What Do Residential Lotteries Show Us About Transportation Choices?

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Abstract

Credibly identifying how the built environment shapes behavior is empirically challenging, because people select residential locations based on differing constraints and preferences for site amenities. Our study overcomes these research barriers by leveraging San Francisco's affordable housing lotteries, which randomly allow specific households to move to specific residences. Using administrative data, we demonstrate that lottery-winning households' baseline preferences are uncorrelated with their allotted residential features such as public transportation accessibility, parking availability, and bicycle infrastructure—meaning that neighborhood attributes and a building's parking supply are effectively assigned at random. Surveying the households, we find that these attributes significantly affect transportation mode choices. Most notably, we show that essentially random variation in on-site parking availability greatly changes households' car ownership decisions and driving frequency, with substitution away from public transit. In contrast, we find that parking availability does not affect employment or job mobility. Overall, the evidence from our study robustly supports that local features of the built environment are important determinants of transportation behavior.

Keywords: affordable housing, car ownership, public transportation

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1 Introduction

A person's residential neighborhood shapes their health, employment, and transportation habits—indeed, almost every aspect of their lifestyle, identity, and opportunities. In turn, the choices people make based on residential location also affect others, through externalities such as pollution, road congestion, and traffic collisions. Thus, urban planners and policymakers increasingly face calls to promote walkability, raise allowable building heights and densities, and reduce the amount of space dedicated to automobile parking. In principle, policies that provide more flexibility for developers will promote a mixture of local amenities and infrastructure that better matches the preferences of the community and allow more households to move to their preferred locations, thereby reducing the implicit regulatory tax imposed by many zoning regulations (Levine, 2005; Glaeser and Gyourko, 2018). In practice, the efficacy of these land-use policies in reducing transportation-related externalities depends heavily on how the built environment ultimately affects people's behavior.

A voluminous international literature in urban planning and economics considers how neighborhood attributes such as public transportation access, residential density, and walkability relate to automobile ownership, vehicle miles traveled, and emissions (e.g. Giuliano and Narayan, 2003; Ewing and Cervero, 2010; Zegras, 2010; Salon et al., 2012; Stevens, 2017). To a lesser extent, researchers have also investigated how the accessibility of job opportunities correlate with employment and household income (Sanchez, 1999; Marinescu and Rathelot, 2018).

A significant challenge for understanding how location-based amenities such as public transportation affect residents' travel behavior and employment opportunities, however, is that people choose where to live, and they do so based in part on local factors such as the availability of parking and public transportation. This self-selection into residential (and workplace) locations means that the vast majority of inferences from the transportation-land use literature are susceptible to selection bias (van Wee, 2009).[1] Fundamentally, the empirical concern is that residential location is a decision made by the residents, rather than an assignment based on some external process. For instance, individuals who do not own cars or otherwise prefer to commute via public transit are more likely to try to live nearby to major rail or bus lines, biasing upward any observed correlation between transit access and utilization (Glaeser et al., 2008). Individuals who prefer owning cars and driving, on

[1]Self-selection is also a major concern in the broader literature on neighborhood effects. For example, non-random residential sorting typically confounds attempts to identify how factors such as racial segregation and pollution impact social and economic outcomes (e.g. Graham, 2018; Christensen et al., 2020).

the other hand, will care more about the provision of parking. Thus, most estimates in the literature that relate infrastructure features to travel behavior lack a straightforward causal interpretation (Sampson et al., 2002; Salon et al., 2012).

A large body of research examines these self-selection challenges from theoretical, empirical, and methodological perspectives. This literature includes a special issue in the Journal of Transport and Land Use (Cao, 2014) and some excellent reviews to which we refer the reader for more detail (Bhat and Guo, 2007; Mokhtarian and Cao, 2008; Cao et al., 2009; van Wee, 2009; Cao and Chatman, 2016). One key finding is that the direction of self-selection bias is difficult to predict, as it depends on the extent to which neighborhood characteristics match residents' travel preferences (Manaugh and El-Geneidy, 2015; Cao and Chatman, 2016). A related line of argument suggests that residential sorting is an important channel through which development exerts an impact on travel, especially if it helps residents find housing in neighborhoods that are consonant with their preferences (Levine, 1998; Chatman, 2014; Naess, 2014).

Often, however, a more specific causal interpretation is desired, particularly when seeking to understand the impacts of non-marginal changes to the built environment, and how policy changes will affect travel decisions in existing neighborhoods where few people will re-sort (i.e., move) in the short term. Studies often attempt to correct for residential selection bias using statistical controls, propensity score matching, instrumental variables, joint models of residential location and mode choice, panel data, or related methods (see Mokhtarian and Cao, 2008; Cao et al., 2009, for reviews). These bias-correcting techniques considerably change quantitative results, including reducing the estimated impacts of land-use characteristics like urban density on vehicle travel by fifty percent or more (Stevens, 2017).

All these methodological approaches, however, are only partial solutions. Longitudinal studies of movers, for example, can better control for within-household characteristics, but face the challenge that movers may be moving in order to better align their travel preferences with neighborhood characteristics. Joint and structural models, meanwhile, require strong assumptions, especially considering that the selection bias involves both observable and unobservable factors (Pinjari et al., 2007). Because joint models estimate the choice of residential neighborhood, they are also ill-equipped to assess the impacts of building-specific attributes such as parking provision. Indeed, while residential parking provision might be expected to have a major impact on travel behavior (Shoup, 2005; Manville and Shoup, 2005), empirical studies are few in number and typically cannot consider biases from residential self-selection (e.g Weinberger, 2012; Guo, 2013). In short, the empirical challenge is that residential “self-selection leads to non-random heterogeneity in choices and behaviour” (van Wee, 2009).

As in nearly all areas of social science research, randomized experiments are the gold standard to identify causal effects. In principle, researchers could randomly assign households to different types of neighborhoods and then observe their behavior, but this is rarely practical or ethical (Cao et al., 2009). Randomization has been successfully employed to analyze how federally-subsidized housing vouchers via the Moving to Opportunity program affect economic opportunities, crime, and public health outcomes (Katz et al., 2001; Ludwig et al., 2001; Leventhal and Brooks-Gunn, 2003; Feins and Shroder, 2005; Kling et al., 2007; Sanbonmatsu et al., 2011; Chetty et al., 2016). Similar lotteries for housing assistance or public housing have also been used to analyze labor market and health outcomes in Canada, Ethiopia, India, and the Netherlands (Adair et al., 2016; Barnhardt et al., 2017; Bowen et al., 2018; Franklin, 2019; van Dijk, 2019). All of these studies, however, primarily evaluate the effects of randomly moving households *away* from particular residential locations—such as out of government-provided housing projects—rather than the effects of assigning people to live in specific residential locations.

In this paper, we leverage the housing lottery programs in San Francisco to overcome the aforementioned research limitations and provide causal interpretations of the impacts of specific neighborhood characteristics and parking provision on households’ transportation behavior and economic outcomes. In San Francisco, nearly all new housing developments with ten or more residential units must offer a government-specified share of “inclusionary” units at below-market-rate (BMR) prices, either directly on-site, directly off-site, or indirectly off-site by paying a fee. As might be expected, demand for new BMR units substantially exceeds the available supply—one recent lottery for 95 rental units attracted 6,580 household applicants (Badger, 2018). Because of the very low odds of winning, eligible households generally apply indiscriminately to many different housing lotteries. Those that are fortunate to eventually win a BMR unit are thus effectively assigned to live in specific buildings and neighborhoods. In essence, San Francisco’s housing lotteries provide as-good-as-random assignment of people into homes.

Conceptually, our approach is most similar to Lin et al. (2017) and Manville (2017), who study travel behavior among public housing residents who have limited choices of where to live. In both of these studies, however, the as-good-as-random allocation was assumed rather than being a primary characteristic of the setting—and this key assumption could not be directly tested.

Our research design compares transportation behavior and economic outcomes across households that won different BMR lotteries, which thereby provides effectively random variation in their residential building characteristics like on-site parking availability and neighborhood-level characteristics such as bicycle infrastructure and accessibility of public transportation. In doing so, we provide the first evidence to our knowledge about transportation behavior and economic outcomes for a population that is in effect randomly assigned to live in particular places. To validate our empirical strategy, we assess whether households are selective in the types of BMR housing projects for which they apply, finding that lottery participation decisions are indeed as-good-as-random. We then present findings from a survey that we conducted of about 2,700 of these households currently residing in BMR units, asking them questions about their transportation choices and employment.

