.6 years (average)	5.1 years (max)
Dependent variable:			
Weekly transit rides	-1.85 (-3.57 to -0.13)	-2.03 (-2.99 to -1.07)	-2.21 (-4.49 to 0.07)
Minutes daily walking/biking	15.72 (-6.98 to 38.42)	-3.17 (-10.87 to 4.53)	-22.05 (-38.39 to -5.72)
Weight (kg)	-1.13 (-7.79 to 5.54)	-0.32 (-3.05 to 2.4)	0.48 (-5.64 to 6.6)

Each row reports coefficients from a regression of the specified dependent variable on winning the car lottery, controlling for a cubic in lottery entry date, household income, district fixed effects (FEs), household size, household members employed full-time, household members employed part-time, and age. Negative values imply fewer transit rides and minutes daily walking/biking and lower weight in winners, compared to losers. Parentheses contain 95% CIs. N = 937 individuals.

Table S9: Age-stratified Relationships Between Winning Lottery and Transit Usage, Activity, and Weight, Controlling for Income, District FEs, Employment, and Age

Time since winning:	0.1 years (min)	2.6 years (average)	5.1 years (max)
Dependent variable:			
	Individuals age 40 or older		
Weekly transit rides	-1.66 (-3.58 to 0.26)	-1.3 (-2.62 to 0.02)	-0.95 (-4.28 to 2.38)
Minutes daily walking/biking	10.1 (-6.47 to 26.67)	-1.48 (-11.15 to 8.18)	-13.06 (-33.2 to 7.08)
Weight (kg)	1.62 (-4.69 to 7.93)	3.7 (0.03 to 7.38)	5.79 (-2.22 to 13.79)
	Individuals age 50 or older		
Weekly transit rides	-2.1 (-4.88 to 0.68)	-0.56 (-2.56 to 1.43)	0.97 (-4.23 to 6.17)
Minutes daily walking/biking	21.49 (-4.69 to 47.67)	4.84 (-8.1 to 17.77)	-11.82 (-35.79 to 12.15)
Weight (kg)	-2.29 (-9.74 to 5.17)	5.1 (-0.32 to 10.52)	12.48 (0.39 to 24.57)

Notes: Each row reports coefficients from a regression of the specified dependent variable on winning the car lottery, controlling for a cubic in lottery entry date, household income, district fixed effects (FEs), household size, household members employed full-time, household members employed part-time, and age, and limiting the estimation sample to individuals with age ≥ 40 or age ≥ 50. Negative values imply fewer transit rides and minutes daily walking/biking and lower weight in winners, compared to losers. Parentheses contain 95% CIs. N = 462 individuals (40 or older) or N = 245 individuals (50 or older).

Poisson regression rather than least squares. Table S10 presents results from this model. The coefficients imply that winning the lottery reduces transit rides by approximately 46%, or 2.9 weekly rides (the average number of weekly rides for non-winners was 6.2 rides). These estimates are nearly identical in magnitude to our least squares results.

4 Energy use and weight gain calculations

To calculate energy usage corresponding to the additional time spent walking and bicycling, we combined our regression estimates, the average weight in our sample (70 kilograms), and published estimates of energy usage for different activities. Previous research has found that walking and bicycling burn approximately 4 kilocalories (kcal) per kilogram (kg) of body weight per hour (Ainsworth et al., 2000). A decrease of 30 minutes (0.5 hours) of daily activity thus translated to 4 kcal/kg-hr $\cdot$ 70 kg $\cdot$ 0.5 hrs = 140 kcal. To predict weight gain we applied basal metabolic rate (BMR) equations which specify that one kg of additional weight increases BMR by approximately 12 kcal (Henry, 2005). One kg of fat contains approximately 10,000 kcal, so we computed the dynamic equations $\text{weight}_{t+1} = \text{weight}_t + 0.0001 \cdot \text{kcal surplus}_t$ and $\text{kcal surplus}_t = \text{kcal surplus}_0 - 12 \cdot (\text{weight}_t - \text{weight}_0)$ out to a period of 5 years.

References

Ainsworth, Barbara E., William L. Haskell, Melicia C. Whitt, Melinda L.

Table S10: Relationships Between Winning Lottery and Transit Usage, Poisson Model

Time since winning:	0.1 years (min)	2.6 years (average)	5.1 years (max)
Dependent variable:			
Weekly transit rides	-0.6 (-1.1 to -0.1)	-0.61 (-0.85 to -0.36)	-0.61 (-1.21 to -0.01)

The row reports coefficients from a Poisson regression of weekly transit rides on winning the car lottery, controlling for a cubic in lottery entry date. Negative values imply fewer transit rides, compared to losers. Parentheses contain 95% CIs. N = 937 individuals.

Irwin, Ann M. Swartz, Scott J. Strath, WILLIAM L. O Brien, David R. Bassett, Kathryn H. Schmitz, and Patricia O. Emplaincourt, "Compendium of physical activities: an update of activity codes and MET intensities," *Medicine and science in sports and exercise*, 2000, *32* (9; SUPP/1), S498–S504.

Henry, C. J. K., "Basal metabolic rate studies in humans: measurement and development of new equations," *Public Health Nutrition*, October 2005, *8* (7a), 1133–1152.

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