The responses to our survey confirm the importance of accessibility by walking, bicycling, and transit in shaping household transportation choices. Even in a city such as San Francisco, where walkable neighborhoods are the norm and public transit quality is quite high by U.S. standards, accessibility substantially impacts people's travel and commuting decisions. On-site residential parking has even larger effects: increased parking causes more car ownership and more driving while reducing transit use, regardless of a neighborhood's transit accessibility. Moreover, additional parking does not improve employment or labor market mobility among households in our sample. In summary, the evidence from our study robustly supports that urban residents' transportation behavior—but not their employment—is affected by local features of the built environment, and particularly so by parking.

2 Setting: San Francisco affordable housing programs

San Francisco is often ranked as one of the least affordable cities in the United States (e.g. NAHB, 2019). In response, the city has developed and implemented a range of programs to increase the availability of affordable housing and to provide down payment assistance for qualified home purchases. Most of these programs are administered by the Mayor's Office of Housing and Community Development (MOHCD). We focus on the Inclusionary Housing program, under which a government-specified portion of units in most new residential developments must be made available at below-market-rate prices (or rent) to households whose income is below specified thresholds. Given San Francisco's high incomes, a two-person household generally can qualify while earning up to $118,200, equivalent to 120 percent of city median income.

For private developers, the BMR percentage requirements and thresholds have varied over time since the Inclusionary Housing program was established in 2002, but as of December 2019, twelve to twenty percent of on-site housing units (depending on the project's size) must be set aside for low- or middle-income households. Alternatively, developers can directly provide off-site affordable housing or pay a fee that is used to supply off-site affordable housing. BMR housing projects are also developed using a mix of public and private funds by the city's Office of Community Investment and Infrastructure. Some projects cater to specific groups such as seniors, people who are homeless, and people with disabilities.

Although specific eligibility requirements and funding sources vary between and within these programs, a lottery mechanism is used to allocate all BMR units that we study in this paper. First, would-be residents apply to each lottery; no fee is required at this stage. Second, applicants are randomly assigned a rank. Then, eligibility is verified for those receiving a sufficiently high rank. Finally, units are offered to eligible applicants in their lottery rank order within certain priority groups. Applicants from higher-priority groups—such as tenants displaced by no-fault eviction or fire—are more likely to win BMR units, but about two-thirds of successful applicants are in the lower-priority group of residents who live or work in San Francisco.

Projects also vary by the amount of parking that is provided. In the early years of the BMR program, projects had a one-to-one ratio of parking spaces to units, and the cost of parking was bundled in with the rent or sales price. In line with subsequent zoning reforms, however, more recent projects have unbundled parking from the rent or sales price—i.e., residents are free to decline a parking space, but accepting it entails an added cost. At the same time, parking ratios of less than one space per unit or even zero parking have become more common. For projects that have a parking ratio of less than one space per unit, spaces are offered in lottery rank order within each priority group.[2] For example, in a project with ten BMR units and a parking ratio of 0.5:1, the first five lottery winners would be guaranteed an offer of parking, but remaining lottery winners would only be offered parking if higher-ranked applicants declined to take (and normally pay for) a parking space. Developers are required to offer parking spaces to BMR units at the same ratio as they provide for market-rate units.

[2]Parking intended for BMR units often goes unclaimed, even in buildings with less than one space per unit. Winning housing lotteries is highly prized, but households seem less concerned about "parking lotteries."

3 Methods and Data

3.1 Housing lottery applications

To validate our assumption that housing assignments are as good as random, we use a dataset of all 107,310 applications to 59 BMR housing lotteries held between July 2015 and June 2018, which we call our applicant sample. Because the applicant sample is only available for a three-year period, it excludes many housing projects that are included in our primary survey sample.[3] However, the applicant sample also encompasses 14 projects which are not present in our survey sample; these projects are currently managed by a nonprofit housing organization or by another city agency, precluding survey distribution to these units. In addition to lottery rank and priority group status, the applicant sample provides basic demographic information from lottery applications such as income, gender, and race.

3.2 Household survey design

Our primary data survey sample consists of all BMR units for which we have occupancy and parking data, and comprises 2,654 units in 197 projects that were occupied as of April 2019. Almost all (2,605) of these units were built under the Inclusionary Housing program. We obtained data on project-level characteristics directly from MOHCD and supplemented these data using land use permit approval records to fill in missing data such as parking ratios. As shown in Figure 1 and Table 1, our survey sample provides meaningful variation in households' building-level and neighborhood characteristics. BMR units are distributed throughout the city, giving a range of walking environments and proximity to public transit, as well as substantial variation in on-site parking availability.[4] Units are roughly evenly split between rentals (53 percent of units) and for-sale units; although more projects are ownership (65 percent), these tend to be smaller in scale.

Our survey asked all BMR residents in our survey sample about their frequency of travel by mode; car ownership; employment status; the location of the respondent's workplace or school (if any); and their interactions with neighbors. These survey questions are not intended to calculate vehicle miles traveled or other common metrics of transportation usage, which would require a substantially more complex survey instrument, impacting response rates and increasing recall bias. Similarly, our employment questions allow us to create

[3]The application sample period is shorter due to changes in how MOHCD processes and retains data.
[4]Our survey sample is also spatially representative of San Francisco. See Appendix Figure A1.

coarse measures of labor market mobility.[5]

The survey questionnaire was mailed with a reply-paid envelope in June 2019 to 2,654 primary occupants of inclusionary housing units in the MOHCD database. Appendix Figure A2 shows the paper survey instrument. In addition, 1,693 of these (same) occupants received an email version of the survey with a personalized link to an online survey platform. Questions were provided in English, Spanish, Filipino and Chinese. As an incentive for participating, respondents were eligible to win one of ten randomly-awarded $100 Visa gift cards. After merging cases where we received both an online and a mail-back response, we obtained 779 completed surveys, a response rate of 29.4 percent. We attribute this high rate to our efforts to keep the survey very short (one side of an A9-size card), simple and minimally intrusive questions, the pecuniary incentives, and the twin modes of distribution.

3.3 Transportation accessibility measures

Our analyses consider how four primary measures of transportation accessibility affect household behavior. We quantify private automobile accessibility using each building's ratio of parking spaces per residential unit. We use the Center for Neighborhood Technology's AllTransit performance score to measure transit frequency and quality, and we use the WalkScore company's Walk Score and Bike Score metrics to measure accessibility by walking and cycling, respectively. Walk Score and Bike Score were accessed via the API at www.walkscore.com, and are based on accessibility to retail, services, and other destinations, as well as neighborhood design factors such as block length and bike lane provision (Manaugh and El-Geneidy, 2011; Hall and Ram, 2018; Osama et al., 2020).

Whereas many analyses of how land-use relates to transportation behavior focus on the "D" variables such as density, land-use diversity (mix), and distance to transit (see Ewing and Cervero, 2010, for a meta-analysis), our accessibility variables arguably provide a better measure of household transportation choices in our setting (Handy, 2018). For one, each of our measures is specific to a particular mode of transportation. In contrast, factors like urban density and street connectivity can affect household decisions through multiple channels, such as by making frequent public transportation service feasible and by providing more direct travel paths for walking to local destinations (Barrington-Leigh and Millard-Ball, 2020). Accessibility is also the more proximate influence—households do not make travel decisions directly in response to density, land-use mix, or connectivity, but in response to how

[5] We impute some missing responses for Question 1: where a respondent left one transportation mode frequency blank but answered for other modes, we impute a response of "less often"—the lowest-frequency.

these factors affect accessibility. Finally, transit accessibility can be changed more directly through policy, for example by changing service frequencies or routes. We therefore focus on accessibility-oriented metrics rather than (for example) sheer density, because these proxies more comprehensively reflect the variation in households' abilities to access destinations using particular travel modes.

As would be true for nearly any measures of transportation accessibility, our explanatory variables are correlated through spatial variation. For instance, a location that has a relatively higher Walk Score is also likely to have a relatively higher transit score, and buildings with good transit accessibility tend to have less parking.[6] To address this collinearity, our preferred regression specifications include the parking ratio and only one of the other accessibility measures, an approach that captures the meaningful spatial variation in accessibility while providing regression estimates that can readily be interpreted.

4 Results

4.1 Demonstrating as-good-as-random housing assignment

We begin our empirical analysis by demonstrating that assignment of lottery-winning households to housing units is as-good-as-random, which facilitates causal inference. To do so, we examine the patterns of lottery participation and repeat-entrant behavior among households in our applicant sample. While each lottery is itself random by design, households might possibly choose to selectively enter only certain lotteries, for example by forgoing the chance to rent or buy in a building without parking or in one that is distant from a transit stop.

A reasonable hypothesis is that households are not selective, given the low probability of winning any lottery. As shown in Figure 2, BMR projects attract up to 6,575 applicants, while the average lottery in our applicant sample offers only 27 units (median = 11 units; maximum = 170 units). With the exception of a handful of projects that cater to seniors or other specific populations, the odds of winning a rental unit lottery are extremely small—the average success rate of these applications is only 1.2 percent. Lotteries for ownership units attract a much smaller pool of applicants, likely because of the need to obtain a mortgage down payment, but ownership lotteries still have an average success rate of only 12 percent. Across all lotteries in our applicant sample, the average success rate is 1.5 percent.

[6] In our survey sample, the correlation between a building's AllTransit performance score and Walk Score is 0.76. The correlation between a building's parking ratio and AllTransit performance score is -0.33.

We confirm our hypothesis that households are not selective using regression analysis. Specifically, we estimate whether a household is more (or less) likely to participate in a particular housing lottery depending on how the characteristics of that lottery differ from those of the first lottery that the same household entered. For each household in the applicant sample, we defined the set of relevant lotteries as those with a lottery date between that of the first and last lotteries in our dataset that the household entered. We then estimate whether a household's decision to skip or enter each of these lotteries is explained by the characteristics of the associated project. We measure project characteristics (such as the parking ratio) in terms of their absolute differences from that of the first lottery in our dataset that the household played, which we take to be the baseline preferences of the household. All explanatory terms are first standardized using a z-transformation (mean = 0, sd = 1). We control for household-specific fixed effects, as some households are more attentive in general to lottery availability and participate more often overall. We also control for lottery-specific fixed effects, as some lotteries are relatively better-advertised, have less restrictive eligibility criteria, or otherwise attract entry from a broader section of the population.

We find no evidence that households skip lotteries based on project or neighborhood characteristics such as parking and transit accessibility. Table 2 presents linear probability models for lottery skipping using different subsamples of lottery-applying households. The first column includes all households that we observe playing at least two lotteries (as there cannot be skipping by households that played only a single lottery). If households were selectively participating based on their baseline preferences, then we should see that an absolute change in project characteristics—relative to those of the first lottery entered by that same household—would be associated with a larger propensity to skip a particular lottery. In contrast, the regression estimates indicate no evidence of lottery selectivity. For instance, we find that a one standard deviation difference in the parking ratio of the building, equivalent to 0.43 parking spaces per unit, is associated with a tiny 0.5 percentage point decrease in the probability of the household participating in the lottery. We find similarly small and almost always statistically insignificant relationships for the other explanatory terms. The one significant estimate, for Walk Score, is quantitatively small and thus has little practical import, further indicating a lack of selectivity in lottery participation.

The same null patterns continue to hold as we restrict the estimation samples in Column (2) to use only households that (eventually) won a lottery, i.e. those that we surveyed, or even further restrict in Column (3) to our survey respondents.[7] On the whole, the evidence in Table 2 clearly supports that households—quite understandably—are not selective in their participation in these low-odds housing lotteries. Nor do we detect any bias from differential patterns of survey response—for example, if households in buildings with better transit access or lower parking ratios are more or less likely to respond to the survey (Appendix Table A1).

4.2 Survey analysis for transportation

Having demonstrated as-good-as-random assignment of people into homes, the remainder of our analysis focuses on the household survey that we fielded. We begin by examining the relationship between household car ownership and a building's parking provision and neighborhood transportation accessibility. Figure 3 demonstrates a clear and substantive trend: the more parking in a building, the more likely a resident household is to own a car. In buildings with no on-site parking, only 38 percent of households own a car. In buildings with at least one parking space per unit, more than 81 percent of households own automobiles. Moreover, for buildings with intermediate amounts of parking, the pattern in Figure 3 shows monotonically increasing car ownership rates.

A similar relationship between parking provision and car ownership is shown by the regression models in Table 3. In Column (1), a minimal univariate linear specification indicates that a one standard deviation increase in a building's parking ratio—about 0.43 additional spaces per unit—causes a household to be 14 percentage points more likely to own a car.[8] As discussed above in Section 3.3, parking ratios are correlated with the other neighborhood-level factors such as transit-accessibility and walkability. However, Columns (2) through (4) show very similar estimates (12 percentage points) using specifications that also include regressors for accessibility by transit, walking, and bicycling, along with survey respondent-level controls. That the estimate remains unchanged when adding the control terms is further indirect evidence of the as-good-as-random assumption. Transit accessibility emerges as a somewhat smaller influence on car ownership, and is insignificant in Column (4), likely because of the strong collinearity noted above between transit, walking and bicycling accessibility. On the whole, car ownership appears to be strongly influenced by features of

[7]These null results are similarly unchanged when further restricting the sample to include only the 45 lotteries for projects included in both our application sample and our survey sample, as well as for numerous other sampling restrictions. Empirically, a given household's lottery participation is highly unpredictable.

[8]We estimate linear probability models for all binary outcomes. Results from logistic regressions are qualitatively very similar.

the local built environment.[9]

In addition to impacting car ownership, parking ratios and transportation accessibility also affect household transportation mode decisions. Figure 4 shows the raw correlations between project- and neighborhood-level transportation availability characteristics (rows) and surveyed households' travel behavior (columns). As expected, the frequency of driving (bottom row) increases with the building's parking ratio and decreases with neighborhood transit, walking, and cycling accessibility. The frequency of bicycling, walking, and transit use (the top three rows) show the opposite relationship to that for driving. Across the board, these correlations strongly support the conclusion that households choose between driving and other modes of travel based on the quality and availability of modes of transportation.

The raw correlations provide compelling evidence that transportation choices depend on features of the local built environment. To more formally estimate the importance of these transportation availability measures in shaping households' choices, we present multivariate regression analysis in Table 4. In Panel [A], the dependent variables are a respondent's self-reported frequency of travel by single-occupant vehicle, public transportation, walking, and bicycle, respectively. The survey asked how often the respondent travels by each mode, on a 1 to 4 ordinal scale where a value of 4 is "daily," a value of 3 is "2-3 times a week," a value of 2 is "2-4 times a month," and a value of 1 is "less often." As expected, increasing accessibility by transit, walking, or bicycling increases the frequency of use of the corresponding mode, even after controlling for respondents' household characteristics, as well as for the building's parking ratio. Nearly all of the estimates are statistically significant at the five percent level (the p-value for Transit Score in Column (2) is 0.055), and most magnitudes are nontrivial. A one standard deviation increase in the building's Walk Score, for instance, causes about a 24 percentage point increase in the likelihood that a household's walking behavior falls into a more frequent bin.

In the case of public transit use, a building's parking ratio also has an effect—and one that is more than twice as large as that of transit accessibility. More on-site parking reduces transit use while increasing the frequency of driving by a similar amount. The parking ratio also has a smaller but still statistically significant negative impact on the frequency of walking. Our estimates show no detectable impact of on-site parking on bicycling, although

[9] Household decisions pertaining to car ownership are also likely to be affected by the price of residential parking, which is strongly related to supply. In our applicant sample, 76 percent of successful lottery applicants were offered a parking space, but only 28 percent of them accepted a space. Low acceptance rates are unsurprising given the cost of parking ranges from $100 to $350 per month for the rental units in our applicant sample, and from $33,000 to $138,124 as a one-time payment for the ownership units.

bicycling frequency is low for this population—83 percent of respondents report bicycling "less often" than 2-4 times a month.

The analysis above refers to all trips made by survey respondents. Similar patterns are shown in Panel [B] of Table 4 for commute trips to work or school. Increased residential parking leads to a higher probability of commuting by private car (driving alone or carpooling) and a lower probability of commuting by transit. Greater transit accessibility has the opposite effects, although these results are not always as statistically significant.

The impact of parking and transportation accessibility on commute mode choice appear to be more muted than for non-work trips. This might be because commute trips are relatively more constrained, for example by workplace parking options or transit proximity, whereas non-commuting trips entail more choice of potential destinations for (say) shopping or recreation. Another constraint relates to long distances that may preclude walking or bicycling. For this reason, Column (5) of Table 4 restricts the sample to only commutes made either by transit or private car. These estimates show even more clearly that commuters substitute between driving and transit based on the building's on-site parking availability. Also note that the outcome measures for all trips and commute trips are not directly comparable. Panel [A] considers ordinal frequencies of use of all modes for all purposes, whereas Panel [B] uses binary outcomes for respondents' primary mode of commuting.

4.3 Survey analysis for employment

Finally, we evaluate employment outcomes and focus on two key transportation factors that the literature suggests may affect labor market opportunities, particularly for low-income workers. Access to public transportation and to private vehicles have both been found to improve employment outcomes, although the evidence is mixed (Sanchez, 1999; Blumenberg and Ong, 2001; Sanchez et al., 2004; Grengs, 2010; Blumenberg and Pierce, 2014).

For our surveyed households who are essentially randomly-assigned to a residential location, Table 5 suggests that neither transit accessibility nor parking ratios have any impact on the probability of a respondent being employed full-time (Column (1)). There is a similar null relationship with other labor market outcomes in Columns (2) to (4).[10] One possibility is that these estimates are only indicative of the strong economy and minimal unemployment

[10]Two other measures of labor market outcomes are provided by employment turnover and commute time. Greater availability of on-site parking has no detectable impact on either of these outcomes, although greater transit accessibility appears to have a moderate influence on both (see Appendix). Responses for our measure of social capital (survey question 7 in Appendix Figure A2) are largely unrelated to transportation availability, other than a small and not very robust positive association with the building's Walk Score.

in San Francisco at the time of our survey in 2019. An alternative explanation is that small changes in car ownership and transit access have little relevance for employment prospects after residential self-selection is fully accounted for via as-good-as randomization. For example, residing in a low-accessibility neighborhood might be correlated more generally with being unemployed because of some third factor such as discrimination in both housing and employment markets.

5 Conclusions

In this paper, we use San Francisco's residential housing lotteries to study how local parking and transportation accessibility affect household behavior. Because the odds of winning any specific lottery are low and there are no monetary costs of entry, households are understandably quite unselective about which lotteries they enter. As we demonstrate, those who are fortunate to win any lottery are thus as-good-as-randomly assigned into living in particular residential locations. Our primary contribution is to present findings with a straightforward causal interpretation, in contrast to nearly all research on the implications of transportation accessibility for travel and employment outcomes, which is susceptible to selection bias from residential sorting. We also demonstrate the importance to travel choices of on-site parking provision, which has been ignored in most transportation-land use studies because of data limitations and because this selection bias is likely to be even more acute. Finally, we demonstrate the potential to use accessibility metrics to measure land use characteristics, in place of density and other "D" variables which are one step removed in the causal chain.

The generalizability of our findings is qualified because our evidence is limited to a single city, and to households that are eligible for affordable housing programs. In San Francisco, however, these programs target a wide income range: households earning up to 120 percent of median income ($118,200 for a two-person household in 2019) are often eligible for these housing lotteries.

We find that neighborhood-level accessibility has statistically significant and quantitatively meaningful impacts on household decisions about car ownership and travel. In this way, we confirm that the findings of the larger literature on the land use-transportation connection (e.g. Ewing and Cervero, 2010; Stevens, 2017), and show that earlier findings are not simply a product of selection bias.

Specifically, greater transit accessibility reduces the propensity to own and drive a car, while increasing the propensity to ride transit. Greater walk and bicycle accessibility also increase the propensity to use those modes. These findings are not surprising, but confirm that the land use-transportation relationships commonly shown in this literature are not simply a product of self-selection and other biases. Even within San Francisco, transit accessibility substantially affects car ownership and travel behavior—increasing transit accessibility from the level of an outer suburban neighborhood (the 5th percentile) to the citywide median would increase the share of those commuting by transit rather than by car by 6.5 percentage points. San Francisco is a more walkable, bikeable, and transit-accessible city compared to most locations, suggesting that even more substantial household responses to increased bus scheduling, for example, might be expected in places where transit service is minimal at present.

We also document a more novel relationship between the residential parking provided in a building and transportation outcomes. Given that households who wish to own a car likely have numerous external parking options—to park on-street, park in a public garage, or rent a space in a nearby building—one might surmise that neighborhood-level rather than building-level parking supply would most affect transportation outcomes. However, we show that a building's parking ratio not only influences car ownership, vehicle travel, and transit use, but has a stronger effect than transit accessibility. Buildings with at least one parking space per unit (as required by zoning codes in most U.S. cities, and in San Francisco until circa 2010) have more than twice the car ownership rate of buildings that have no parking. If parking is provided on-site for free or at a reduced price (typically, $100 per month), then households appear to take advantage of this amenity. In contrast, households without access to on-site parking are more likely to forgo car ownership altogether.

One natural concern about reducing required parking ratios is that this might limit employment opportunities, particularly for lower-income households such as those we study in this paper. Given that many jobs are inaccessible by public transit, access to a car can theoretically improve employment outcomes and labor market turnover. However, we find no evidence that this tradeoff exists.

Transit accessibility evolves over decades and a concerted effort to improve local infrastructure requires large amounts of public funding. Parking ratios, in contrast, require only regulatory changes to zoning codes: removing minimum requirements from zoning codes and possibly replacing them with maxima instead. Such zoning reforms could also yield other benefits including reducing housing costs and increasing land available for new housing and commercial development, as well as reducing motor vehicle trips and associated harms. Our findings suggest that the potential for private automobile trip reductions is large and does not depend on car-free households relocating to car-free buildings. Moreover, reducing space dedicated to parking appears to come without employment downsides. Where streets are relatively walkable and transit service is frequent, parking emerges as the key factor shaping household travel behavior—and parking is a factor that is highly amenable to low-cost policy reforms that can rapidly provide benefits.

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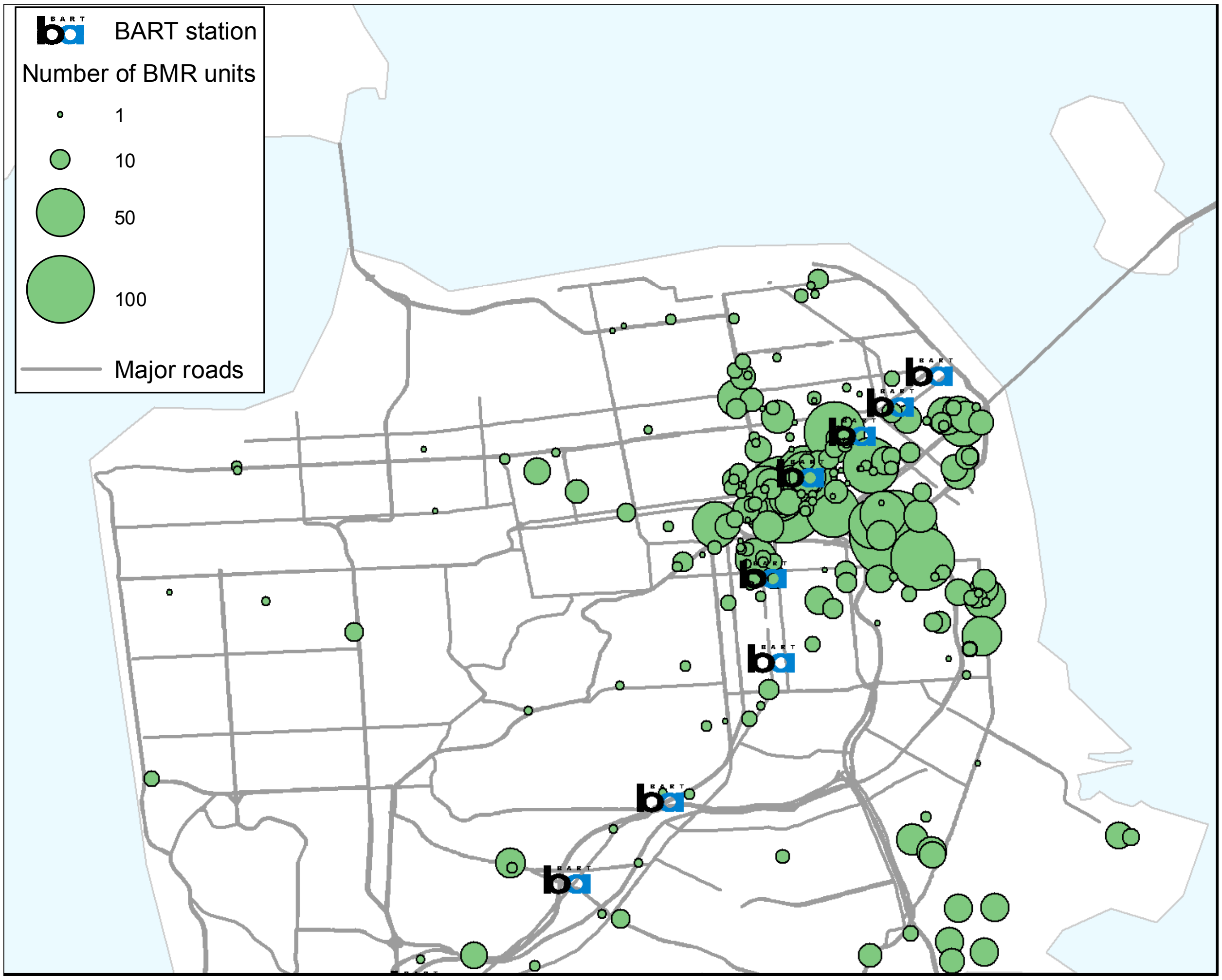
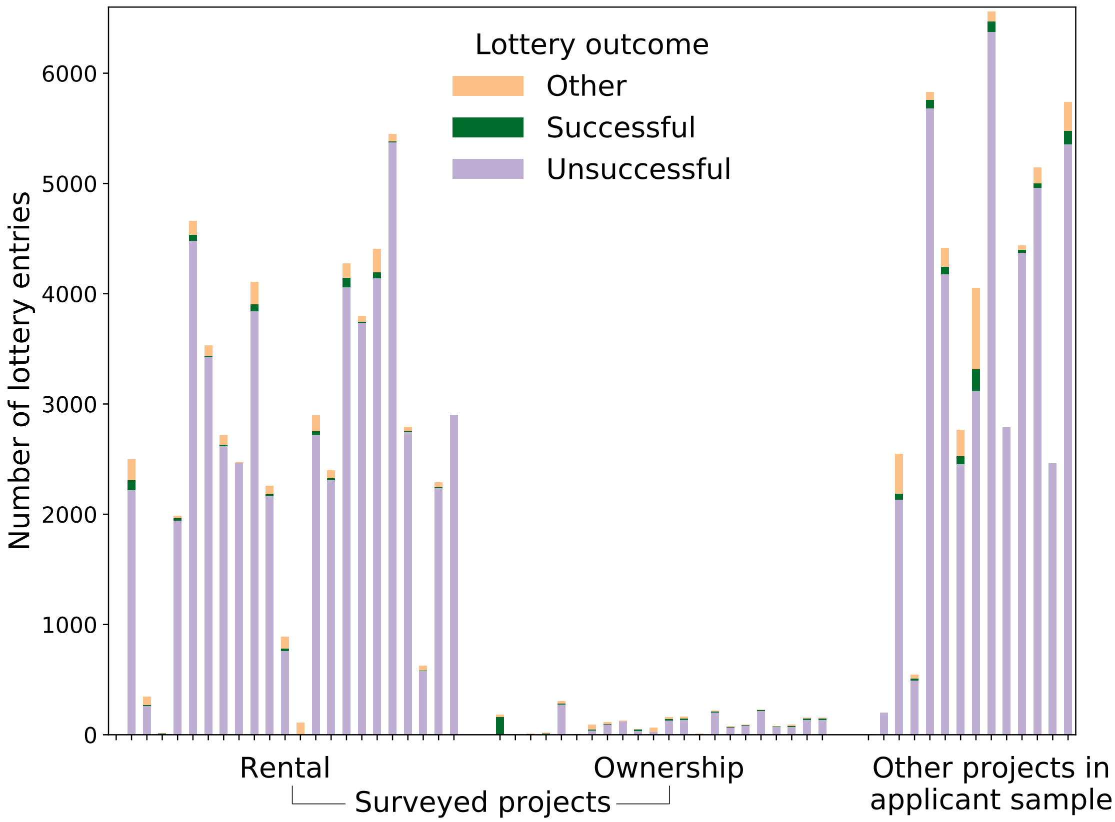
Figure 1: Locations of surveyed below-market-rate residential projects in San Francisco



Source: Authors' analysis of Mayor's Office of Housing and Community Development (MOHCD) data.

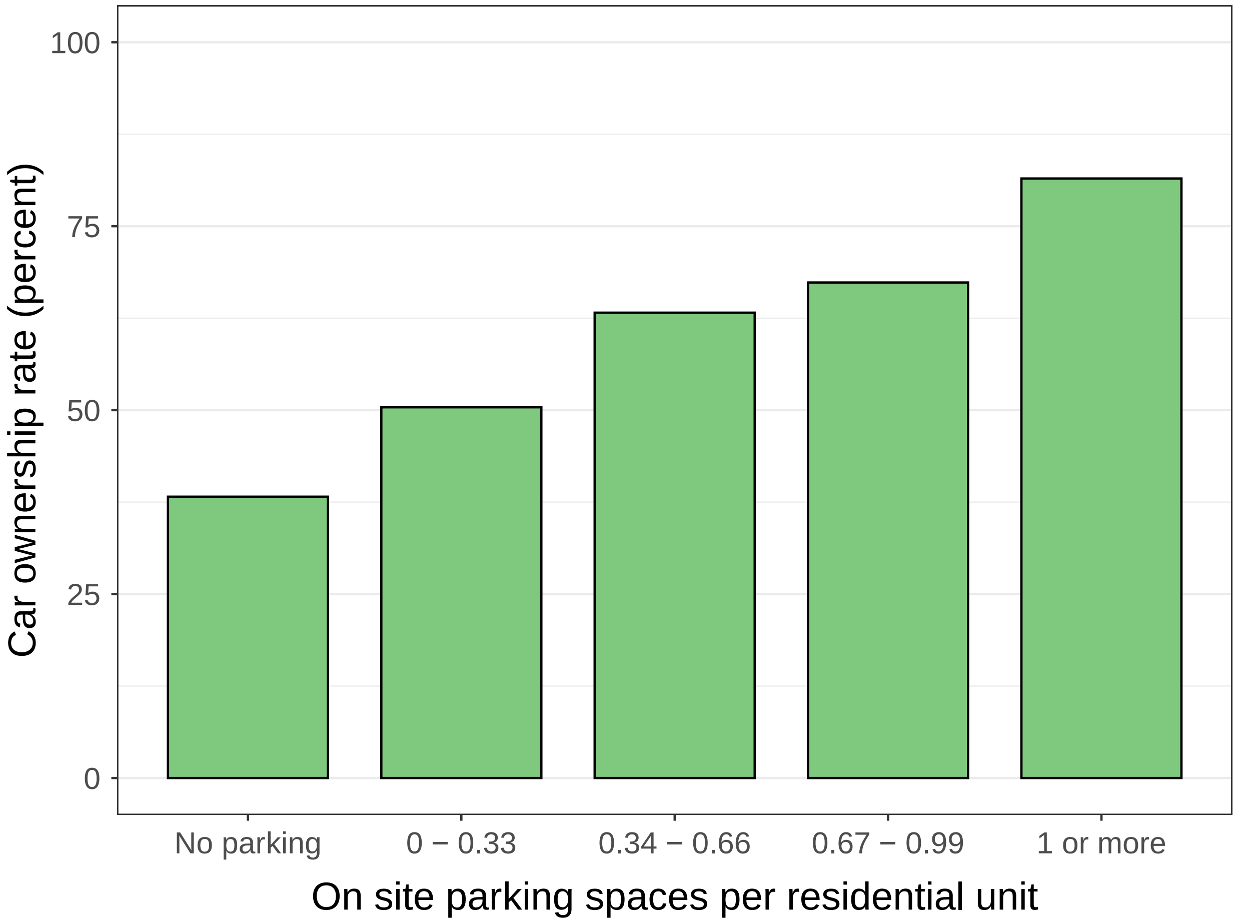
Figure 2: Number of entrants across BMR residential lotteries by application outcomes



Source: Authors' analysis of MOHCD data.

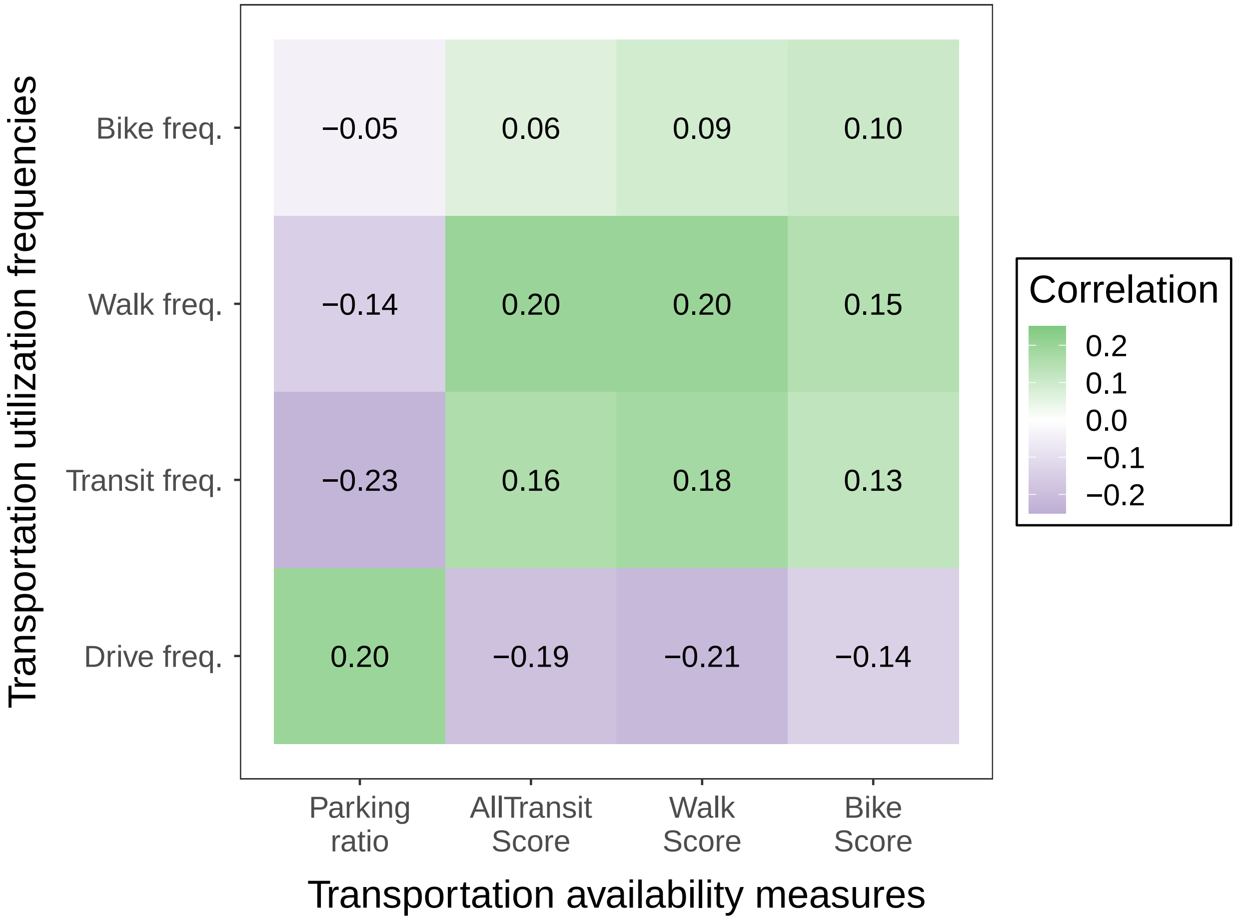
Notes: Available application data include lotteries held from July 2015 through June 2018. Each stacked bar shows outcomes for a specific BMR residential lottery, ordered horizontally by date. "Other" lottery outcomes include applications that were withdrawn, disqualified, or that have an unknown outcome.

Figure 3: Survey responses for car ownership by residential parking ratio



Source: Authors' analysis of MOHCD data and authors' survey.
Notes: Each bar contains a set of BMR projects binned by the on site residential parking space ratio, with bars' heights corresponding to the share of included survey respondents that own any automobiles.

Figure 4: Survey responses for household transportation utilization: Correlation matrix



Source: Authors' analysis of MOHCD data and authors' survey.

Notes: Surveyed transportation utilization frequencies are measured in increasing order using a discrete four-point scale of: "less often," "2-4 times a month," "2-3 times a week," or "daily."

Table 1: Summary attributes of surveyed below-market-rate (BMR) projects

	Mean	SD	Range
Number of residential projects	197		
Year completed	2008	6	1992 - 2018
Number of on-site BMR units	13.5	22.3	1 - 170
Total on-site residential units	86	105	10 - 540
Parking ratio (spaces per unit)	0.77	0.43	0.00 - 2.42
Distance to nearest rail stop (meters)	611	593	38 - 3203
AllTransit performance score	9.8	0.3	7.5 - 10.0
Walk Score	93	12	16 - 100
Bike Score	85	16	22 - 100

Notes: Table 1 shows statistics for San Francisco BMR projects. Walk Score and Bike Score are measured on a 0-100 scale, and are obtained from walkscore.com. The Transit Score refers to the AllTransit Performance Score calculated by the Center for Neighborhood Technology. It considers frequency, connectivity and access to jobs, and is measured on a 0-10 scale.

Table 2: Identification tests for lottery skipping: Regression estimates

	Dependent variable: I{skipped lottery}		
	(1)	(2)	(3)
Abs(Δ) in std. parking ratio	0.005	0.003	0.010
	(0.005)	(0.007)	(0.015)
Abs(Δ) in std. Transit Score	−0.001	−0.007	0.011
	(0.005)	(0.016)	(0.022)
Abs(Δ) in std. Walk Score	0.014**	0.021	0.034
	(0.005)	(0.014)	(0.019)
Abs(Δ) in std. Bike Score	−0.004	0.003	−0.004
	(0.005)	(0.011)	(0.015)
Sample	All applicants	Winner occupants	Survey respondents
Average skip rate	0.779	0.759	0.743
Household fixed effects	Yes	Yes	Yes
Lottery fixed effects	Yes	Yes	Yes
Number of households	18,574	481	159
Number of lotteries	59	59	59
Observations	290,085	10,165	3,441
R^2	0.397	0.345	0.340

*p<0.05; **p<0.01; ***p<0.001 Notes: Standard errors two-way clustered by household and lottery. An observation is either a household application to a lottery (107,310 in total) or a household skipping of a lottery (182,775). Each column presents estimates from a separate linear probability regression model.

Table 3: Survey responses for car ownership: Regression estimates

	Dependent variable: I{own any cars}			
	(1)	(2)	(3)	(4)
Std. parking ratio	0.143***	0.121***	0.121***	0.118***
	(0.023)	(0.026)	(0.025)	(0.026)
Std. Transit Score		−0.048***	−0.037*	−0.021
		(0.012)	(0.016)	(0.025)
Std. Walk Score				−0.030
				(0.029)
Std. Bike Score				0.014
				(0.032)
Average car ownership	0.668	0.668	0.668	0.668
Controls	No	No	Yes	Yes
Observations	758	758	758	758
R^2	0.075	0.086	0.137	0.138

*p<0.05; **p<0.01; ***p<0.001 Notes: Standard errors clustered by residential project. Controls are residency duration, residency type (rent or own), household income, household size, survey recipient gender, and survey recipient race. Each column presents estimates from a separate linear probability regression model.

Table 4: Survey responses for transportation utilization: Regression estimates

	Transportation mode				
	Private car	Transit	Walking	Bicycling	Car if car/transit
	(1)	(2)	(3)	(4)	(5)
Panel [A] Frequency of use of transportation modes for all trips					
Std. parking ratio	0.202***	−0.242***	−0.178**	−0.063	
	(0.059)	(0.051)	(0.060)	(0.037)	
Std. Transit Score	−0.152**	0.097			
	(0.049)	(0.051)			
Std. Walk Score			0.235***		
			(0.061)		
Std. Bike Score				0.090***	
				(0.023)	
Panel [B] Primary mode of transportation for commute trips					
Std. parking ratio	0.073*	−0.069*	0.013	−0.004	0.115**
	(0.030)	(0.034)	(0.029)	(0.013)	(0.041)
Std. Transit Score	−0.086***	0.001			−0.017
	(0.016)	(0.016)			(0.019)
Std. Walk Score			0.059***		
			(0.015)		
Std. Bike Score				0.029***	
				(0.007)	
Controls	Yes	Yes	Yes	Yes	Yes
Panel [A] dep. var. avg.	2.195	2.627	2.875	1.351	—
Panel [A] observations	766	766	766	766	—
Panel [A] R^2	0.082	0.082	0.110	0.075	
Panel [B] dep. var. avg.	0.384	0.314	0.211	0.068	0.550
Panel [B] observations	544	544	544	544	380
Pabel [B] R^2	0.102	0.053	0.065	0.049	0.098

*p<0.05; **p<0.01; ***p<0.001 Notes: Standard errors clustered by residential project. Controls are residency duration, residency type (rent or own), household income, household size, survey recipient gender, and survey recipient race. For Panel [A], each dependent variable frequency measure is treated as a continuous outcome formed from a four-point scale where a value of 4 is daily, a value of 3 is 2-3 times a week, a value of 2 is 2-4 times a month, and a value of 1 is less often. For Panel [B], dependent variables are binary indicators for primary commuting mode and each regression includes only respondents who are either employed or a student. Each column presents estimates from a separate linear regression model.

Table 5: Survey responses for employment status: Regression estimates

	Dependent variable			
	Work full-time	Work part-time	Looking for work	Student
	(1)	(2)	(3)	(4)
Std. parking ratio	−0.014	0.008	0.004	0.003
	(0.017)	(0.014)	(0.007)	(0.012)
Std. Transit Score	0.001	0.0004	0.0002	−0.004
	(0.010)	(0.008)	(0.003)	(0.008)
Dep. var. average	0.865	0.095	0.023	0.026
Controls	Yes	Yes	Yes	Yes
Observations	660	660	660	660
R^2	0.075	0.028	0.029	0.046

*p<0.05; **p<0.01; ***p<0.001 Notes: Standard errors clustered by residential project. Controls are residency duration, residency type (rent or own), household income, household size, survey recipient gender, and survey recipient race. Each of these regressions includes only respondents who are either employed, looking for work, or a student. Each column presents estimates from a separate linear probability regression model.

A Online Appendix

A.1 Additional detail on methods

A.1.1 Applicant data sample processing

The applicant sample consists of individual applications and does not link repeat applicants across lotteries for different projects. Therefore, we first match people who apply to multiple lotteries based on (i) their date of birth and (ii) any of the following: first name, last name, or address. We also match applicants based on all of the following: first name, last name, and address. We use a chained matching process that iteratively links groups of applicants who are matched on each of the combinations. For example, a group that matches on first name and date of birth would be combined with another group that matches on address and date of birth, if the groups have overlapping members. The chained process, rather than relying on matching specific fields or fields is necessary because of errors, spelling variations, and missing data in the applicant dataset. Identifying information was hashed (scrambled) by MOHCD prior to providing us the dataset, in order to safeguard individual privacy. Thus, we are unable to clean errors and spelling variations manually.

A.1.2 Lottery success rates

As noted in Section 2 of the main text, many applicants have some "preference" in the stratified lotteries, most often because they already live or work within San Francisco. However, even households with a "Live-Work preference"—two-thirds of successful applicants—have an average lottery success rate of only 1.7 percent. Current neighborhood residents, who are given even more priority, have an average success rate of 2.6 percent.

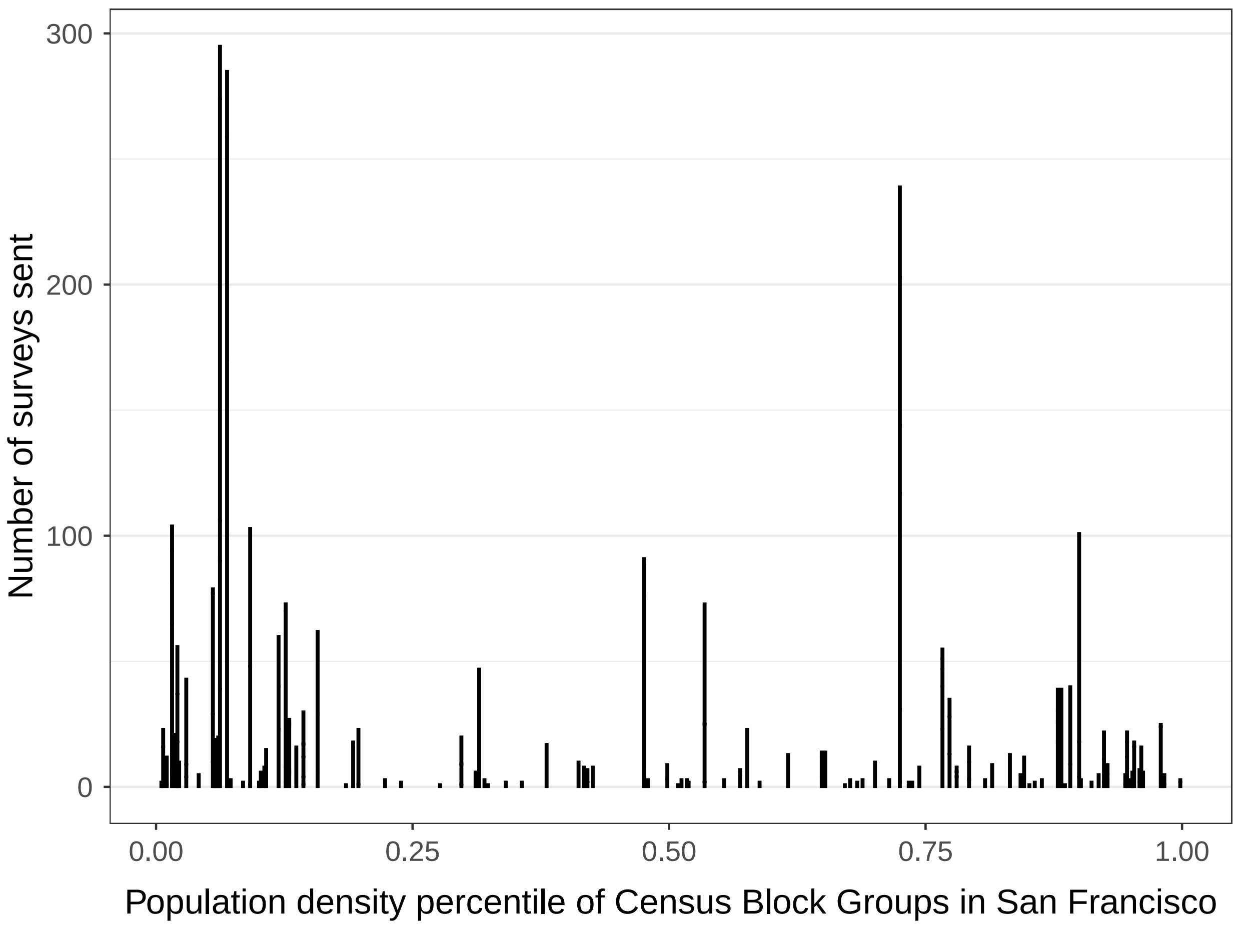
A.1.3 Household survey

Figure 1 maps the location of surveyed below-market-rate housing developments, and Table 1 shows their summary characteristics. Together, the figure and table indicate that our survey sample provides meaningful variation in households' building-level and neighborhood characteristics. BMR units are distributed throughout the city, giving a range of walking environments and proximity to public transit, as well as substantial variation in on-site parking availability.

Figure A2 shows the A9 postcard-size paper survey instrument that was mailed to households. The survey was also provided online using Qualtrics.

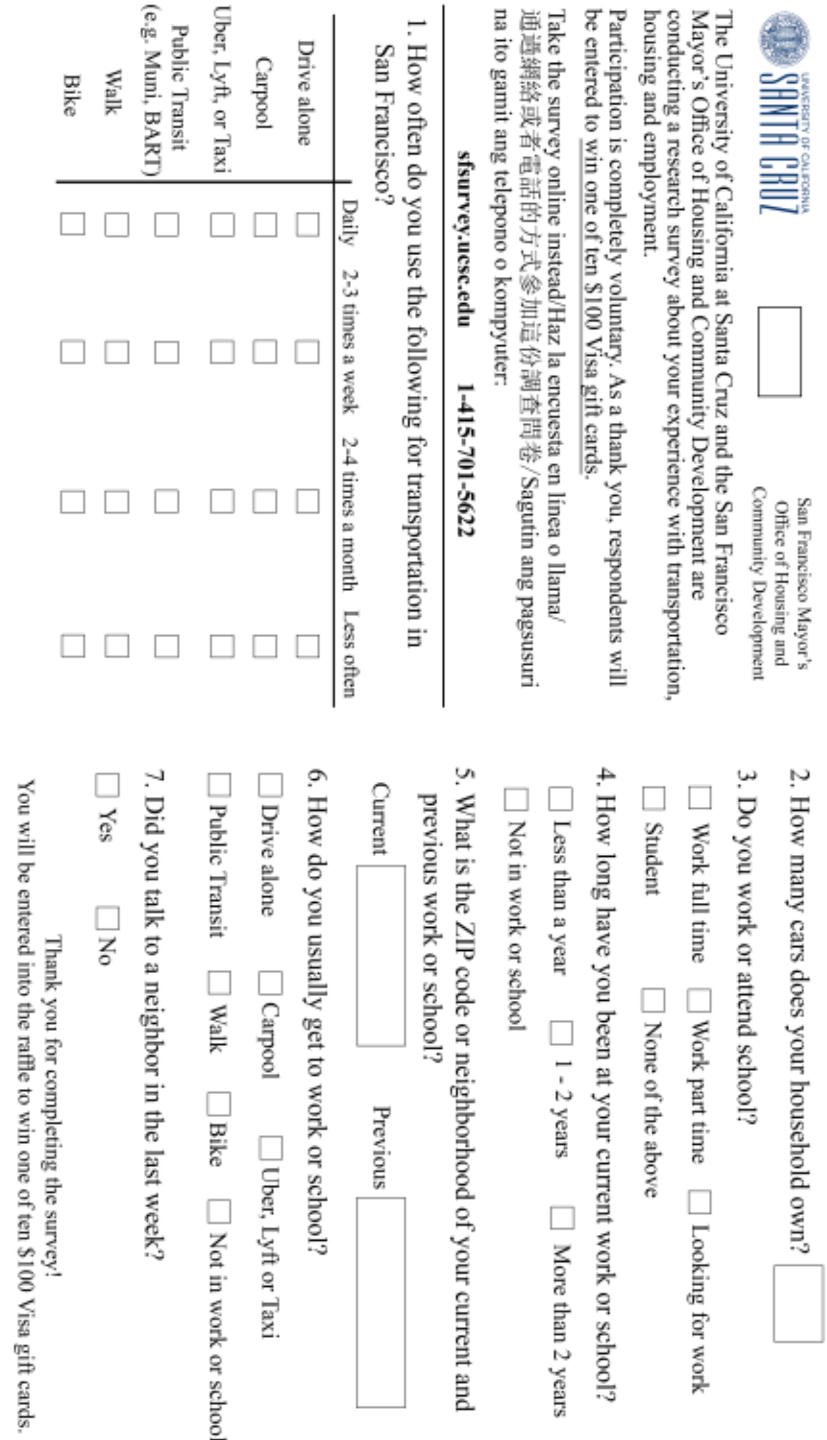
One potential source of bias is differential patterns of survey response—for example, if households in buildings with better transit access or lower parking ratios are more or less likely to respond to the survey. Table A1 uses a linear probability model to evaluate whether households' propensities to respond to our survey vary with their project characteristics, namely, the local transportation accessibility. As in the main text, all explanatory variables are z-standardized. Thus, for instance, the interpretation of the first coefficient in Column (4) is that, controlling for the local Walk Score, Bike Score, Transit Score, and the survey recipient's income and demographic variables, a one standard deviation increase in the building's parking ratio causes a 0.3 percentage point increase in the likelihood of survey response—a minuscule association. The estimates for the other independent terms likewise support that there is no survey response selection bias, as do the less-saturated specifications in Columns (1) through (3). Overall, these null results strengthen our confidence that possible bias in survey response rates is unlikely to be a factor for our subsequent findings.

Figure A1: Distribution of population density of surveyed projects



Notes: The average population density of Census Block Groups in our sample is 11,208 people per square kilometer—the 48th percentile—compared to an average of 11,236 for Block Groups in the city overall.

Figure A2: Example of survey postcard



UNIVERSITY OF CALIFORNIA SANTA CRUZ

San Francisco Mayor's Office of Housing and Community Development

The University of California at Santa Cruz and the San Francisco Mayor's Office of Housing and Community Development are conducting a research survey about your experience with transportation, housing and employment.

Participation is completely voluntary. As a thank you, respondents will be entered to win one of ten $100 Visa gift cards.

Take the survey online instead/Haz la encuesta en línea o llama/通過網絡或者電話的方式參加這份調查問卷/Sagutin ang pagsusuri na ito gamit ang telepono o kompyuter:

sfsurvey.ucsc.edu 1-415-701-5622

1. How often do you use the following for transportation in San Francisco?

	Daily	2-3 times a week	2-4 times a month	Less often
Drive alone	☐	☐	☐	☐
Carpool	☐	☐	☐	☐
Uber, Lyft, or Taxi	☐	☐	☐	☐
Public Transit (e.g. Muni, BART)	☐	☐	☐	☐
Walk	☐	☐	☐	☐
Bike	☐	☐	☐	☐

2. How many cars does your household own? ☐

3. Do you work or attend school?

☐ Work full time ☐ Work part time ☐ Looking for work

☐ Student ☐ None of the above

4. How long have you been at your current work or school?

☐ Less than a year ☐ 1 - 2 years ☐ More than 2 years

☐ Not in work or school

5. What is the ZIP code or neighborhood of your current and previous work or school?

Current ☐ Previous ☐

6. How do you usually get to work or school?

☐ Drive alone ☐ Carpool ☐ Uber, Lyft or Taxi

☐ Public Transit ☐ Walk ☐ Bike ☐ Not in work or school

7. Did you talk to a neighbor in the last week?

☐ Yes ☐ No

Thank you for completing the survey!

You will be entered into the raffle to win one of ten $100 Visa gift cards.

Notes: Figure A2 shows a postcard of the authors' survey, which was also provided online via Qualtrics.

Table A1: Identification tests for survey response: Regression estimates

	Dependent variable: I{survey respondent}			
	(1)	(2)	(3)	(4)
Std. parking ratio	−0.0001	−0.005	−0.003	−0.014
	(0.010)	(0.012)	(0.012)	(0.011)
Std. Transit Score		−0.011	−0.013	0.015
		(0.017)	(0.023)	(0.016)
Std. Walk Score			−0.013	−0.011
			(0.013)	(0.011)
Std. Bike Score			0.022	0.022
			(0.015)	(0.013)
Average response rate	0.294	0.294	0.294	0.294
Controls	No	No	No	Yes
Observations	2,654	2,654	2,654	2,654
R^2	0.00000	0.0004	0.002	0.038

$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$ Notes: Standard errors clustered by residential project. Controls are residency duration, residency type (rent or own), household income, household size, survey recipient gender, and survey recipient race. Each observation is a household to whom we (e)mailed a survey. Each column presents estimates from a separate linear probability regression model.

A.2 Additional analyses of labor market impacts

The main text shows the impact of our transportation accessibility measures on employment rates. Two other measures of labor market outcomes, which we discuss here, are provided by employment turnover and commute times. Greater accessibility may enable workers to change jobs, and in doing so increase wages, reduce commute time, or otherwise increase employment satisfaction. Column (1) of Table A2 shows the impact of parking ratios and transit accessibility on the share of employed/student respondents who have been at their current job or school for less than two years; Column (2) does the same for a shorter one-year period. The remaining columns measure the impacts on commute distance and time directly.

Greater availability of on-site parking has no effect on any of these labor market outcomes, although greater transit accessibility appears to moderately promote employment turnover and shorter current commute times. Estimates show no relationship between parking or transit accessibility and former workplace/school commutes or with the change from former to current workplace/school commutes, in time or distance. A one standard deviation improvement in Transit Score increases the share of respondents occupied at their current job or school for less than two years by 3 percentage points—a meaningful effect given that only 22 percent of respondents have been at their workplace for such a short period. The results are almost identical when limiting the sample to respondents in full-time work. Similarly, we find that a one standard deviation increase in Transit Score reduces commuting times by about ten percent—and reduces the likelihood of having a long (> 25 minutes) commute by about 30 percent. In other words, greater transit accessibility increases the likelihood of garnering new employment and reduces commute times.

Table A2: Survey responses for employment duration and commutes: Regression estimates

	At current work/school		Current commute via driving		
	< 2 years	< 1 year	Distance (m)	Time (min.)	> 25 min.
	(1)	(2)	(3)	(4)	(5)
Std. parking ratio	0.010	0.004	−742.9	−0.383	−0.007
	(0.018)	(0.017)	(671.5)	(0.631)	(0.015)
Std. Transit Score	0.030**	0.024*	−1,366	−1.369*	−0.041**
	(0.011)	(0.011)	(846.6)	(0.668)	(0.013)
Dep. var. average	0.222	0.110	6,748	13.05	0.11
Controls	Yes	Yes	Yes	Yes	Yes
Observations	644	644	634	634	634
R^2	0.066	0.047	0.052	0.063	0.051

*p<0.05; **p<0.01; ***p<0.001 Notes: Standard errors clustered by residential project. Controls are residency duration, residency type (rent or own), household income, household size, survey recipient gender, and survey recipient race. Each of these regressions includes only respondents who are either employed or a student. The current commute distance is the estimated driving distance in meters and the current commute driving time is estimated as of 8:00 AM on a weekday using Google Maps. Each column presents estimates from a separate linear regression model.